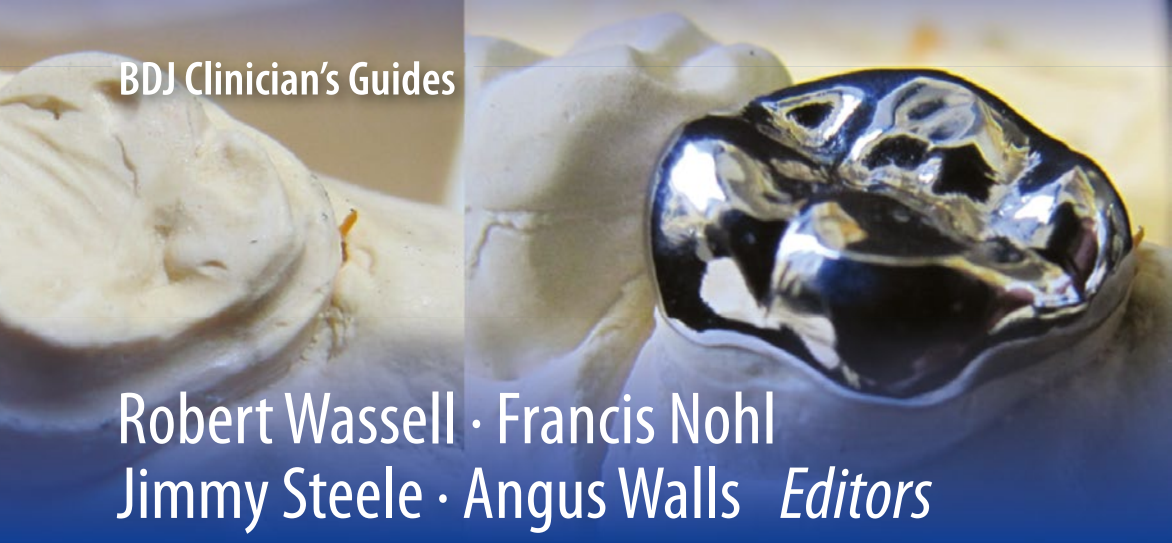

BDJ Clinician's Guides

Robert Wassell · Francis Nohl
Jimmy Steele · Angus Walls *Editors*

Extra-Coronal Restorations

Concepts and Clinical Application

Second Edition

BDA
British Dental Association

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This book is dedicated to the memory of our special friend and colleague, Professor Jimmy Steele, CBE, who sadly died in November 2017. A remarkable man whose skill, knowledge, and influence extended across a wide range of dentistry and far beyond. We are privileged to have had his important contribution to both the first and second editions of this book.

Preface

In 2002 the *British Dental Journal* published "Crowns and Other Extra-coronal Restorations", a landmark series of articles. This became a clinical guide defining contemporary materials and techniques for restoring individual teeth. A major update is now timely because of important developments and changes, for example the significant shift to adhesive dentistry. So, to de-emphasise the wholesale use of crowns, the title has changed simply to *Extra-coronal Restorations*. This new edition must also reflect the major advances in materials, including developments in digital dentistry and in high strength ceramics.

A new team of authors give fresh insight into this intriguing area of dentistry. They come from five UK university dental schools with their affiliated dental hospitals, and research centres/ institutes. Consequently, all have considerable knowledge, expertise, and experience in their chosen clinical fields. The editors are the same gang of four from 2002. Now older, and hopefully wiser, they have witnessed dentistry change across four decades.

The book is divided into five parts:

Part I: Evidence Based Extra-coronal Restorations
Part II: A Healthy Start
Part III: Managing Future Risk
Part IV: Materials and Aesthetics
Part V: Planning and Provision of Extra-coronal Restorations

Parts I–IV provide an evidence base for providing extra-coronal restorations with a reliable clinical performance while Part V is a practical guide to the relevant procedures.

To ensure restorations are successful we emphasise "A Healthy Start" and "Managing Future Risk", subjects often covered superficially or not at all in other operative texts. Within the parts there are new chapters covering periodontal aspects of restoration, tooth surface loss, implant crowns, and methods of adapting crowns to existing partial dentures. In line with modern dental education, each chapter starts with clinically relevant learning points. In addition, clinical tips make the book suitable for senior dental undergraduates, postgraduates, and practicing dentists. Given the book's tight focus, its scientific content should also be of interest to dental academics.

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Thanks are due to the editors of the *British Dental Journal* and the former publication house, BDJ Books, for supporting the complete restructuring and rewriting of this book.

Dr. Amar Naru, who is both a highly skilled dentist and renowned professional artist, has drawn most of our diagrams. They elegantly and without fuss depict a mine of information.

Distinguished clinicians have provided clinical cases: Matthew Brennand-Roper, Edinburgh; Margret Corson, Newcastle; Marco Ferrari, Siena; Matthew Garnett, Newcastle; Konrad Staines, Bristol; and the late Eoin Smart, Newcastle. These contributions are acknowledged in the legends of individual figures. The authors have also shared their images in unstinting support of the book.

Stuart Graham Scott and Mark Pickersgill from Newcastle Dental Hospital provided valuable laboratory material and images. Special thanks to Jan Howarth for her patience, help, and photographic expertise. Thanks also to Krishna Bhatia, Edinburgh Dental Institute, and to Smileline SA, Switzerland, for providing photographic images.

We are grateful to Elsevier for allowing us to publish under licence Fig. 2.5 in Chap. 2.

The editors are indebted to all the authors for waiving royalty payments in favour of the British Dental Association Benevolent Fund.

Contents

Part I

Evidence Based Extra-coronal Restorations

Introduction

1

Jimmy Steele and Robert Wassell

1.1 Learning Points

This book provides learning points at the start of each chapter which relate to major areas of clinical relevance. The introduction asks dentists to:

- Consider the consequences of providing extra-coronal restorations, particularly where failure will result in damage to an already prepared and weakened tooth
- Recognise that patients may view dental restorations as normal consumer goods causing disappointment unless expectations are managed
- Advise patients of the realities of having irreversible dental treatments, not only in terms of improved dental and general health, but bad impacts too
- Use scientific evidence (where available) to inform choice of restoration
- Select, where suitable, minimally destructive, adhesively retained restorations
- Plan and perform work to a high standard employing sound biological and mechanical principles.

In addition to the above learning points, the introduction outlines the content of each of the Book's five parts, mentioned previously in the preface.

The production and placement of some beautiful pieces of porcelain in the mouth is a seductive process when it transforms a smile. All the authors of this book have been there and done that. The day of final cementation, it is a fabulous feeling as you replace the slightly dingy temporaries with true sparkle. So, in that moment, have

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you ever paused to reflect on what you have really done? Alternatively, are you just living in the moment, internally celebrating your own technical genius, because these moments can become addictive? Covering teeth in a shell of ceramic (or metal, or both) might be seductive, sometimes necessary, or at least advisable but almost always biologically destructive.

Try and answer a simple pair of questions; how long will this restoration last and what happens when it fails? Can you answer these? Two things are certain:

- Unless your patient is quite elderly it is unlikely that the beautiful crown will outlive its owner
- Its failure will probably not just mean making a new crown and sticking it on.

Inevitably, the preparation weakens the tooth underneath and crown failure, which is not inevitable in the remaining lifespan, but, likely, usually leads to further tooth damage. That restorative cycle cannot usually be repeated too often without terminal damage.

1.2 Excellence and Consumerism: A Patient's Perspective

Our patients usually live in a world that is very different to ours where it can be difficult to distinguish dental restorations from normal consumer goods. No doubt, some consumers would like to be able to choose their crown or veneer and perhaps have it replaced repeatedly until they get one they like. If not perfectly satisfied, they may also like to be able to take it back to the shop and have a full refund or choose a replacement item. These are of course illusions but may be reinforced by the language that we use to sell dentistry. This is a challenge for clinicians because clearly there are fundamental differences between providing health care and selling consumer goods. The changes we make are also fundamental and irreversible and can have a bearing (good or bad) on long-term health.

We are lucky now that technologies have been developed over four decades, particularly adhesive approaches, which allow us to use much less destructive techniques. That means fewer dentine tubules are opened and less hydroxyapatite slurry disappears up the aspirator, with huge benefits in terms of tooth health and long-term vitality. These technologies have transformed dentistry, and this book explores them. The authors recognise that if dentists are going to employ them successfully, they need to know what they are doing and why. You need to plan correctly, know your options and your materials, and then finish the job with an attention to detail that would leave a normal human being cold.

1.3 The Use of Evidence

Talking of leaving the normal human being cold, we need to think about evidence. This understanding is not about taking what is written here as some sort of gospel truth. You should question what we write and we have tried to do the same.

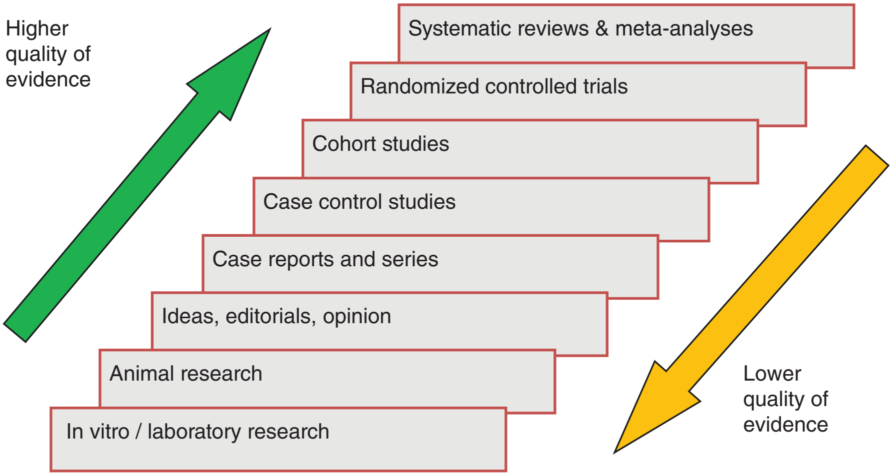

Fig. 1.1 Hierarchy of evidence to support clinical decisions (adapted from Sacket et al. [4])

The concept of basing treatment on sound clinical evidence is now familiar, or should now be familiar, to all dentists. As a clinician in this area of work, it can be difficult to interpret or even find meaningful evidence about what approach is "best" or, in response to the question above, how long *your* restorations should be expected to last.

In this book, we have tried hard to find the best evidence we can, starting with systematic reviews of which there have recently been an increasing number. However, they do not cover every aspect, and we have often had to refer to lower, or even much lower, levels of evidence (see Fig. 1.1). In many areas, we have had to make judgements based on sound biological or mechanical principles with an empirical rather than an experimental basis. We have tried to be clear about where there is, and is not, a meaningful evidence base. We hope that the result is realistic, balanced, and built around the needs of the patient.

This book consists of five parts which we outline below.

1.4 Part I: Evidence-Based Extra-Coronal Restorations

In some areas of dentistry, data and evidence are relatively plentiful, for example, we have a pretty good understanding of the merits of various interventions related to caries prevention and periodontal treatment, to give two examples. However, when it comes to laboratory-made restorations, we are not nearly as well served. The reasons for this relative lack of excellent clinical data are complex. In part, it is because we have not been particularly good, as a profession, at setting up the trials that would deliver this evidence, but let's not beat ourselves up about this because the fact is that there are valid reasons why the collection of such data (in conventional clinical trials) is very challenging. We will look at these in Chap. 2, but one of the most important reasons is that the time it takes to be able to record a meaningful outcome is not a matter of months or even a year or two; it could be a decade before we are able to make judgments about the relative effectiveness of some of these treatments. Consequently, the technology often moves faster than the evidence collection, so some reports may relate to a redundant technology. That is nobody's fault, but it is a daily challenge to clinicians who seek to provide truly evidence-based care. Nevertheless, there is clinical evidence to back some of our restorative treatment. It must be interpreted meaningfully, and this will also be considered.

Where we are confident that our treatment can make a difference, a lack of trials is not a viable reason to refuse treatment. But, as clinicians, we should never be too confident (despite other rational reasons for choosing a treatment) that we are doing the right thing; this is all a matter of balance.

1.5 Part II: A Healthy Start

Importantly, we need to avoid the temptation of diving in to tooth preparation before existing dental disease, and the background risks are diagnosed and brought under control. This includes not only caries and periodontal disease but also tooth surface loss (tooth wear), mucosal disease, occlusal disease, and temporomandibular disorders. Of course, the medical history (see Chap. 18) is an essential part of risk assessment.

General dental practitioners (GDPs) in the UK will be familiar with the generic preventative advice issued by Department of Health. This advice covers caries, periodontal disease, and dental erosion [1]. It also advises on smoking cessation and the carcinogenic risks of alcohol consumption. However, GDPs must use their knowledge and clinical judgement to tailor specific advice and management for individual patients [2].

Patient recalls are an important part of primary dental care because some disease-free patients may go on to develop caries and periodontal disease later [3]. A simple and effective way is to identify patients who are *not at risk* from those who are *at risk*. In this way, resources can be concentrated on those who need more targeted action for the full range of dental diseases [2]. This approach is easier and more reliable than assessing risk on a green, amber, red basis (see Fig. 1.2).

1.6 Part III: Managing Future Risk

To prevent extra-coronal restorations failing prematurely, all dentists need to know what they can do during treatment and beyond to have a positive influence. As mentioned above they also need to recall patients at appropriate intervals. The five chapters in Part III explore how future risk of failure can be managed in the following areas:

- Preserving pulp vitality
- Periodontal considerations (including surgical options)

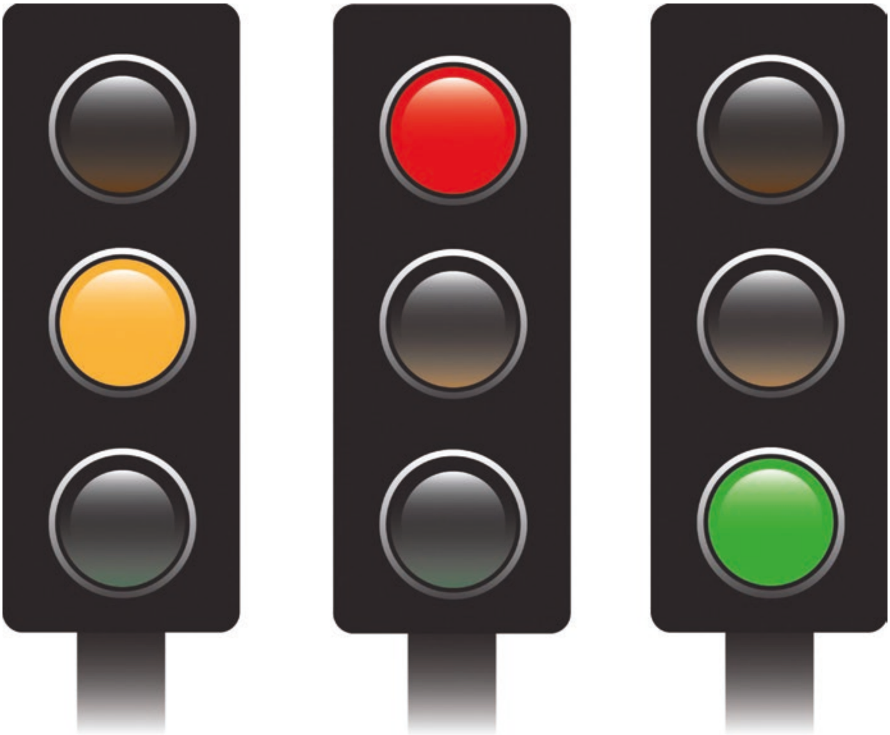

Fig. 1.2 The "red", "amber", "green", system describes three levels of risk but is not always reliable. The preferred alternative is simply to distinguish patients at risk from those not at risk. Patients at risk of caries show a change in clinically or radiographically detected caries status since the last screening examination. Patients at risk of periodontal disease have a Basic Periodontal Examination score of 3 or greater (see Chap. 4)

- Viability of posts and cores
- Occlusal control
- Tooth surface loss.

1.7 Part IV: Materials and Aesthetics

The development of dental materials in the past two decades has been phenomenal, and this is reflected in the length of Chap. 14 for which we make no apology. This chapter outlines the development of CAD/CAM, high-strength ceramics, and composites but does not neglect metallic restorations which still have important clinical uses, particularly in restoring bruxists. Read it over several sittings or dip in and out as a reference.

The materials used to lute (cement) restorations are equally important, and Chap. 15 considers developments in adhesive bonding, including methods of pre-conditioning the surface.

Dentists may be faced with having to recement an implant crown and need to know about the various types of implant abutment available. Others may already be attending a course on how to restore implants with crowns. Chapter 16 gives a good overview.

A restored smile is a dentist's shop window. Chapter 17 looks not only at the technical aspects of achieving good results but also at the ethical implications of providing irreversible and sometimes damaging treatment. Also addressed are digital shade matching and issues of creating good aesthetics with implant crowns.

1.8 Part V: Planning and Provision of Extra-Coronal Restorations

Part V provides a practical outline which will be of interest to dentists wanting to improve their technique. Dentists must think about multiple factors and integrate appropriate solutions when making a diagnosis and treatment plan. This is what makes dentistry at once challenging and attractive. Of course, technical skills are critical for successful extra-coronal restorations. So, detailed instructions plus hints and tips are provided in the journey through:

- History and examination—why is it important?
- Core build-ups and post placement
- Fundamentals of tooth preparation
- Gingival management and retraction
- Impression materials and techniques
- Provisional restorations
- Fitting and cementation.

The final chapter reviews “Adapting crowns to existing prostheses”, allowing dentists to offer extra-coronal restorations without having to replace an existing but satisfactory partial denture.

We hope you find the book an intriguing and worthwhile read.

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Clinical Performance

2

Claire Field, Heidi Bateman, Richard Holliday, and Robert Wassell

2.1 Learning Points

This chapter will emphasise the need to:

- Be alert to restorations which may be used as a more conservative alternative to crowns
- Carefully evaluate clinical studies of restorations and be aware of the factors which may bias outcomes
- Identify factors (including bruxism) which adversely affect veneer performance
- Be aware of the high clinical success rate of ceramic inlays and onlays
- Be cautious when using composite inlays and onlays in bruxists and in patients with a previous high caries rate
- Manage expectations when prescribing implant crowns and arrange follow-up for any mechanical issues and supportive peri-implant care, particularly in patients susceptible to peri-implant disease.

How long will a restoration last? This is a simple question, but not so easy to answer. Before discussing clinical performance, we need to consider the main types of extra-coronal restoration and give an idea of numbers provided. There are now a bewildering number of restorative systems and materials, many lacking the quality,

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long-term studies required to make an informed, evidence-based decision about what best to use and when. Nevertheless, there is some useful information available on how restorations perform, and the aim of this chapter is to guide the reader through it.

2.2 Types of Restoration

Extra-coronal restorations comprise crowns, partial coverage crowns, onlays (with or without an inlay component) and veneers. As can be seen from Table 2.1, these restorations can be made from a variety of materials (detailed in Chap. 14) and luted (cemented) either conventionally or adhesively (Chap. 15).

Crowns are still the most commonly provided extra-coronal restoration, but increasingly there is a trend to use adhesively retained restorations which benefit the patient by having minimal tooth preparation. This trend is reflected in the British Society of Restorative Dentistry’s rationale for crown provision (Box 2.1) [1].

Of course, crowns are not only used to restore individual teeth (Fig. 2.1) but also dental implants (Chap. 16). We will consider performance of implant-retained crowns at the end of the chapter.

So, the well-informed dentist needs to be aware of all types of extra-coronal restoration, both conventional and adhesively retained.

Table 2.1 Indirect restorations can be classified in many ways

Type of restoration	Description	Examples
Conventional restoration	A restoration retained using conventional dental cements in combination with tooth preparation features designed to prevent disruption of the cement and displacement of the restoration	Crown, partial coverage crown, onlay[a] (metal, ceramic, ceramo-metal or composite)
Adhesively retained restoration: (a) Minimal preparation (b) Conventional restoration cemented adhesively	A restoration retained using adhesive technology, often resin based for strength and chemical bonding. Minimal preparation adhesive restorations do not rely to the same extent as conventionally cemented restorations on tooth preparation geometry to retain the restoration Conventional restorations luted adhesively	Veneers (ceramic or composite[a]) Onlays (metal, ceramic, ceramo-metal or composite[a]) Crown, partial coverage crown, onlay[b] (metal, ceramic, ceramo-metal or composite)
Implant crown	A restoration replacing a single tooth attached to a dental implant either via an abutment or directly (implant head connection). The crown may be retained either by a screw or a cement lute	Crown (ceramic or ceramo-metal)

[a]Composite may be applied either directly or made as an indirect restoration luted adhesively
[b]Onlays may have an inlay component but inlays per se are classed as intra-coronal restorations

Box 2.1: Rationale for Crown Provision

- To restore the form, function and appearance of teeth which are badly broken down, worn or fractured to the extent *that simpler forms of restorations are contraindicated or have been found to fail in clinical service.*
- To improve the form and appearance of unsightly teeth *which cannot be managed by more conservative cosmetic procedures.*
- To reduce the risk of fractures occurring in extensively restored teeth including endodontically treated posterior teeth.
- More rarely, to alter significantly the shape, size and inclination of teeth for cosmetic and functional purposes.
- To restore a dental implant.

Highlighted in italics is the need to consider first more conservative procedures [1].

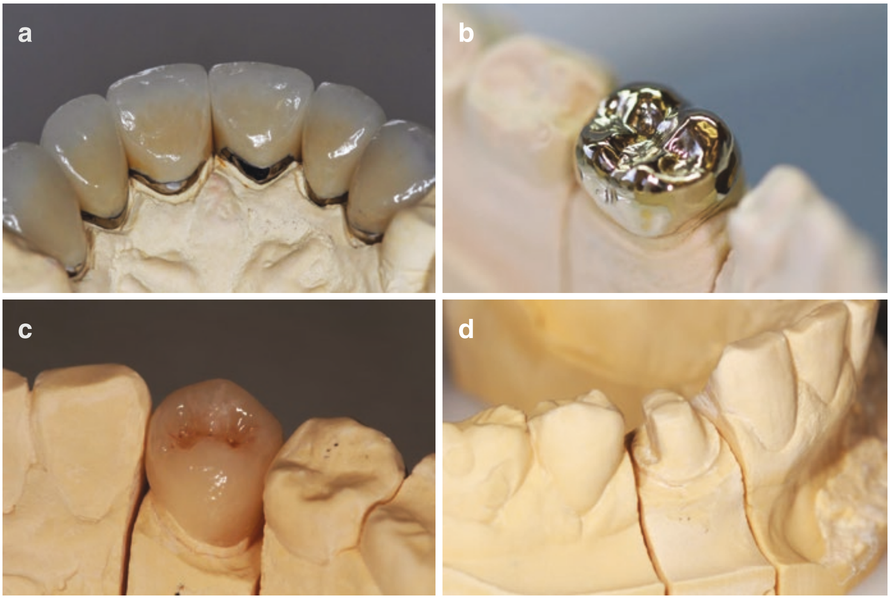

Fig. 2.1 Crowns come in a variety of materials, e.g. ceramo-metal (**a**), all-metal (**b**), ceramic (**c**). Crown preparation, particularly for some ceramic materials, can leave little remaining tooth structure (**d**)

2.2.1 Conventional Restorations

A conventional restoration is distinguished by needing a tooth preparation so it can be luted with conventional cement (e.g. zinc phosphate, zinc polycarboxylate and glass ionomer). A properly designed tooth preparation (see Fig. 2.2) not only eliminates undercuts so the restoration can be slipped onto the tooth; it also helps control stresses within the cement lute which prevents the restoration being pulled or rotated off by occlusal forces (see Chaps. 15 and 20). This is an important consideration because conventional cements are inherently brittle and, like a piece of crisp bread, will fail at relatively low tensile stress. Despite the adhesive properties of glass ionomers and zinc polycarboxylates, they are still too brittle to be used with tooth preparations which are short or too tapered (Chap. 15).

Preparations for conventional restorations require sufficient remaining tooth to be effective, often in combination with a core build-up made of restorative material to replace lost tooth structure. The core build-up may be retained by mechanical undercuts or adhesively or both (see Chap. 19).

Tooth preparation may further weaken what remains of an already compromised tooth predisposing to failure. To deal with this problem, several strategies can be considered including surgical crown lengthening (see Chap. 10) or using the root canal prepared to accommodate a retentive cemented post (see Chaps. 11 and 19). The other increasingly important approach is to use an adhesively retained restoration.

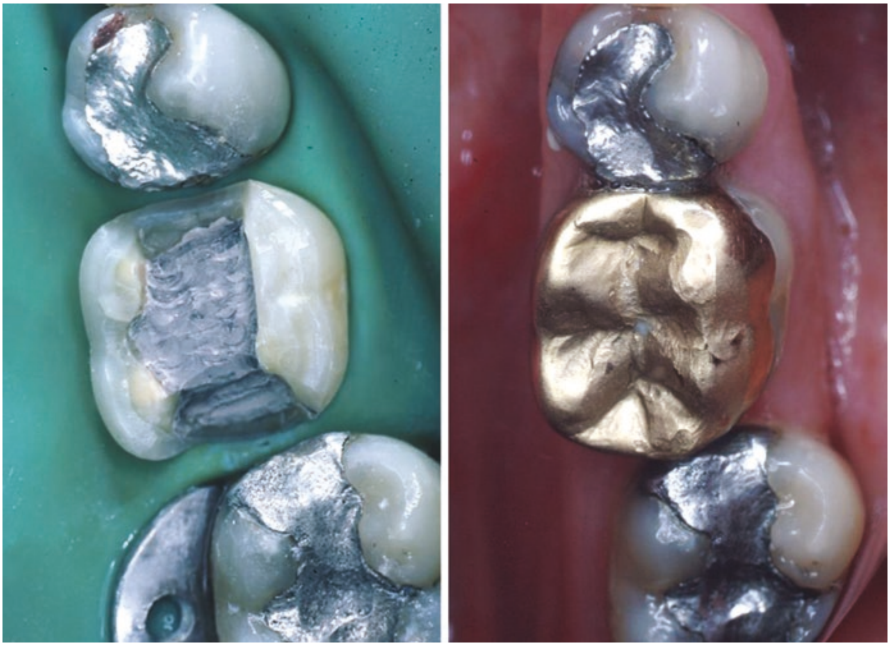

Fig. 2.2 A preparation for a conventionally cemented gold onlay. The preparation geometry retains the cemented restoration effectively via the near parallel walls of the box forms and occlusal isthmus

2.2.2 Adhesively Retained Restorations

Since their introduction in the 1970s, enamel and dentine bonding systems have evolved considerably leading to the widespread use of restorations requiring little or no retentive features in their preparation design. These developments started largely in the 1980s with adhesively retained bridgework, but ceramic veneers and onlays (metal or ceramic) soon followed. Indeed, tooth preparation may occasionally be unnecessary with the retention of the veneer or onlay relying entirely on the strength of the resin cement and its bond to tooth and restoration. These are most correctly called "minimal preparation adhesively retained restorations" but colloquially they are also called "adhesive restorations" (Figs. 2.3 and 2.4). Of course, the bond to enamel is stronger and more reliable than the bond to dentine, so it is important to have sufficient enamel for a reliable bond. It is also worth remembering that

Fig. 2.3 A preparation for an adhesively luted metal onlay. Without a strong adhesive lute, the geometry of the preparation, with its short axial wall height, would be insufficiently retentive

Fig. 2.4 A preparation for an adhesively luted ceramic restoration (shown right). Again, retention of the restoration relies on the adhesive lute. The orange wedges with stainless steel inserts protect the adjacent proximal surfaces during tooth preparation. Courtesy of Marco Ferrari

different restorative materials need specific bonding procedures (e.g. etching of some ceramics with hydrofluoric acid or impregnation of alloy surfaces with silica). However, some materials (e.g. zirconia ceramics) are notoriously difficult to resin bond (see Chaps. 15 and 24). So, bonding is particularly technique sensitive and will have failure built in if the correct procedure is not followed.

Conventional restorations may also be luted adhesively, particularly if a tooth preparation is short or tapered. Such restorations may also be considered "adhesive restorations". However, tooth preparation is usually not minimal resulting in considerable underlying dentine being exposed. Therefore, temptation to use adhesives for a simple solution to unretentive tooth preparation must be tempered by the need for a meticulous bonding technique.

Nevertheless, when appropriately prescribed and skilfully placed, adhesively retained restorations offer reliability and the benefit of preserving tooth tissue, thereby safeguarding longevity of the tooth. These are extremely important considerations when restoring worn, fractured or young vital teeth, where the chances of further pulpal insult need to be minimised. In addition, adhesively retained restorations are often the only viable conservative option where a tooth has already lost a significant amount of tissue and where removal of further tissue to incorporate retentive features (e.g. grooves and boxes) could render it unrestorable. Adhesive technology may also be employed in the placement of posts in endodontically treated teeth, which will be explored in Chap. 19.

2.3 Numbers of Restorations

A phenomenal number of teeth are restored with indirect restorations every year. Information from the NHS Health and Social Care Information Centre reports 822,700 crowns, 28,600 veneers and 181,600 inlays (we assume some of these inlays will have an onlay component) were prescribed within NHS primary care dentistry in England in 2014/2015 alone. These figures are comparable with previous years [2, 3]. This of course does not include restorations provided in the private sector, where levels of provision are not reported. However, the overall number of crowns in the population across England, Wales and Northern Ireland can be derived using data from the 2009 Adult Dental Health Survey: a staggering 37% of dentate adults had artificial crowns with on average 3 per person giving an estimated 47.6 million crowns [4]. How many of these crowns have been cemented conventionally or adhesively is unknown.

As already mentioned crowns by their very nature require destructive tooth preparations, so a move to adhesively retained restorations with more conservative tooth preparation will spare more tooth tissue. Adhesive technology is also likely to be used increasingly to repair and extend the lifespan of existing restorations.

Nevertheless, using adhesive technology to retain indirect restorations can have its disadvantages. Many dentists have already experienced the frustration of removing a failed crown luted with adhesive cement. A conventionally cemented crown simply requires the crown to be sectioned with a bur, and the brittle cement is then easily fractured to allow the two fragments of crown to be removed. By comparison an adhesively retained crown with its tougher resin cement often needs to be ground away entirely—unless the resin bond has failed. Crowns with high-strength ceramic cores compound the problem of crown removal as they can take several diamond burs to cut through. Techniques and technology to deal with failure are advancing, and this is needed, given that most failures are likely to be encountered in an increasingly ageing population with the additional requirements and challenges faced within gerodontology.

2.4 Clinical Performance of Restorations

As mentioned in Chap. 1, many restorations will eventually need to be replaced or repaired, but sometimes failure is catastrophic leading to the loss of the restored tooth. There are many modes of failure, and being aware of them should help us prescribe and design restorations which perform well and should they fail cause least damage. It is helpful to think about failure occurring at one or more “sites” (Table 2.2). Whilst the site of failure of many restorations appears blindingly obvious, it can be notoriously difficult to be sure why a restoration has failed. For example, the pulp of a restored tooth may eventually become nonvital, but how do we know whether this resulted from thermal damage during tooth preparation or subsequent microleakage?

Despite these difficulties, it is worth being aware of the multiple factors working singly or in combination which may predispose to failure (see Box 2.2). This complexity means dentists must think about many things simultaneously, make sensible choices and work skilfully to get a long-lasting restoration with which the patient is happy.

Table 2.2 Types of failure according to site of failure *with biological complications shown in italics* (NB “Restoration” also includes the lute and any core build-up)

Site of failure	Types of failure
Tooth	*Caries* *Periodontal disease/gingival disease/gingival recession* *Pain/pulpal sensitivity* *Loss of pulp vitality/apical periodontitis* Fracture of prepared tooth/core build-up Wear of opposing tooth
Interface	Bond failure of lute or core leading to microleakage or loss of retention
Restoration	Physical disintegration (seen as roughness, wear, marginal deterioration) Fracture (of ceramic or composite or of alloy posts) Corrosion (of alloys) Distortion (of alloys) Aesthetics (deterioration of shade match, marginal staining)

Box 2.2: Factors Contributing to the Overall Outcome of an Indirect Restoration
Patient factors—Ability to care for the mouth as a whole-controlling oral hygiene and diet, ability to tolerate treatment, ability to achieve moisture control, aesthetic desires, economic factors

Tooth factors—Condition and amount of the remaining tooth structure, presence and type of core, vitality and endodontic status, ability to provide retention and resistance form, location in the arch, absence of disease processes, occlusal scheme, presence of parafunction/bruxism, previous bleaching

Material factors—Type of bonding system employed, the material that is being bonded to the tooth, preparation of the bonding surfaces, presence of eugenol-containing temporary cement

Operator factors—Ability of the operator to perform technique-sensitive procedures, clinician preferences

Patients often ask, "How long will this restoration last?", but few dentists have their own follow-up data to provide an accurate answer. Even if they did it is likely that materials being used now will be different to those being used say 10 years ago. The dental literature contains several studies which might provide a guide, but bear in mind that compared with your practice, there may be differences in operator skills, thus the patients' disease susceptibility, in combination with operator skill, material selection, parafunction, occlusion, prevention and maintenance regimen will influence survival in an individual. So, if you are tempted to give the patient a percentage survival rate based on the literature, it is worth mentioning the above caveats. The same cautious advice would apply to advising government and commercial agencies sponsoring dental care.

If you are being sold a new or different restorative product, it is worth having an insight into the validity of the data, either clinical or laboratory, being presented. Some reputable companies sponsor clinical studies of their products, but many don't. Instead they may present lab data (e.g. tensile strength, hardness, bond strength, wear resistance and microleakage) which makes for impressive charts and diagrams but cannot be relied upon to predict clinical performance [5]. The main value of lab data is for screening new products to ensure they are not fatally flawed before being launched. If there is only lab data, it is the dentists that carry out the clinical trial—unofficially!

Before we consider clinical evidence supporting the use of extra-coronal restorations, we need to discuss briefly how clinical performance is measured. This should also provide a useful foundation when reading clinical studies.

2.5 Getting to Grips with Clinical Performance

This section provides a rough guide to clinical studies of restoration durability. Readers needing more detailed information can find this elsewhere [6].

The strongest evidence of clinical efficacy is provided by systematic reviews or meta-analyses of randomly controlled clinical trials (RCTs). The repository for RCTs and meta-analyses is the Cochrane Collaboration which holds a huge amount of data regarding drugs trials, but relatively little on clinical studies of restorations. This reflects not only the financial and time constraints in carrying out these trials but also the difficulties in designing RCTs free from bias. The Cochrane Collaboration defines five main types of bias: *selection bias, performance bias, detection bias, attrition bias* and *reporting bias* [7].

It's relatively easy to eliminate bias with drugs trials but not so with trials of extra-coronal restorations. For example, with drug trials both the prescribing doctor and evaluator of clinical outcome are blind to which patients are taking the drug and which the placebo. This effectively eliminates *performance* and *detection bias*. By contrast, with trials of extra-coronal restorations, it is difficult if not impossible to hide the type of restoration from the providing dentist and the follow-up evaluator—either of whom may prefer a particular type of restoration. Furthermore, *attrition bias* caused by patients failing to attend is less likely with drug trials where follow-up is relatively short term compared with trials of restorations lasting many years. Of course, dentists blessed with a loyal patient following may command better long-term attendance. Nevertheless, their studies may be subject to *selection bias* in choosing patients most likely to have a good outcome with the chosen treatment. *Reporting bias* may manifest where trials are withheld from publication for whatever reason so that the literature may not provide a full picture of restoration performance.

In addition to possible issues of study bias, you need to be aware of the lack of consensus over definitions of survival, success and failure [8]. However the following advice may be useful:

- "Survival" is generally taken to mean a restoration is still in situ, but does not take full account of its condition
- "Success" provides criteria in respect of the restoration's condition (e.g. US Public Health Service Corps (USPHS)) [9], but these may differ or be variously modified between studies [8]
- "Failure" implies that the restored tooth needs further intervention, but not always in relation to the restoration. The decision to intervene is often clinically based and may lack adequate criteria. There are also differences between studies as to what constitutes a failure (requiring a restoration to be replaced) and a partial failure (where it is repaired or recemented).

This lack of agreed definitions prevents the results of clinical trials of extra-coronal restorations being easily combined in the form of a meta-analysis.

Nevertheless, there are clinical studies which provide at least an indication of restoration performance. Bearing in mind that almost all trials of extra-coronal restoration will be at least mildly biased, what other factors should the reader be looking for to ensure a study has some validity?

Firstly, find out what sort of study it is. There are basically two main types: efficacy studies and effectiveness studies. *Efficacy studies* compare the performance of the test restoration against a comparator with known characteristics. These are often carried out in universities, and the best ones are randomly and prospectively controlled and provide internal validity by controlling for variables affecting restoration failure (Box 2.2). *Effectiveness studies* consider how well restorations perform in a routine clinical setting—sometimes rather disparagingly described as "in the field". These often do not have a comparator group and are occasionally retrospective. Retrospective studies can suffer from inconsistent data collection.

Secondly, check for details of the study design. If different types of restoration are being compared in an efficacy study, the design may be parallel arm or split mouth. Parallel arm involves two separate groups of patients, whilst split mouth has only one group of patients. Each patient in a split mouth trial has at least one pair of similar teeth restored: one tooth with the test restoration and the other with a comparator. Treatments should of course be randomised. Often, however, trials only place test restorations and compare clinical performance with the results of other studies which may well introduce multiple sources of bias.

Thirdly, look for adequate details of the clinical variables including:

- Restoration materials
- Case selection and patient demographics
- Placement conditions including cement type
- Operator: single or multiple, skills and experience
- Preparation design
- Calibrated examiners for follow-up.

Fourthly, check the number of patients who are lost to follow-up. Preferably, more than 70% of patients should complete the trial, but less than 60% may indicate a weak study. However, the longer the study, the greater the loss to follow-up, so at 10 years a 60% return would not be unreasonable. Finally, consider the statistical analysis and whether sufficient patients have been enrolled to give the analysis sufficient "power". Be aware that an underpowered study may show "no significant difference" where in reality one exists (Type II error). Some dentists are excellent statisticians, but many are not. As a rule of thumb, if the paper has been published in a reputable scientific journal, this implies statistical methods have been scrutinised. Look also for a qualified statistician as a named author or in the acknowledgements. A personal observation is that over the past 10 years or so scientific journals have become increasingly rigorous statistically, but older papers may not always be so robust.

So far, we have considered prospective clinical trials of extra-coronal restorations and have seen that in comparison with drugs trials, bias is difficult to avoid. Lower down the hierarchy of clinical evidence is the cohort study. Despite its apparent lowly position, this sort of effectiveness study has provided invaluable information in respect of the large number of restorations placed by multiple dentists in the National Health Service. Two major cohort studies of crowns [10] and veneers [11, 12] placed in NHS primary dental care are described in the sections below. These studies give a general idea of restoration performance in the real world—although sadly following the UK's new dental contract in 2006, this detailed data is no longer collected.

In these cohort studies, large groups of NHS patients were identified who had been provided with either a crown or a veneer. Restoration failure was recorded if a dentist submitted a claim for further treatment of a logged tooth. Hence, the decision was a clinical one and not reliant on research criteria. Life table analyses were used to calculate probability of restoration survival because restorations were placed over a considerable number of years and followed up for differing lengths of time. Graphs of cumulative probability of survival against time (Kaplan-Meier plots) indicate the proportion of restorations surviving at varying times and allow demographic variables possibly affecting outcome to be compared (see Fig. 2.5). The advantage of using this type of analysis is that it includes provision for those restorations unable to be evaluated at follow-up [14].

Whilst providing invaluable data, these studies have three limitations: firstly, only demographic comparisons could be made (e.g. effect of patient age on veneer survival) but not the effect of clinical variables (e.g. veneer material and cement type); secondly, because patient recruitment is staggered over several years, there are fewer patients eligible to be reviewed with increasing length of follow-up, which means the results are truer earlier in the study; and thirdly, the results incorporate significant heterogeneity so are not generalisable to individual dentists.

The results of restoration longevity studies can be presented in several ways:

- Proportion of restorations surviving after a specified time
- Probability of survival at specified times
- Annual rate of failure.

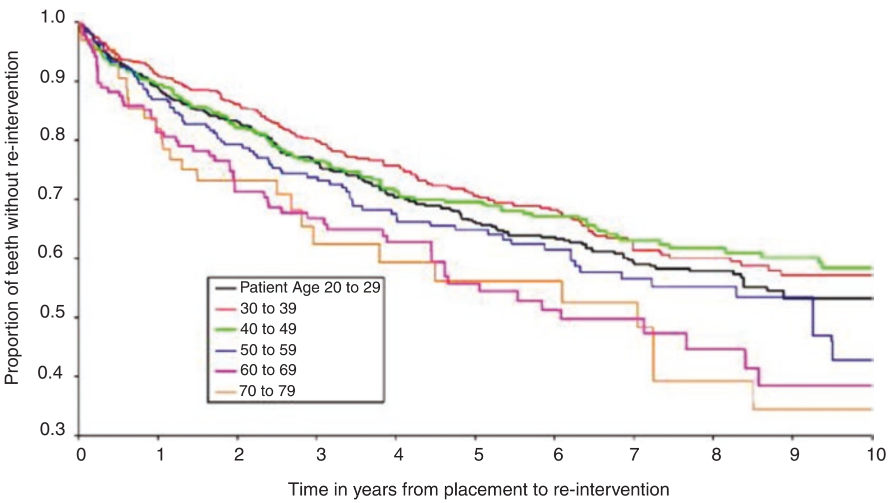

Fig. 2.5 Kaplan-Meier plot showing the proportion of ceramic veneers surviving up to 10 years [11, 12]. The effect of age can be clearly seen with older patients having poorer veneer survival. Differences between groups can be tested statistically using Cox proportional hazards regression [13]. *Reproduced under licence from the Journal of Dentistry*

In the following section, we consider how well different types of restoration perform. To allow comparisons to be easily made between studies, it is tempting to adjust the results to show only annual rate of failure. However, doing so risks making false assumptions because of the differences in the way studies are carried out and differences in patient populations.

2.6 Examples of Clinical Trial Results

The following sections provide an insight into restoration performance. Readers should of course bear in mind that most clinical studies are imperfect. Ultimately success and longevity, particularly in adhesively bonded restorations, will be dependent on the design, manufacture and placement of the restoration and how the cement interacts with tooth tissue and restorative material within the challenges of the oral environment. These will include not only dietary and oral hygiene challenges but also occlusal and erosive challenges (Chaps. 12 and 13).

2.6.1 Crowns

In this section, we will consider the performance of crowns cemented with either conventional cements or resin adhesives. However, there is a paucity of studies where the primary focus is the type of cement used. Most studies focus on the material from which a crown is made. Whilst all-metal and ceramo-metal restorations are often cemented with conventional cement and all-ceramic restorations are often cemented adhesively, it would be unwise to assume this if not specified in the study. The only crowns that must be cemented adhesively are those made from relatively weak feldspathic ceramics. Although sometimes called "dentine-bonded crowns", they should ideally be bonded to enamel. These restorations are essentially ceramic veneers extended circumferentially to involve all tooth surfaces and will be considered in the feldspathic veneer section below.

Ceramo-metal crowns are often considered the gold standard against which other crowns are judged. These robust crowns have served dentists and patients well for over half a century, but achieving excellent aesthetics is technically difficult. A good aesthetic result can be achieved more easily with some of the etchable all-ceramic systems (Chap. 14), because these systems give increased scope for lifelike translucency. So how well do all-ceramic crowns compare with ceramo-metal ones?

In a systematic review, Sailer et al. considered the 5-year survival and complication rate of single crowns. They included 54 studies reporting high-strength all-ceramic crowns and 17 reporting ceramo-metal crowns. No reference was made to the types of cement used. They concluded that for the majority of types of all-ceramic crowns, survival rates were similar to those reported for ceramo-metal crowns [15], which was 95.7% after 5 years. Unfortunately, this similarity did not extend to fixed bridgework where all-ceramic bridges frequently suffered chipping and partial loss of the overlying veneer ceramic, particularly with some zirconia-based frameworks [16].

Wang's systematic review of all-ceramic crowns reported similar results with a 5-year fracture rate of 4.4%. There was a significantly higher fracture rate for crowns on molar teeth compared with premolars (8.1% c.f. 3.0%) and crowns on posterior teeth compared with anteriors (5.4% c.f. 3.0%). About half the fractures involved the high-strength core of ceramic crowns which would not have been repairable. Again, no information was given on whether crowns were adhesively retained [17].

As mentioned in the previous section, Burke and Lucarotti [10] carried out an important 10-year efficacy study of crowns placed within the General Dental Services in England and Wales. The study selected 21,809 NHS patients who had crowns placed between the end of 1990 and early 2002 and when, or if, re-intervention was subsequently recorded over an 11-year period. The dominant group of crowns placed during this time was ceramo-metal (80%). They reported that at 10 years, full-coverage metal crowns had the highest survival (68%), which was longer than for ceramo-metal and all-ceramic. All-ceramic crowns had the shortest survival (48%) at 10 years. They suggested other factors also influenced the outcome including patient's age, payment exemption status and a root treatment in the same course of treatment as the crown. These factors may of course reflect underlying dental disease susceptibility.

Over a 102-month observation period, Jokstad reported survival of single crowns cemented with resin-modified glass-ionomer luting cement compared with zinc phosphate [18]. No statistically significant difference between the two cements was shown. The results for "no negative events" was 89% (85% zinc phosphate, 93% resin-modified glass ionomer), whilst those of "no re-cementation or loss of vitality" were 96% (95% zinc phosphate, 97% resin-modified glass ionomer).

Developments in indirect composite have made composite crowns an interesting possibility. Survival at 5 years has been reported as 88.5% though increased plaque accumulation was noted, making them perhaps more suited to long-term provisional restorations [19]. However, further developments including CAD/CAM machined composites, as described in Chap. 14, could make composite crowns a cost-effective, longer-term, repairable option.

With most types of crown, excellent results are possible with good patient selection and meticulous clinical technique. However, a reduced time in service can be expected if dental disease is not controlled. This limitation and the possibility of crowned teeth becoming nonvital (see Chap. 9 for further details) should be discussed with patients. As ever, further evidence is needed to determine the best materials and cements. In addition, the influence of clinical variables on crown longevity, such as the amount of remaining tooth tissue [20], needs to be investigated to ensure teeth are not replaced prematurely with implants.

Keeping in mind the differences between study outcomes may reflect differences in patient populations (e.g. disease susceptibility, bonding difficulties, tendency for bruxism), or different healthcare systems in which the crowns were placed (e.g. privately vs public funded, material and laboratory differences) or study biases and definition differences as discussed previously. This is relevant for all restorations whether cemented conventionally or adhesively. We consider adhesive restorations below.

2.6.2 Adhesive Restorations

2.6.2.1 Veneers

Veneers comprise a layer of tooth-coloured material (Fig. 2.6) attached to the surface of a tooth. They are frequently used to improve aesthetics by modifying the colour, shape or position of a tooth [21]. There are three main types of veneer determined by material: feldspathic ceramic, non-feldspathic (generally high-strength ceramics) and composite (direct and indirect).

Clinically, successful veneers are dependent on careful case selection. Veneers are most suited to the treatment of teeth requiring minimal or no preparation, treatment of intrinsic staining resistant to bleaching (or possibly performed in conjunction with bleaching), where adequate enamel remains for bonding and for the treatment of minor imbrications. Planning, material selection, handling and maintenance all contribute to the overall success of these restorations.

Reasons for veneer failure include debonding, fracture, marginal discolouration and defects, especially when bonded to dentine or existing restorations [11]. Failure may also result from pulpal involvement following tooth preparation or from subsequent microleakage or caries. Gingival problems are rarely reported in clinical studies. However, a frequent finding clinically is oedematous swelling in response to a defective margin or recession revealing an unsightly margin. Aesthetic failure may be immediate if a patient proclaims they do not like what is provided. Alternatively, unhappy patients may return later with unsightly margins or discoloured cement showing through a translucent veneer. Clearly, patient satisfaction is important, but clinical studies often fail to report it or do so inconsistently.

Fig. 2.6 A veneer held in a thickness gauge. These restorations sometimes conceptually resemble false finger nails but with good case selection and immaculate technique are considerably more aesthetic and durable. Courtesy of Andrew Keeling

Feldspathic Veneers

So how long do feldspathic veneers last? This depends on which studies you look at and for how long the veneers have been followed up.

Short term over 3 years, a systematic review including over 2000 restorations gave a 92% cumulative survival rate for indirect veneers, outperforming direct composite restorations [22].

Long-term over 10 years or more, successful outcomes requiring no further intervention or repair range widely between 96 and 53%. The importance of bonding to enamel is emphasised by Layton who reported 95% survival at 10 years [23, 24] and 96% at 21 years [23, 24]. Another 20-year study where veneers were not bonded exclusively to enamel had a lower survival of 80%. Fracture was the most common mode of failure. More veneers failed when used to restore nonvital teeth, and failure was nearly 8× more likely in bruxist patients [25].

Burke provided 10-year data on outcomes of 2562 veneers in NHS primary dental care and found only 53% of veneers surviving without intervention [11]. Factors detrimental to veneer survival were male gender, patients over 60 years of age (Fig. 2.2), change in care provider and those with higher dental treatment needs [11, 12]. Again, the relatively high failure rate may be explained by the factors discussed above for crowns.

As mentioned in the previous section, a feldspathic veneer may be extended circumferentially to comprise a full-coverage “dentine-bonded crown”. A survival rate of 94% at 4 years has been reported for these restorations, with fracture being the main mode of failure [26]. Whether better results can be achieved with the newer high-strength ceramics when etched and resin bonded would be worth trialling.

Non-feldspathic Veneers

Non-feldspathic veneers made from a variety of high-strength ceramics have been suggested for use in areas requiring greater flexural strength or where there is a greater loss of tooth tissue. Systematic review of non-feldspathic ceramic veneers, for which there is a paucity of data, does not show any better outcomes than feldspathic veneers with over 90% survival at 5 years but as low as 66% at 10 years [27]. Indeed, in a systematic review comparing the different veneering materials found at 5 years, there were no statistical differences in survival or mode of failure [28]. These slightly disappointing findings may be explained by case selection favouring the use of high-strength ceramics in areas of high occlusal stress or where more dentine is exposed. They may also reflect the use of relatively weak glass ceramic materials. A recent study suggests better performance from the stronger lithium disilicate material, e-max™ (Ivoclar Vivadent), with between 1.3 and 1.5% of veneers reported fractured at 4 years [29]. This was a retrospective study using data from dental laboratories so other modes of failure may have been missed. Clearly better controlled, longer-term, prospective studies are needed to clarify which if any of the non-feldspathic ceramic veneers perform best.

Often veneers are provided for teeth with existing fillings. Some authorities suggest bonding to the existing filling as it is conservative of tooth tissue [30], but other studies report higher failure rates [31, 32]. Failure may be due to resin bonding to the existing filling being compromised by water sorption and lack of availability of reactive sites in the resin of the old composite. Furthermore, preparation of an existing composite filling will expose un-silinated filler particles which can be difficult to bond to. For longer-term stability, it may be prudent to replace the filling shortly before the preparation or immediately after the veneer is fitted. These approaches also help to ensure that the filling is properly bonded to the underlying tooth. An existing but satisfactory composite may also be conditioned using airborne particle abrasion as described in Chap. 15.

Composite Veneers

Composites can be applied directly to veneer a tooth, or a composite veneer may be made indirectly and luted into place. There is limited data for the performance of direct and indirect composite veneers versus ceramic veneers [33–35]. Although patients were initially satisfied with all three types of veneer, two and a half years later, they were more satisfied with ceramic veneers. It should be remembered that this study was carried out almost 20 years ago and had methodological issues preventing a valid statistical analysis [36]. More recently a small clinical study involving only 10 patients reported a trend at 3 years to a lower survival rate for indirect composite veneers (87%) compared with ceramic veneers (100%) [37]. Having such a small number of patients meant the study was underpowered to show a statistically significant difference. In addition, although both types of veneer had transient post-operative sensitivity, there was a non-significant trend to a higher incidence with composite veneers. So, doubts remain clinically with indirect composite veneers over possible higher levels of pulpal sensitivity following veneer placement and their longer-term wear and aesthetic characteristics. They do however provide a cost-effective and modifiable option to the clinician. Furthermore, direct composite veneers require minimal tooth preparation. Advances in composite technology are promising and may eventually make direct composite at least as good aesthetically as ceramic veneers. Clearly, long-term data are needed to inform material choice and technique.

Despite being badged as a "conservative adhesive restoration", indirect veneers of any description should still be prescribed with caution. This is because any intervention will start a tooth on its journey along a restorative spiral of re-intervention, removal of further tooth tissue, risk pulpal involvement and may even lead to eventual tooth loss. Patients must be informed of the risks before they begin and understand that veneers do not have a 100% success rate. Indeed, after only 5 years, 9% of veneers of various types suffered from marginal discolouration and nearly 8% marginal gaps [28]. Not every patient would regard this as acceptable bearing in mind veneers are largely provided electively on otherwise healthy teeth for aesthetics and cosmetic gain. Patients should also be aware that bruxism carries an 8× higher risk of veneer fracture, as mentioned previously [25]. Not every patient is given this information with sufficient time to make an informed consent, so it should come as no surprise that veneers are involved increasingly in cases of litigation [12].

2.6.2.2 Onlays

These restorations are designed to cover all or part of the occluding surface of posterior teeth or anterior teeth. Some authorities use the term “overlay” to indicate full occlusal coverage, but we prefer just to use the term “onlay”. Traditionally, onlays were made of cast metal alloy and included an inlay component within the tooth preparation to give sufficient retention when used with conventional cements. Nowadays, onlays are made from a variety of materials including alloys, ceramics and composites. Onlays continue to be made using casting for alloys and sintering for ceramics, but high-tech CAD-CAM methods are becoming increasingly accessible (see Chap. 14). If onlays do not have a retentive inlay component, they should be cemented adhesively with resin cement. Adhesive cement may also help reduce fracture in ceramic restorations [38]. Another advantage of resin adhesive is that it helps fill the larger marginal discrepancies associated with some ceramic restorations, compared with cast metal.

Metal Onlays

These restorations are sometimes called “shims” when used on posterior teeth without a retentive inlay component or on anterior teeth. It is best to avoid the term “palatal veneer” for a metal onlay as veneers are tooth-coloured restorations. Alloys used for onlays include Type III gold, nickel-chromium, and cobalt-chromium-tungsten. Methods to improve bonding to alloys are considered in Chap. 15.

Metal onlays are commonly used in the treatment of tooth wear (see Chap. 13) and are particularly suited to patients with bruxism who generate high occlusal forces. Metal onlays have suitable wear characteristics and high fracture resistance. Data for adhesively cemented metal onlays is limited. However, a success rate of 89% over 56 months has been reported for metal palatal shims with similar results on posterior occlusal surfaces [39, 40]. Better results can be expected when more enamel is available to bond to [41]. At least one report indicates that metal onlays have superior performance compared with ceramics and composites [42, 43], but risk of bias cannot be excluded.

Whilst metal onlays are less aesthetic than tooth-coloured ceramics and composites, they do have a major advantage: metal onlays can be made in thinner section—down to 0.5 mm—although 0.7 mm is preferred clinically to resist distortion and subsequent decementation. For bruxists we recommend at least 1 mm occlusal thickness to reduce the risk of a posterior onlay wearing away and perforating.

Ceramic Onlays

Clinical wisdom recommends ceramic onlays be made in thicker section (2 mm occlusally) to prevent fracture due to the brittle nature of the material. There is now supporting evidence for the use of ceramic inlays and onlays for restoring posterior teeth: a 10-year meta-analysis of 2154 restorations reported a survival of 91% for both feldspathic and glass ceramic inlays and onlays (covering at least one cusp and including full cuspal coverage). Failures were related to fractures/chipping (4%), followed by endodontic complications (3%), secondary caries (1%) and debonding (1%). More failures were reported in molars and root-treated teeth [44]. However, the authors had insufficient data to quantify the risk of cuspal coverage, tooth sensitivity, effect on opposing teeth and patient satisfaction. The increasing use of stronger ceramics (e.g. lithium disilicate) may further improve results but needs to be clinically trialled [29].

To protect ceramic restorations from bruxism, a soft or hard occlusal splint (Chap. 13) may be advisable; however, it is not known to what extent this approach may improve restoration longevity, and it relies of course on patient compliance.

Composite Onlays

Composite onlays lack a wealth of long-term data, but some insight into their performance can be gained from studies undertaken in the 1990s which systematically compared composite inlays against direct, incrementally placed composite restorations. Importantly, these well-controlled studies, which included restorations with cuspal coverage, found no difference in clinical performance [45, 46]. This finding came as a surprise as the rationale for making the restoration indirectly was to enhance the composite's physical properties by heating to 120 °C and to reduce problems from polymerisation shrinkage (e.g. tooth sensitivity and marginal adaptation). These expected benefits did not materialise largely because directly placed composites continue to polymerise after placement, so heating only gave an initial benefit. Furthermore, inlays are not immune to the effects of polymerisation shrinkage which may cause potentially disruptive stresses in the resin lute. In addition, subsequent water absorption causes slight swelling of the composite restoration. This swelling may be beneficial to compensate the polymerisation shrinkage of directly placed composites but detrimental to composite inlays where the swelling may place strain on the restored tooth or the interface between tooth and restoration [46].

Over the past two decades, the physical properties of composites have been improved, largely through improvements in filler technology, leading to composite inlays being promoted yet again in the hope of improved clinical performance [43, 47]. Although recent studies appear to support the use of indirect composite restorations, some studies were uncontrolled and retrospective [48]. Others gave only 3- and 4-year observations [49, 50] but showed annual failure rates of between 3 and 5%. Such results are not exceptional when compared with an extensive meta-analysis of 2585 class II direct composites highlighting a mean annual failure rate of 1.8% at 5 years increasing to 2.4% at 10 years [51]. This meta-analysis emphasised the main reasons for composite restoration failure are caries and restoration fracture with larger restorations involving more surfaces being at increased risk. Patients with moderate to high previous caries experience have the highest risk of a carious failure, whilst patients with a history of bruxism have a greater risk of restoration failure [52]. These factors should be considered clinically when prescribing either direct composites or indirect composite restorations.

One disadvantage of indirect composite restorations with an inlay component is that they often require additional tooth removal to prepare a cavity free from undercut. This and the lack of convincing evidence showing improved clinical performance [42, 43] make a strong argument for placing composite restorations directly rather than indirectly. However, laboratory-made composite restorations are sometimes easier to place clinically, and the decision will often also be based on personal preference.

Some patients have multiple posterior teeth with severely worn occlusal surfaces (see Chap. 13). The temptation to restore them only with composite should be tempered by the catastrophically high failure rate of 52% reported at 3 years for a microfilled composite when used either directly or indirectly [53]. Although stronger composites are now available, a recent audit has shown 16% failure of both posterior and anterior restorations for worn teeth after only a few months [54]. Better results may be anticipated when composites are prescribed in combination with strategically placed restorations having a metal or ceramic occlusal surface. By restoring adjacent teeth with more wear-resistant occlusal surfaces, the composite may be protected from high occlusal forces, but its success rate has not been reported.

There is limited information comparing inlays made of composite or ceramic. One systematic review of two RCTs reported the overall 3-year success rate was 94% for composite inlays and 97% for ceramic inlays, but the difference was not statistically significant. The authors cautioned against extrapolating these early results to the long term because the study involved only 138 restorations, and the 2 trials exhibited a high risk of bias and heterogeneity [55]. Furthermore, the effect of cuspal coverage was not studied.

Clearly, onlays offer a much more conservative approach to restoring teeth than crowns and clinically appear to last well in selected cases with sufficient remaining enamel for bonding. Further clinical research is needed to define optimum material and bonding combinations.

2.7 Implant Crowns

Implant-supported and retained restorations are becoming an increasingly mainstream treatment option. Technology has improved, costs have reduced and more dentists have received training in implant dentistry. In the UK we can get an indication to the scale of the potential numbers by looking at the most recent Adult Dental Health Survey which showed that at least 1% of dentate adults had an implant or a dental implant restoration [56]. This could well be an underestimate as several restored implants may be missed in “the field” conditions of the survey. What proportion of these figures is represented by implant crowns is unknown (Fig. 2.7).

In the USA the American Academy of Implant Dentistry claimed that 5.5 million implants were placed in 2006 [57]. Their more recent estimate is over 3 million people in the USA have implants, and this number is growing annually by 500,000 (data source unspecified) [58]. Whilst 3 million sounds impressive, it represents a similar proportion of the adult population with implants as in the UK.

The evidence base for implant crowns faces the same limitations as discussed previously for tooth-retained extra-coronal restorations, namely, the difficultly in controlling for the wide range of variables that can affect success (see Box 2.2) and the lack of randomised controlled trials.

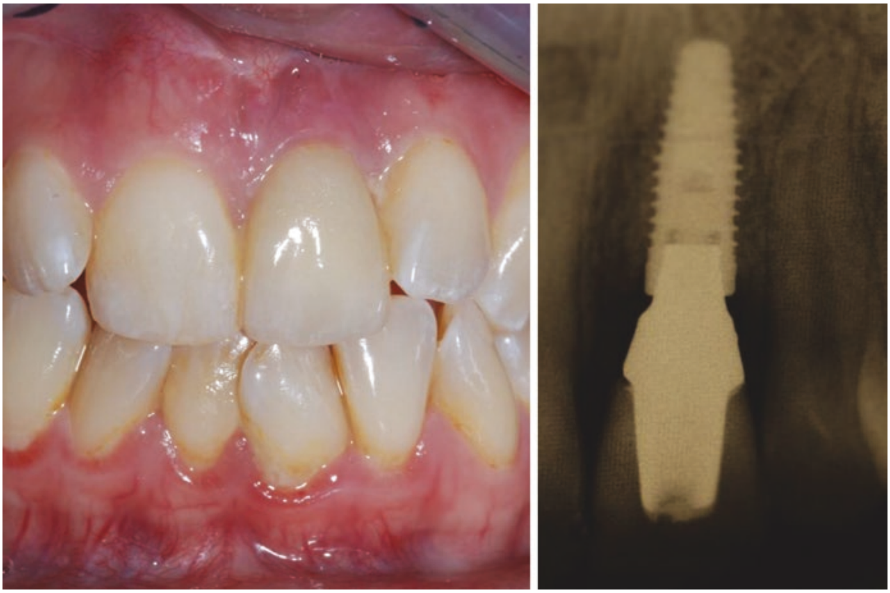

Fig. 2.7 Implant crown replacing tooth 22. The radiograph shows the threaded, osseo-integrated implant to which is screwed a separate abutment and over which is cemented an all-ceramic crown. Courtesy of Margaret Corson

Implant dentistry is a relatively new field and is rapidly evolving. An interesting piece of research looked at studies over time (pre- and post-2000) and found decreasing failure rates, suggesting a positive learning curve in implant dentistry, for example, with regard to screw technology where 5-year survival rates of screw-retained prosthesis increased from 77.6% to 96.8% [59].

It is worth noting that implant survival rates are high—at least in the medium term—with 5-year survival rates for implants supporting crowns reported to be 97.2% (95.2% at 10 years) [60]. However, the maintenance burden of these restorations is significant with relatively high biological and prosthodontic complications. The survival of the crowns themselves (implant supported) was 96.3% at 5 years decreasing to 89.4% at 10 years [60]. The three most common technical complications are abutment or occlusal screw loosening (5-year cumulative incidence: 8.8%), loss of retention of cemented retained (5-year cumulative incidence: 4.1%) and fracture of the veneering material (5-year cumulative incidence: 3.5%) [60]. Furthermore, the biological complications were also significant with 5-year cumulative rates of peri-implant mucosal lesions being 7.1% with 5.2% of implants having bone loss exceeding 2 mm after 5 years [60].

Implant-supported restorations often span more units than a single crown, ranging from simple single-unit cantilever designs to full-arch restorations. These restorations are prone to similar levels of complications, and it is important that patients and practitioners are aware of this maintenance burden. For example a recent systematic review [61] and consensus statement [62] highlighted that only 66.4% of patients were completely free from any complications at 5 years. The complications were similar in nature to implant-retained single crowns including fracture of the veneering material (13.5%), peri-implantitis and soft tissue complications (8.5%), loss of access-hole restoration (5.4%), abutment or screw loosening (5.3%) and loss of cementation (4.7%).

Peri-implantitis around implants, like periodontal disease around teeth, is caused by microbial induced inflammation. Both lead to bone loss which may eventually progress to the loss of an implant or tooth. Reviews report peri-implantitis prevalence ranges widely from 1 to 47% [63, 64]. This variability may reflect differences in the susceptibility of patients between studies, e.g. because of underlying periodontal disease, systemic disease (e.g. diabetes), smoking or genetic differences. It may also be due to differences in operator skill, implant material and design and diagnostic criteria. It does however raise a concern that in the longer term a proportion of implant patients may have increasing issues from peri-implantitis and a general need for supportive periodontal therapy (SPT) to include peri-implant maintenance. If possible, peri-implantitis should be prevented because removing an established biofilm from an inaccessible implant screw thread is notoriously difficult. Therefore, SPT needs to be intensified in disease susceptible patients showing early signs of inflammation (bleeding on probing) and bone loss [64, 65].

In summary, implant crowns are a highly successful treatment modality that offer an excellent option to patients with missing or severely compromised teeth—but they are not “fit and forget”. They are, by their complex nature, prone to high complication rates and high-maintenance demands. The scope of implant dentistry is vast and many aspects are beyond the scope of this book. Nevertheless, aspects of material choice, abutment considerations and cementation will be covered throughout the relevant chapters of this book (Chaps. 14, 16 and 24, respectively).

Conclusion

Crowns and other extra-coronal restorations are still major treatment modalities, generally offering good performance and longevity. Although technology and treatment concepts have evolved, the evidence base is less than perfect due to the complexities of conducting research in this field. Part of the difficulty is the wide range of variables (patient factors, tooth factors, material factors and operator factors) able to influence success. Nevertheless, crowns remain an important treatment modality, particularly implant crowns, but for restoring teeth there are now many types of adhesive restorations. There is an increasing amount of evidence that these minimal preparation alternatives offer a viable and less-destructive alternative to crowning. However, careful case selection and meticulous technique are essential to a good outcome.

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Part II

A Healthy Start

3 Caries Management

Heidi Bateman, Angus Walls, and Robert Wassell

3.1 Learning Points

This chapter, the first in the “Healthy Start” part, will emphasise the need to:

- Recognise and control caries to limit future CARS (caries associated with restorations)
- Identify clinical and patient factors associated with increased caries risk
- Identify patients for whom advanced tooth restoration poses too great a risk of failure—unless they respond to preventive advice
- Consider dry mouth a potent risk factor, determine its cause and where possible work with the patient’s medical team to modify xerostomia-related or sugars-containing medication
- Offer preventative counselling including dietary and oral hygiene advice and consider additional fluoride over and above regular fluoride toothpaste
- Advise patients with xerostomia including recommending a suitable salivary substitute.

Ensuring your patient’s oral environment is healthy before you provide advanced restorations—or indeed any definitive restorations—is key to increasing restoration longevity. Teeth restored with beautiful crowns, veneers or onlays are of limited value when patients continually develop caries necessitating further treatment which compromises not only the life of the restoration but also the life of the tooth.

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Thus, delivering preventive advice and stabilisation treatment should be your starting point.

Once a surface is restored, it enters a cycle of restoration and re-restoration which may continue while the tooth remains in the mouth. Older patients are retaining their teeth for longer [1] and are more likely to have a higher restorative burden as there is an accumulation of treatment over time [2]. This group of patients is therefore most likely to have, or have future need of, indirect restorations as a means of improving structural integrity of their teeth. Caries remains a problem in older populations, both on the crowns of teeth and the roots. In some populations the crowns are affected by more new carious lesions than the roots, and this nearly all comprises *caries associated with restorations or sealants* (CARS otherwise known as recurrent caries) [3, 4].

Spending time at the start of your patient consultation on preventative advice before finalising a treatment plan and commencing treatment is a good investment. Part of carrying out a thorough patient assessment includes a caries risk assessment. By considering clinical and patient factors (Table 3.1), this will allow you to tailor prevention to risk for your patient and to identify patients in whom advanced prosthetic care is contraindicated because of too great a disease risk (Fig. 3.1).

Plaque and dietary substrate directly link to dental caries, so assessment of your patient's current (and previous) diet and oral hygiene regime is important. In addition to this, there are several factors which will be seen clinically and indicate an individual's likelihood of future dental caries. These include previous caries experience, presence of exposed root surfaces, reduction in saliva and, in the case of root caries, presence of a partial denture. Xerostomia, or dry mouth, may be a result of

Table 3.1 Key points in caries risk assessment (clinical and patient factors)

Clinical factors	Patient factors
Previous caries experience	Oral hygiene
Reduction in saliva	Diet
Presence of a partial denture	Medication
Exposed root surfaces	Medical conditions

Fig. 3.1 Active caries affecting tooth crowns and roots. The disease must be controlled before considering advanced restorative work

disease (either directly in something like Sjögren's syndrome or indirectly through, for example, radiotherapy for head and neck cancer destroying salivary tissue), surgery or medication.

Over 400 medications have been identified with a known xerostomic side effect, but commonly implicated are medications for depression and high blood pressure [5] and polypharmacy. Medications may also be dentally damaging because some, particularly generic medicines, contain sugars [6]. So, there may be multiple jeopardy when cariogenic and xerostomic effects are enhanced by prolonged oral clearance in patients on long-term medication. Often there are branded sugars-free alternatives which doctors may be persuaded to prescribe.

Emphasis on prevention is essential to promote an oral environment the patient can maintain and that will reduce future caries risk. Patient information and involvement are key—a risk assessment is invaluable and should contribute to informing the overall treatment plan. By discussing with your patients their current risk status and how this can be modified from "at risk" to "not at risk", you can lay the foundation for long-term oral health and successful treatment outcomes.

For many patients, the key areas of effective prevention are dietary advice, oral hygiene advice and consideration of additional fluoride. For those patients, whose risk is increased by their medical condition or medication, liaison with their doctor or other members of their care team may be required.

3.2 Dietary Advice

This can be generic, providing information on frequency and types of sugars and avoiding them between mealtimes and before going to bed. Advice can then be specifically tailored to the individual by discussing pragmatic but nutritionally sensible alternatives to sweets (Fig. 3.2), biscuits, sugary drinks and sugars-packed breakfast cereal. When a patient is judged at high caries risk, a prospective diet diary is a critical tool to identify sources of added sugars in diet. Patients should agree an action plan and be followed up after a few weeks or at appointments for dental treatment [7].

Fig. 3.2 Avoiding cariogenic sweet foods and drinks between meals—to succeed, patients must buy into the message

A few patients may require referral to their doctor or a state registered dietitian for expert guidance and support. These include patients on special diets for medical reasons or those with extreme dietary patterns [7].

3.3 Oral Hygiene Instruction

Brushing technique, frequency and use of interproximal cleaning aids should again be tailored to the patient. These are also important in managing periodontal disease, so are considered further in Chap. 4.

In terms of medical history, consider the potential impact of conditions which may impair ability to maintain oral hygiene. This may include patients with arthritic conditions affecting wrists/fingers, sarcopenia (loss of muscle mass, strength and function related to ageing) or those who have extrapyramidal conditions or who have had a stroke. Vision problems which lead to impaired close focus (e.g. presbyopia) and cataracts may make an individual's self-monitoring of their oral hygiene challenging. Cognitive impairments or dementia may result in a person being perfectly capable of self-care, but they can simply forget to do it. This is by no means an exhaustive list but indicates the range of conditions that need to be considered. Solutions are not always simple, particularly where patients are unable to carry out tailored oral hygiene procedures. A huge step forward is when carers are actively involved.

3.4 Fluoride

Consider whether additional fluoride (over and above the use of a fluoridated toothpaste) in the form of varnishes, mouthwashes and higher concentration fluoride toothpaste (e.g. 2800 or 5000 ppm) [8] would be indicated, tailored to risk. If a patient judged at higher risk of caries warrants the use of supplementary fluoride, they should be monitored to ensure caries risk is controlled with the new diet and fluoride regime before embarking on advanced prosthetic care.

3.5 Other Modifying Factors

Management of xerostomia may be as simple as advice on regularly sipping water or may include consideration of salivary substitutes or salivary stimulants. Not all salivary substitutes are the same, and some will suit patients better than others. Several are made using animal products, which may make them unsuitable for people from certain religious groups, vegans and vegetarians. Most are neutral pH, but one is acidic (Glandosane™, Fresenius Kabi). Acidic substitutes and stimulants should not be used for dentate patients. If a fluoride-containing saliva substitute is not chosen, patients should be advised to use an additional fluoride mouth rinse.

Detailed advice on preparations and prescribing (medical and dental) can be found online [9].

As mentioned above, it may be worth investigating if sugars-free options of long-term medication are available and writing to the patient's general medical practitioner to ask if a change to a sugars-free version could be made, explaining the reason for your request [10]. Obviously there will be occasions when this is not possible, so in these cases, appropriate supportive advice should be provided and additional preventive measures implemented. Doctors may struggle to find alternative medications that are less xerostomic, but it is still worth addressing.

Finally, the frequency of recall interval should be planned in line with current guidance, taking risk assessment into account [11].

Conclusion

If you, together with your patient, reduce the risk of future dental disease, you will create a favourable environment for placement of indirect restorations and contribute to optimising restoration longevity.

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Periodontal Considerations

4

Arindam Dutta, Louise O'Dowd, Angus Walls, and Robert Wassell

4.1 Learning Points

This chapter will emphasize the need to:

- Identify patients with periodontal disease and less commonly with aggressive periodontitis—conditions affecting prognosis both for restored teeth and implants
- Spot local risk factors which prevent effective plaque control
- Appreciate the role of systemic factors (extrinsic, disease, hormonal and genetic factors) and emerging evidence for nutrition and obesity
- Be familiar with measurements and observations indicating increased risk of periodontal disease
- Carry out appropriate periodontal treatment addressing risk factors where possible; provide appropriate oral hygiene instruction and arrange a suitable supportive periodontal maintenance programme.

In the previous chapter, we considered how caries may be controlled to ensure a healthy start. Now we look at periodontal disease which is prevalent in a significant proportion of the population [1] and in some patients may result in tooth loss through progressive loss of supporting tissues [2, 3]. Recognition of active

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periodontal disease is crucial during assessment of patients for whom restorations are being considered. Not only is restorative treatment more predictable when the periodontal foundations are secured, but there is a medicolegal expectation for periodontal disease to be diagnosed and managed [4].

The tool recommended for periodontal screening [5] is the basic periodontal examination (BPE) recorded using the WHO periodontal probe [6]. The BPE score for each sextant alerts a clinician to the presence and severity of periodontal breakdown. Sextants that have been scored 3 (3.5–5.5 mm) and 4 (>5.5 mm) indicate the presence of periodontal disease. However, the score relates to the worst tooth in a sextant and gives insufficient information on the distribution and extent of disease. So, where periodontal disease is detected, the BPE must be followed by a more comprehensive examination, often referred to as six-point periodontal chart. This provides a detailed tooth-by-tooth evaluation and a baseline for follow-up. The examination involves recording periodontal probing depths (Fig. 4.1), position of the gingival margins with respect to the amelo-cemental junction (indicating recession) and the presence of bleeding, plaque and suppuration at six sites around each tooth. Mobility of teeth and furcation involvement are also noted. Based upon these clinical findings, a radiographic assessment is undertaken to establish the extent of interdental bone loss. The recommended views include horizontal and vertical bitewing radiographs, parallel periapical radiography and, in some instances, panoramic views [7].

By considering a patient's presenting history and clinical and radiographic findings, a periodontal diagnosis can be made [8], which characterizes the nature, extent and severity of the disease. Whilst periodontitis can take several forms, in this

Fig. 4.1 Aggressive periodontitis presentation with excellent oral hygiene (**a**) but increased probing depths recorded with the UNC 15 probe (**b**)

Box 4.1: Clinical Features of Aggressive Periodontitis [52]

- Early age of onset (<25 years old) with more severe disease predicted for younger individuals.
- Loss of periodontal tissue occurs at multiple permanent teeth and often starts with first molars. Incisors are often involved too.
- The tissue loss occurs because of microbial infection,[a] but patients are otherwise healthy.
- Radiographically, lesions show vertical bone loss typically at the proximal surfaces of posterior teeth with a similar pattern bilaterally.
- In advanced cases, there may be severe horizontal alveolar bone loss as lesions progress from localized to generalised.
- There is a relatively high progression rate of periodontal tissue loss.
- Primary teeth may also be affected, but early exfoliation due to periodontal tissue loss is uncommon.

[a]Infection has been blamed on *Aggregatibacter actinomycetemcomitans* and *Porphyromonas gingivalis* [8], but antibody levels do not correlate well with disease severity [52]. This leaves doubt as to whether their association with the disease is causal. Defects in the host's immune response to the dental biofilm are regarded as more important. These have yet to be defined sufficiently for diagnostic purposes [52].

chapter we will be considering the ubiquitous chronic periodontitis but also the less common aggressive periodontitis (see Box 4.1).

Accurate diagnosis ensures that cause-related treatment is planned and delivered appropriately before providing indirect restorations. In this way dentists can assure a more predictable functional and aesthetic outcome. Aggressive periodontitis should be identified not only to instigate rigorous treatment but also to advise patients for whom implants are planned that they may experience a significantly higher failure rate and faster rate of bone loss around fixtures [9]. By comparison, healthy implant patients and implant patients with treated chronic periodontitis both had lower levels of bone loss and fixture failure after 3 years [9]. Nevertheless, dentists should not be complacent—an analysis of 24 studies followed up for between 1 and 16 years suggests poorer outcomes when placing implants in patients with a history of periodontal disease [10]. As discussed in Chap. 10, peri-implant maintenance therapy is needed for implants like periodontal maintenance therapy is for teeth [11].

Even if periodontal disease is absent, there may be periodontal observations such as thin biotype, recession defects and gingival trauma which may influence future prosthodontic care. The design and technical process of delivering indirect restorations can, in turn, influence future periodontal health. This is of importance in a periodontally susceptible individual and will be explored in more detail in Chap. 10.

The primary etiologic agent of periodontal disease remains dental plaque, although dentists wanting to use the latest terminology will call it "dental biofilm" [2, 12]. Within the dental biofilm of periodontal patients are specific microbial complexes known to have a pathogenic role in this process [13]. Therefore, an important objective of periodontal treatment is to support patients to maintain consistently low plaque scores. The role of professional mechanical plaque removal (PMPR) in conjunction with oral hygiene instruction (OHI) helps reduce plaque scores and gingival bleeding. However, thorough and repeated OHI itself will provide equally good outcomes for preventing gingival inflammation [14]. Psychological interventions such as the goal setting, planning and self-monitoring (GPS) approach are important methods that help improve oral hygiene-related behaviour in patients with periodontal disease [15].

A range of products is available to aid mechanical plaque control. Studies have compared the efficacy of powered and manual toothbrushes on plaque and gingival scores. A recent systematic review has indicated that, based on moderate quality evidence, powered toothbrushes reduce plaque and gingivitis more than manual toothbrushes, both in the short and long term [16]. Nevertheless, side effects (e.g. gingival recession and sensitivity) were either not reported or inconsistently reported. So, whilst many individuals may benefit from powered toothbrushes, they may not be suitable for everyone. Patients whose systemic condition prevents them using routine oral hygiene procedures may need help with adapting toothbrushes with larger hand grips. In addition, carers may need to be instructed in toothbrushing where patients are unable to brush themselves [17].

In patients with established periodontal disease, interdental cleaning aids are particularly important. The relationship of the interdental papilla to the size of the gingival embrasure determines the choice of the interdental cleaning methods (Figs. 4.2, 4.3 and 4.4), and several options are available (Fig. 4.5). For treatment to be effective, patients need to master oral hygiene techniques tailored by the dental team to address their individual needs.

When patients carry out interdental cleaning effectively, it often appears to have a dramatic effect on gingival health. However, a Cochrane review [18] of seven studies reported only low-quality evidence for interdental cleaning producing a significant reduction in gingivitis compared with brushing alone. Interdental brushing gave a 52% better reduction in gingivitis compared with flossing, but again the evidence was low quality. These results may reflect either on the quality of the studies, the efficacy of the patients' cleaning or both.

The genetic profile of the patient may well influence the host response to dental plaque. This relationship is becoming clearer for aggressive periodontal disease [19] but not so for chronic periodontitis [20]. However, there are local and systemic risk factors which may affect the development and progression of disease. Whilst some of these are unmodifiable, many of the local and some of environmental and disease-related risk factors are modifiable, to a varying degree. Success will hinge on achieving patient "buy-in" and successful collaboration with other dental and medical professionals such as hygienists, hygiene-therapists and medical practitioners. Effective periodontal management is described by some clinicians as a "ten-ninety split"—10% is down to what is done in the dental surgery, but 90% relies on what the patient does at home. We will consider the clinical contribution further at the end of the article.

Fig. 4.2 Range of interdental cleaning aids including floss, floss with a pronged holder, Superfloss™, various sizes of interdental brushes and a single-tufted brush (Courtesy Krishnakant Bhatia)

Fig. 4.3 In a Type I gingival embrasure, the interdental papilla fills the embrasure space completely and is best cleaned by gently see-sawing floss through the interdental contact, wrapping it around each tooth individually and then moving it in an apico-coronal direction, so the cleaning action is carried subgingivally

Fig. 4.4 Type II (partial loss of the interdental papilla) and Type III (complete loss of the interdental papilla) gingival embrasures can be cleaned with the aid of interdental brushes

Fig. 4.5 Cleaning around a bridge pontic can be performed using Superfloss™ (**a**) or a single-tufted brush (**b**). A single-tufted brush is also used to clean proximal surfaces of teeth adjacent to edentulous spaces and around fixed orthodontic appliances

4.2 Local Risk Factors

Clinicians should identify and manage local risk factors during the disease control (preventive) phases of the treatment plan. Local risk factors are primarily those which negatively affect local plaque control (see Table 4.1). These include the presence of calculus, dental caries [21], approximal restorations [21], overhanging and poorly contoured restorations, removable partial dentures, enamel pearls and complex radicular anatomy including grooves and concavities [22]. If these factors are allowed to remain, the effectiveness of periodontal debridement and oral hygiene will be compromised. Where possible, they should be corrected, for example, by removal of calculus, recontouring or replacing defective restorations and smoothing interproximal restoration surfaces. Anatomical factors are more difficult and sometimes not amenable to modification.

Existing restoration margins need careful assessment. Open margins will lead to plaque accumulation that may not only affect periodontal tissues but also lead to dental caries, with pulpal and possibly periradicular consequences. The location of a crown margin with respect to the free gingival margin is particularly important in

Table 4.1 Local factors (modifiable and unmodifiable) retaining dental biofilm and limiting oral hygiene

Local factors
Modifiable
• Calculus • Caries • Subgingival restoration • Overhanging or poorly contoured restorations • Open restoration margins • Removable partial dentures • Deep traumatic overbite • Occlusal trauma • Insufficient keratinised tissue • Gingival hypertrophy • Furcations favourable to surgical correction
Unmodifiable
Complex root anatomy: • Grooves (e.g. mid-palatal groove on incisor) • Concavities • Furcations unfavourable to surgical correction

determining the response of the periodontal tissues. A supragingival margin is generally considered optimal as it does not impede oral hygiene procedures and is recommended for restoration margins not involving the aesthetic zone. Ideally, subgingival margins required for aesthetics should not be made more than 0.5 mm below the free gingival margin to allow home care maintenance. Extending margins deeper than 1 mm subgingivally runs the risk of adverse periodontal response [23]. Where restorative work is planned, patients need to understand the periodontal implications including the possibility that margins placed subgingivally may eventually become visible through gingival recession (see Chap. 20). If a restoration is taken too far subgingivally, it invades what is termed the "biologic width", and this is further discussed in Chap. 10.

Further local risk factors include a deep overbite with consequent trauma to gingival tissues [24] and occlusal trauma [25] which may also contribute to the progression of periodontal disease. Teeth with plaque-induced chronic periodontitis that are subject to jiggling forces are at risk of periodontal ligament widening, increased mobility and alveolar crestal bone loss, which in turn may worsen existing chronic periodontitis [26]. Occlusal contacts may need to be adjusted to ensure occlusal forces do not exceed the adaptive capabilities of each patient's dental attachment apparatus. This is best done once the biofilm-related inflammation has been brought under control [27].

The presence of an adequate zone of keratinised tissue around teeth used to be thought important for maintenance of periodontal health [28], but subsequent research has shown that control of inflammation is key to preserve the integrity of the periodontium [29]. Indeed, the width of keratinised tissue is irrelevant with teeth restored with supragingival margins [30]. However, teeth restored with subgingival margins generally have better periodontal health when a zone of at least 2 mm of keratinised tissue is present. This makes a strong argument not to use subgingival margins in thin zones of keratinised tissue, but if they are essential gingival surgery may need to be considered (Chap. 10).

4.3 Systemic Risk Factors

Systemic risk factors for periodontal disease can contribute to disease progression by influencing the host response. The nature of this influence depends on the factor involved and a patient's inherent disease susceptibility. Systemic factors (see Table 4.2) can operate at many levels:

- By impairing an individual's ability to clean their teeth adequately
- By influencing the growth of dental biofilm
- By contributing to periodontal disease progression by altering the host response through:
  - Extrinsic factors
  - Systemic disease factors
  - Hormonal factors
  - Genetic factors

Table 4.2 Examples of systemic factors which may contribute to periodontal disease progression

Systemic factors
Limitation of oral hygiene ability
• Stroke • Learning difficulties • Parkinson's disease • Rheumatoid arthritis
Influence on dental biofilm growth and accessibility
• Xerostomia • Drug-induced gingival hypertrophy
Extrinsic effects
• Smoking
Disease effects
• Diabetes • Leukaemia • Acquired neutropenia
Hormonal effects
• Pregnancy • Oral contraceptive
Genetic effects
• Associated with genetic disorders (e.g. Down's syndrome, cyclic neutropenia) • Partly identified in aggressive periodontal disease • Not clearly identified in chronic periodontitis

See text for emerging factors

4.3.1 Extrinsic Factors

The association between smoking and chronic periodontitis is well established and has a dose-dependent relationship [31, 32]. People who smoke do not respond as well to non-surgical periodontal treatment as those that do smoke and often require further treatment [33, 34]. However, smoking cessation results in improved clinical attachment levels and reduced periodontal probing depths after non-surgical treatment [35]. Electronic cigarettes are an unlicensed nicotine-containing product, and its effects on the periodontium are not known. Until research can establish its safety, the dental profession should adopt a cautious approach in recommending them as an alternative to smoking.

4.3.2 Systemic Diseases

In patients suffering from type 2 diabetes mellitus who display poor glycemic control, chronic periodontitis has been demonstrated to have increased severity compared with patients having good glycaemic control [36]. The provision of effective mechanical periodontal therapy is associated with a reduction in glycated haemoglobin levels [37, 38]. This reduction indicates that improved periodontal health may have a beneficial effect on the control of blood sugar levels in type 2 diabetes.

Some haematological disorders (e.g. leukaemia and cyclic neutropenia) are associated with periodontitis. Importantly, a dental healthcare professional may be the first to be alerted to a life-threatening disease because of a rapidly deteriorating periodontal condition. Patients should, of course, be referred without delay for haematological screening.

Cardiovascular disease is not a risk factor for periodontal disease. However, an association between chronic periodontitis and cardiovascular disease has been reported with chronic periodontitis patients having greater odds of developing cardiovascular disease [39]. Following intensive periodontal root surface debridement, a reduction in inflammatory systemic markers does occur; however, there is no evidence of benefit in terms of reducing cardiovascular risk in those already at elevated risk [40, 41]. It is more likely that long-term reductions in periodontal inflammation through a lifetimes' good oral hygiene may moderate cardiovascular risk in ageing

4.3.3 Hormonal Effects

The risk of gingival inflammation in pregnant women has been well documented as compared with postpartum and non-pregnant women, without a concomitant increase in plaque levels [42, 43]. The female sex hormones can contribute to periodontal disease during pregnancy by stimulating microbial growth and facilitating cytokine production from human gingival fibroblasts [44]. There is also an association between periodontal disease and increased risk of adverse pregnancy outcome. This has been reported in a selected population [45–47], but there is no conclusive evidence that treating periodontal disease improves birth outcomes [45, 48].

Women using oral contraceptives, containing ethinylestradiol, gestodene or drospirenone, are at increased risk of severe periodontitis and may develop a dental biofilm containing several periodontopathogens [49].

4.3.4 Genetic Factors

A genetic involvement in the progression of periodontitis is suggested because:

- Some individuals are more susceptible to periodontitis than others
- Some systemic genetic disorders appear to predispose children to periodontitis (e.g. familial and cyclic neutropenia, Down's syndrome, leukocyte adhesion deficiency syndromes, Papillon-Lefèvre syndrome) [8, 50]
- Aggressive periodontitis often clusters in families, and some major and minor gene effects have been identified along with epigenetic effects [51]. However the sex ratio is highly inconsistent with some studies reporting more females and others more males [52], so the mode of transmission still needs to be clarified.

The relationship between genetics and chronic periodontitis is less clear but is being extensively researched. This, along with other emerging evidence, may be helpful in the future with risk assessment and patient management.

4.4 Emerging Evidence

Evidence is emerging for factors such as obesity [53] and micronutrient deficiency [54] having an association with chronic periodontitis. If there is a causal link, it would add weight to providing dietary advice as part of the management of periodontal disease. Currently, dental health professionals providing holistic care should remind patients about government dietary guidelines [55] but would be best to avoid recommending dietary supplements until there is sufficient evidence to identify which, if any, are effective. Of course, if a patient is suspected of a vitamin or mineral deficiency, this should be investigated further by a suitably qualified practitioner. No dentist wants to preside over an undiagnosed case of scurvy!

The roles of interlukin-1 genotype [56], osteoporosis [57] and psychosocial factors (such as stress) in chronic periodontitis are not clearly established and also require further research [32].

4.5 Risk Assessment

Given the rather extensive and complex nature of risk factors involved in periodontal disease, scientific risk assessment for an individual patient requires a multivariate risk assessment model. Variables such as *bleeding scores, residual probing* *depths following treatment, tooth loss experience, residual periodontal bone levels in relation with the patient's age, systemic and genetic factors and environmental factors such as smoking* have been included in a periodontal risk assessment (PRA) model proposed by Lang and Tonetti [58]. Tools such as this can be useful for the dentist and can be used to educate and inform the patient. The PRA and the periodontal risk calculator have also been found reliable in predicting the progression of periodontal disease and tooth loss [59]. Alternatively, dentists must make an approximate evaluation of risk for each patient relying on their clinical experience and underlying knowledge.

4.6 Treatment Modalities

Effective periodontal treatment is not just about debriding root surfaces and encouraging good oral hygiene; it also needs to address any modifiable risk factors relevant to the patient. Patients also need to be committed to a lifelong and often rigorous regime of home care. Enlisting the support of the wider dental team including the hygienist and hygiene-therapist is invaluable from prevention through to supportive maintenance care.

There continues to be debate about the short- and long-term supremacy of non-surgical compared with surgical treatment [60, 61]. Nowadays we recognize the important role of the dental biofilm with its complex polymicrobial communities and extracellular matrix that offer microbes a degree of protection from the influence of antibiotics and antiseptics. In most patients, non-surgical disruption of this biofilm remains the key to disease control. At sites that cannot be reached with toothbrushing alone, instrumentation with either ultrasonic scalers or curettes is required with the aim of reducing the periodontal probing depths so that these areas can be managed by home care techniques [62]. At one time full mouth disinfection was thought to result in better probing depth reductions compared with quadrant-wise root surface debridement [63]. This rigorous disinfection regime used chlorhexidine as a mouthwash, for tongue brushing and for subgingival irrigation. However, recent data reports no difference in clinical outcome between the two approaches [64].

The use of local antimicrobial agents such as chlorhexidine chips, chlorhexidine in xanthan gel, doxycycline gel and 0.5% azithromycin have been reported as adjuncts to root surface debridement in two situations: Firstly, where non-surgical periodontal treatment fails to resolve a limited number of deep residual pockets and, secondly, for relapses during maintenance characterized by the development of localized deep probing depths [65]. Gains in attachment of between 0.3 and 0.6 mm may be achieved with this approach. The use of systemic antimicrobials has been advocated as an adjunct to mechanical debridement on a case-by-case basis in specific patient groups (such as aggressive periodontitis) and conditions such as severe and progressive forms of periodontitis [66]. Recommendations include the use of a combination of antimicrobials such as amoxicillin and metronidazole [65], completion of debridement within a short time span (less than 1 week) and achievement of adequate systemic drug levels on the day of completion of biofilm disruption [66]. Given the overuse of antibiotics in healthcare, dentists should be convinced that the best mechanical treatment and patient motivation have been provided before resorting to the prescription pad.

A surgical approach may be indicated in unresponsive sites (e.g. due to complex anatomy), to improve access, alter bone contour or regenerate the lost periodontal support. Surgery may also be required to restore gingival contour in cases of gingival overgrowth or recession defects (see Chap. 10).

In the vast majority of cases, periodontal disease can be effectively controlled [60, 67]. In treated patients who then receive crown and bridgework with ongoing supportive periodontal maintenance, a good outcome can be expected [68–70] with less tooth loss as compared with removable partial dentures [71]. However, at the outset of periodontal therapy, patients must be made aware of some unwanted consequences of otherwise successful treatment such as gingival recession resulting in potentially unsightly "long teeth" with open gingival embrasures producing black triangles (Fig. 4.6). These exposed root surfaces can become sensitive and susceptible to root caries [72], although the reported incidence is low when an effective plaque control programme is followed [73]. These consequences should be anticipated by the dentist and, where possible, accounted for in the definitive prosthodontic treatment plan, which in some cases may require the prescription of a gingival prosthesis as part of a restoration [74] or a removeable acrylic gingival veneer [75].

Fig. 4.6 Chronic periodontitis (**a**) treated non-surgically resulting in gingival recession on 11 and 21 making them appear unattractively long (**b**). (Courtesy Matthew Brennand-Roper)

Conclusion

Getting off to a healthy start may simply involve patients maintaining already healthy periodontal tissues. However, where either chronic periodontal disease or aggressive periodontitis is diagnosed, establishing periodontal health is not always simple. In addition to oral hygiene instruction, patients may require elimination of local plaque retaining factors or diagnosis of systemic factors, but only some of these are amenable to modification. Roots may be exposed as the gingiva recedes in response to effective treatment, so patients should be made aware of this possibility at the outset. Creating periodontal health is also important to the long-term survival of implant crowns. Whether teeth or implants support restorations, supportive periodontal care is essential, particularly for patients who have had periodontal treatment.

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Endodontic Considerations

5

Simon Stone, John Whitworth, and Robert Wassell

5.1 Learning Points

This section will emphasise the need to:

- Consider the risk of losing pulp vitality because of crown preparation—both for existing restorations and teeth planned for restoration
- Identify endodontic disease in teeth planned for restorations and their surrounding tissues
- Recognise the role of pulp sensibility testing of teeth planned for restorations taking care to avoid acting on false-positive or false-negative results
- Interpret radiographic findings but be prepared to remove existing restorations to check the cavity for previous pulpal exposure, caries, cracks and the quantity of remaining tooth tissue
- Avoid automatically root treating asymptomatic teeth with large restorations before providing extra-coronal restorations, but be prepared to do so if the clinical findings suggest a compromised or nonvital pulp
- Retreat root-filled teeth if there is a strong possibility of improving the situation before providing extra-coronal restorations.

In the previous two chapters, we have explored how caries and periodontal disease can be managed to ensure a healthy start for the provision of extra-coronal restorations. Here we consider the endodontic implications.

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There are often good reasons to protect vital teeth with an indirect restoration, but the biological consequences of tooth preparation, temporisation and restoration should not be underestimated. The act of opening dentinal tubules, and the thermal, chemical and microbial challenges which may result, will place an often already stressed pulp at risk. There is evidence to suggest that up to 20% of teeth prepared for crowns may lose pulp vitality in 15–20 years [1, 2]. We will return to these somewhat worrying statistics in more detail in Chap. 9 when we look at managing future risk and the option of using less destructive tooth preparations.

Keeping in mind the potential for iatrogenic pulp damage, what other endodontic considerations are needed to ensure a healthy start for teeth requiring extra-coronal restorations? Firstly, they should be unaffected by pulpal and periapical problems. Secondly, if teeth have already been root treated, you need to know the quality of that treatment; hence the need for a full preoperative assessment and act to on its findings to reduce the likelihood of future problems.

5.2 Preoperative Assessment

When looking specifically for signs of endodontic disease, examination should begin with the soft tissues lying buccal and palatal to the tooth before moving to an examination of the restorations and remaining tooth structure.

The soft tissues apically to the tooth should be palpated and any discomfort or swelling noted. This is always worth doing if the patient has symptoms or where teeth to be restored have large restorations already or are previously root filled. Look for signs of the surface opening of a sinus tract. When in doubt of its source, as often occurs, carefully insert a medium-sized gutta-percha point before taking a radiograph. Remember that fine and old gutta-percha points are liable to fracture on insertion or withdrawal and should be avoided for this purpose.

In addition to palpation of the soft tissues, percussive tests (Fig. 5.1) should be performed to determine the presence of inflammation in the periodontal ligament which may be suggestive of apical periodontitis. Percussive testing should be compared with results of adjacent teeth as well as teeth on the contralateral side. Should there be pain to percussion, there is a strong possibility that the source of the inflammation is from bacterial breakdown products from an infected root canal, but remember pain on percussion may also occur with other diagnoses. These include periodontal abscesses, occlusal trauma (associated with bruxism and interferences) and cracked teeth.

The presence or absence of a crack can often be determined by selectively applying pressure to individual cusps; this is done most accurately with a device (Fig. 5.2) such as a Tooth Slooth™ (Professional Results, CA). A tooth with apical periodontitis will be painful to both percussive testing and pressure applied to all cusps. On the other hand, a cracked tooth will only respond painfully when pressure/percussion is applied to the affected cusp. Periodontal probing should also take place around the gingival margin; increased probing depths may indicate either the presence of a crack or a sinus from a lateral periodontal or periapical abscess discharging through the gingival sulcus.

Fig. 5.1 Percussion testing by gentle tapping with a mirror handle

Fig. 5.2 Using a Tooth Slooth™. A cracked cusp often causes pain on release of biting on the device

Teeth that are planned for extra-coronal restorations should undergo an assessment of pulp status including electric and thermal pulp sensibility tests (Fig. 5.3). Other tests of pulp vascularity do exist such as laser Doppler and pulse oximetry, but these are not widely used. There is a clinical assumption that teeth that respond normally to both thermal and electric pulp tests have a healthy pulp. However, pulp status is incredibly difficult to determine clinically. Histologically, a pulp may have undergone degenerative change but still be responsive to testing [3]. Pulp tests should not take place on a single tooth; rather any response should be compared with adjacent and contralateral teeth. It is worth noting that teeth with delayed or absent responses may well still have a normal pulp. This is often true of older teeth with reduced pulp chamber volume or mineralised inclusions. So, there is always the possibility of either a false-positive or false-negative pulpal response. However, exaggerated and lingering responses after removing the stimulus are likely to indicate pulpal inflammation, whereas a complete lack of response using multiple testing methods is likely to indicate pulp degeneration, necrosis or previous root canal treatment [4].

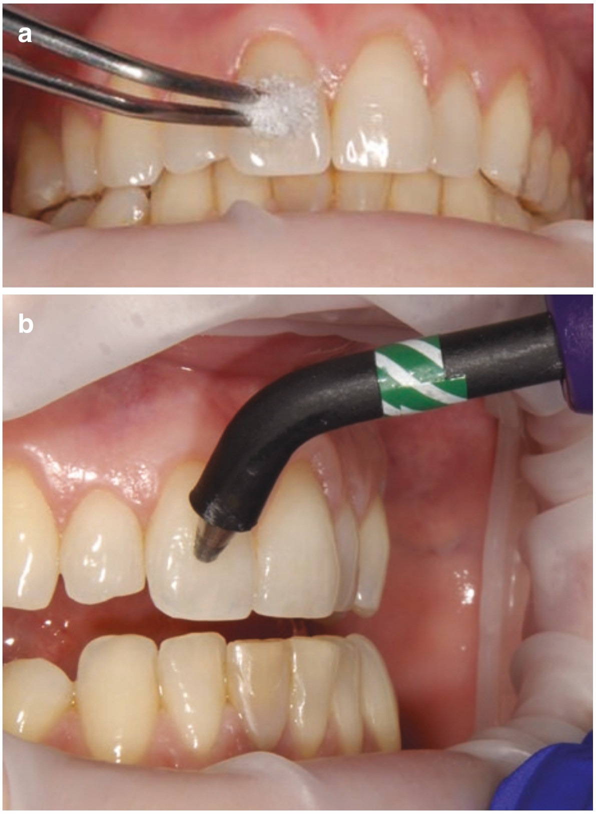

Fig. 5.3 Sensibility testing using ethyl chloride—note the size of cotton pledget needed for sufficient ice formation (**a**). With the electric pulp tester, an electrolyte gel (often toothpaste) is applied to the electrode tip to improve conductivity (**b**)

5.3 Radiographs

Teeth needing to be restored with indirect restorations are frequently compromised in some way, and radiographs are invaluable to supplement the clinical findings and pulp sensibility tests. An accurate interpretation of the radiographs will help determine periapical and periodontal conditions and check for proximal or secondary caries.

In most cases radiographic evaluation should take place initially using periapical films. Loss of, or widening of the apical lamina dura in conjunction with negative pulp testing is likely to be indicative of degenerative pulpal disease. Assuming the tooth is restorable, timely root canal treatment should be provided.

To gain a better understanding of the anatomy of multi-rooted teeth which may require endodontic treatment, consider recording parallax views. This involves taking two separate periapical radiographs of a tooth with the X-ray beam aligned at two different angles. For example, with a lower molar the two canals of the mesial root are often superimposed on a radiograph if the beam is directed perpendicular to the arch. By recording two films, one with the beam angled slightly from the distal and the other slightly from the mesial, the image of canals can be seen separately.

Furthermore, it is relatively straightforward to determine which of the two canals is the buccal and which the lingual—when comparing the two radiographs, the lingual canal appears to move relatively with the tube, whilst the buccal canal appears to move in the opposite direction.

There is much excitement about the use of three-dimensional imaging techniques using cone beam computerised tomography, but for most cases these will neither be practical nor the dose justified [5].

5.4 Removal of Existing Restorations

Remember radiographs are fallible, and it may often be necessary to remove existing restorations to check for caries, pre-existing pulpal exposures and the amount of remaining sound tooth tissue. Whilst symptomatic teeth require restoration removal at the earliest opportunity, other teeth scheduled to receive extra-coronal restorations may not be dealt with until later. This may mean having to act—and possibly carry out endodontic treatment or less commonly extraction—at a later stage when the full clinical picture emerges. Care must of course be taken when removing restorations to avoid further loss of tooth tissue or compromising an otherwise viable pulp.

5.5 Teeth with Compromised Pulps

Teeth that are symptomatic or show clinical/radiographic signs of pulpal involvement can provide predictable foundations for extra-coronal restorations—but only if the pulpal pathology can be successfully managed and subsequent restorations provide an effective coronal seal.

The rather uncomfortable conversation with your patient is best avoided by determining the likelihood of endodontic need *before* crown or onlay placement. The alternative is having to manage the consequences of an acute pulpal or periapical episode soon after preparation or restoration placement. However, it should not be assumed that just because a tooth has a large restoration, it requires elective endodontic treatment. Dentists are advised to take other clinical factors into consideration (e.g. pulpal sclerosis, periapical changes, lack of pulpal response and the possible need to use the pulp chamber to enhance retention of a proposed extra-coronal restoration).

5.6 Previous Root Canal Treatments

It is generally accepted that not all root treatments are carried out to a technically high standard [6–9]. Teeth with inadequate root fillings always provide treatment planning dilemmas. For example, should a tooth that has remained symptom-free for 20 years but clearly has some radiographic deficiencies and a small radiolucent area really be retreated? Unfortunately, there is not a "one-size-fits-all" answer. The history and symptoms will be helpful in these instances and guide an informed

Fig. 5.4 Two cases planned for crown preparation (images on left). A decision was made that endodontic retreatment could improve the restorative outcome (centre). The teeth at 1-year review after core build-up and placement of ceramo-metal crowns (images on right)

decision-making process. A particularly important consideration is the integrity of existing coronal restorations which should be examined for signs that the marginal seal is intact and has not been compromised. Evidence suggests that root canals can become re-infected, even if the seal has only been temporarily lost, with bacteria from the oral environment being able to traverse and colonise root canals [10]. This is probably most relevant in teeth with inadequate root fillings. In appropriately disinfected and obturated canals, micro leakage may progress at a much slower rate and may not pose a clinical problem [11]. That said, teeth with poor coronal restorations or those with root fillings exposed long term to the oral environment should undergo retreatment prior to restoration [10, 12].

As a rule, endodontic retreatment should be considered if there is a strong possibility of improving the clinical picture and providing a more reliable foundation for the restoration. Dentists don't need reminding that root canal treatment can be challenging enough the first time and retreatment can also pose significant technical challenges. Therefore, thought should be given as to whether there can be any improvement made upon the original outcome (Fig. 5.4). The asymptomatic, previously treated cases that radiographically show incomplete resolution present the greatest planning dilemma, and decisions should be taken on an individual case basis. Where appropriate, referral may be required to a dentist with specialist endodontic skills.

Conclusion

Teeth requiring extra-coronal restorations are often compromised in some way, and the potential that further tooth preparation may cause additional irreversible pulpal damage should be born in mind. Nevertheless, it should not be assumed that they automatically need endodontic treatment. A thorough preoperative assessment including radiographs and pulp tests will help determine if the pulp is compromised or nonvital or if there is a pre-existing periapical lesion. It is often necessary to remove existing restorations for a complete assessment. Radiographs will also reveal teeth with pre-existing root fillings some which will be satisfactory and others not. Retreatment should be undertaken where there is a strong possibility of improving the clinical picture.

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Recognising Tooth Surface Loss

6

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6.1 Learning Points

This section will emphasise the need to:

- Distinguish between physiological and pathological tooth surface loss (TSL)
- Attempt to diagnose the cause of TSL from the appearance and patient history recognising that it is not always clear-cut
- Consider using a validated screening tool to tailor TSL management to severity, rate of progression and patient-perceived problems
- Investigate patient behaviours predisposing to TSL and their associated time frames
- Solicit patient cooperation to identify intrinsic erosive factors (e.g. gastro-oesophageal reflux disease or an eating disorder) and intrinsic erosive factors (e.g. fruit juices, wines and sports drinks)
- Distinguish between sleep-related and awake-related bruxism. The former may need to be managed with an occlusal splint, whilst the latter is best tackled with cognitive awareness therapy and self-monitoring.

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Many patients show signs of tooth surface loss (tooth wear). These may be inconsequential if they are minor and not actively progressing, but dentists should be alert to the possibility of an active wear process causing serious clinical problems either now or later. To ensure a healthy start, dentists need to understand what tooth surface loss is, what the various causes are and how it can be measured and monitored. Once tooth surface loss has been identified, how can the risk factors be addressed?

6.2 What Is Tooth Surface Loss?

'Tooth surface loss' (TSL) or simply 'tooth wear' is a term often used to describe the separate or synergistic effects of nonbacterial chemical and physical processes on the surface of dental hard tissues. TSL may involve erosion, abrasion, attrition and abfraction, as outlined in Table 6.1. The term 'tooth wear' implies that TSL is always caused by rubbing surface contact (e.g. between tooth surfaces or between tooth and an abrasive food or tooth paste) but clearly erosion (see Fig. 6.1) and abfraction may occur on non-contacting surfaces. Across Europe the term 'erosion' tends to be favoured to describe general tooth wear rather than specifically chemical-mediated loss, but to avoid confusion, the term TSL will be used in this article.

Some degree of TSL is inevitable throughout life, but it becomes important to patients if it impacts on tooth sensitivity, aesthetics and function. Because TSL is cumulative, the notion of it being physiological or pathological depends on the age of the patient, the rate of TSL and its consequences. Clearly, TSL exposing dentine on occlusal surfaces of molar teeth is not unusual in older patients where it may be regarded as physiological. Indeed, if 30 μm per year of molar enamel loss is considered normal [1], then a low-risk patient may well demonstrate exposed dentine by the age of 70. By contrast in younger subjects, this degree of TSL would certainly be pathological, particularly if it were causing symptoms. In practice differentiating between physiological and pathological, TSL is not always so easy. Nevertheless, it is still a useful concept when explaining to patients who may be worrying needlessly about TSL or to those patients who have TSL which needs the cause identifying, preventative measures instituted, and either careful monitoring or restoration.

It is worth remembering that many factors have the *potential* to cause TSL. Whilst we can identify specific causes of TSL in many of our patients by the appearance of the teeth (see Figs. 6.1, 6.2 and 6.3, and Table 6.2) and the history, the remainder can

Table 6.1 Mechanisms of tooth surface loss, which may act singularly or in combination

Mechanism	Definition from the glossary of prosthodontic terms [17]
Attrition	The mechanical wear resulting from mastication or parafunction, limited to contacting surfaces of the teeth
Abrasion	An abnormal wearing away of the tooth substance by causes other than mastication
Erosion	The progressive loss of tooth substance by chemical processes that do not involve bacterial action
Abfraction	The pathologic loss of hard tooth substance caused by biomechanical loading forces (*causing flexure and chemical fatigue degradation of enamel or dentine at some location distant to the actual point of loading - this often occurs cervically and can be difficult to distinguish from erosion and abrasion*)

prove a mystery. Nevertheless, erosion is implicated in many cases [2]—and there may be multiple wear processes operating synergistically, making the process multifactorial. For example, exposure to erosive substances may cause softening of enamel and exposed dentine which is then rapidly worn away either through hard tissue contact, abrasion by the tongue or parafunctional habits. When two surfaces wear against one another, it is known in engineering terms as 'two-body wear'.

Fig. 6.1 Generalised severe TSL due mainly to erosion (perimolysis) resulting from an eating disorder. Typical of erosion are (1) disproportionately eroded palatal surfaces, (2) tooth tissue loss from non-occluding surfaces, (3) restorations standing proud of the eroded surrounding enamel

Fig. 6.2 Localised mild TSL with early cupping exposing dentine on the incisal edges and left premolar cusp tips. In a young patient, this appearance should prompt polite enquiry into potential erosive factors

Fig. 6.3 Generalised TSL largely resulting from attrition due to bruxism. Note the vertical fracture lines which may indicate heavy occlusal loading [18]

Table 6.2 Clinical signs which may help diagnose the cause of a patient's TSL

Clinical signs of erosion
1. Occlusal 'cupping', incisal 'grooving', 'cratering', rounding of cusps and grooves
2. Wear on non-occluding surfaces
3. 'Raised' restorations
4. Broad concavities within smooth surface enamel, convex areas flatten
5. Increased incisal translucency
6. Clean, non-tarnished appearance of amalgams
7. Preservation of enamel 'cuff' in gingival crevice
8. Minimal plaque, discoloration or tartar on the worn surfaces
9. Hypersensitivity
10. Smooth silky-glazed appearance, sometimes dull surface
Clinical signs of attrition
1. Shiny flat wear facets
2. Enamel and dentin wear at the same rate
3. Matching wear features on opposing occluding surfaces
4. Possible fracture of cusps or restorations
5. Impressions of teeth in cheek, tongue and/or lip
Clinical signs of abrasion
1. Usually located at cervical areas of teeth
2. Lesions are more wide than deep
3. Premolars and canines are commonly affected

Derived from Wetselaar and Lobbezoo 2016 [8]

In this respect, some restorative materials (e.g. roughened and unpolished ceramics) can be particularly damaging to opposing natural tooth tissue, particularly if there are excessive occlusal forces at work. The softened dental tissues may also be abraded by 'three-body wear'. The third body may be coarse food between opposing teeth or toothpaste between brush and tooth.

6.3 Identifying TSL and Addressing the Risk Factors

Whilst TSL has been documented for many years, there is growing interest in how to measure and grade its severity as it further manifests itself within the population. Several clinical tools for screening and grading TSL have been proposed. However, in the main these methods rely on the visible detection of surface loss—so it may already have progressed sufficiently to pose a significant problem to the patient. Some intra-oral devices have been developed for scientific measurement but nothing that can reliably and readily be used in the majority of dental practices [3]. The most recently devised screening tool to date is the Basic Erosive Wear Examination [4], which relies on an approximation of missing tooth tissue. There are some shortcomings with the tool in its current form, particularly with mild and moderate presentations of TSL [5, 6] and the suggested management strategies; as a result, some operators prefer to record TSL using a distinct scale. One scale familiar to many UK dentists is that of Smith and Knight [2]. However, recent developments of a validated Dutch scale [7] have made it a comprehensive tool for both general and

Table 6.3 Criteria derived from the Tooth Wear Evaluation System (TWES) [8] which may be used to quantify the amount of TSL affecting the occlusal surfaces and incisal edges on a five-point ordinal scale

Amount of TSL	Score	Assessment criteria
None	0	No TSL
Mild	1	TSL confined to enamel
Moderate	2	TSL with exposed dentin ≤1/3 of crown height
Severe	3	TSL >1/3 but <2/3 of crown height
Extreme	4	TSL ≥2/3 of crown height

In addition, the palatal aspects of the upper anterior teeth are evaluated on a three-point scale: 0 = no TSL, 1 = confined to enamel, 2 = exposed dentine. If used as an index, the worst tooth is scored within each sextant. Sextant scores are not aggregated, to make clear which sextants are involved. Estimates of original crown height are based on 10, 11 and 12 mm: 10 mm = lower incisors and upper lateral incisors, 11 mm = upper and lower canines, 12 mm = upper central incisors. With severe or extreme TSL, the loss of crown height need not involve the occlusal or incisal surfaces

specialist practice that merits a closer look. The Tooth Wear Evaluation System (TWES) allows not just the grading of severity within each sextant (see Table 6.3) but also a scheme to record the possible origin of the of TSL and whether it is localised or generalised. This then helps determine a course of action related to severity, rate of progression and individual *patient*-perceived problems [8].

Figure 6.4 represents how the various causative factors for erosive TSL interact over time, pushing the patient into periods of enamel softening (demineralisation) followed by re-hardening. Interacting with these erosive challenges where the teeth are softer and more susceptible will be attrition (largely due to bruxism) and abrasion (due to abrasive foods and tooth brushing). It is incredibly important to investigate patient behaviours *and* their associated time frames. Patients need to understand the processes so they can help to identify the causes. Recent consensus statements underpin this advice, but it is worth re-emphasising the importance of the temporal relationships between erosion, abrasion and attrition [8, 9]. A full medical history can be very revealing, but also consider contacting other healthcare professionals involved in the patient's care if you are concerned about underlying causes, for example, with suspected gastro-oesophageal reflux disease (GORD) or eating disorders involving bulimia (self-induced vomiting). GORD is much more common than we think, with up to 10% of the population suffering from the condition [10] and even up to 7% of children aged 2–11 years showing signs of reflux [11]. However it is not always an obvious diagnosis, with a significant proportion of GORD patients showing no obvious gastro-oesophageal symptoms at all [12, 13].

Leaving aside intrinsic erosion from stomach acid, potentially erosive foods and drinks (toward the low extremes of the pH scale) are commonplace and a potent cause of TSL via extrinsic erosion. It is generally accepted that demineralization can occur below the critical pH for enamel (around pH 5.5) and dentin (around pH 6.2). However, some foods and drinks have a pH of 2.5 or less and at this high level of acidity can be highly erosive. In addition to the usual culprits for extrinsic erosion (fruit juices, wines and some medications), sports drinks and fruit-flavoured drinks

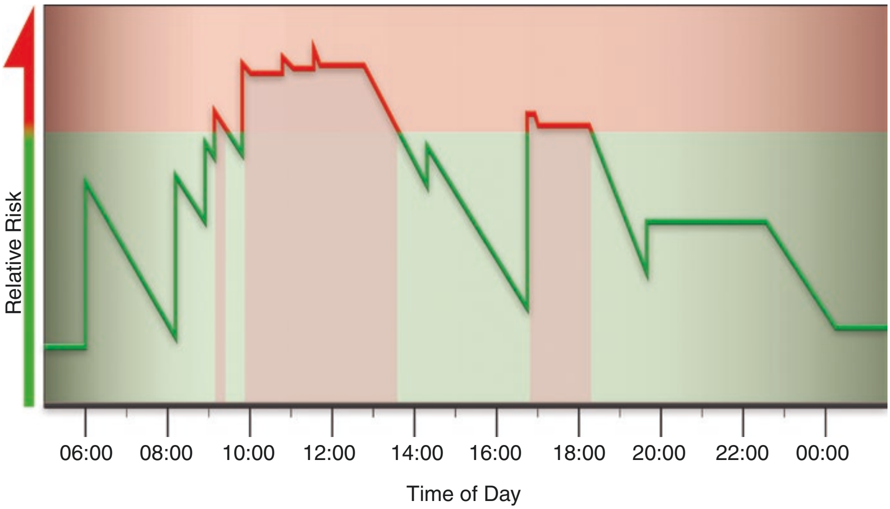

Fig. 6.4 The influence of time in the aetiology of erosive TSL: TSL occurs when the hard tissues are given insufficient opportunity to reharden following an erosive challenge. Conceptually, it is useful to think of a threshold above which the relative risk of TSL is heightened (shown in pink). In much the same way that tooth structure becomes more susceptible to caries below a critical pH, it is the time spent within this critical zone of erosive, abrasive and attritive challenge that significantly heightens the risk of TSL. During this subject's day, several erosive and abrasive challenges have put the hard tissues at increased risk (red lines). With time, the risk will reduce as the tissues reharden in contact with saliva (green lines). Here, mild erosive challenges include slight reflux on waking (06:00) and fruit juices at breakfast time (08:00). The risk of TSL is increased significantly by the abrasive challenge of toothbrushing with an abrasive toothpaste (09:00). Further repeated consumption of erosive foods and drinks in combination with an awake-related bruxism habit means the patient's risk is maintained at a high level (red line: 09:00–13:00 and 17:0–18:15). Longer periods of high risk would result from environmental exposure to abrasive or erosive substances

can be particularly problematic. The temperature of a drink makes a big difference, as does the mode of intake. If a drink made with boiling water is allowed to cool for a few minutes, a relatively small drop in temperature can significantly reduce the erosive potential [14]. Imbibing erosive drinks with a straw placed to the back of the mouth, and avoiding swishing drinks between the teeth, can also help to reduce erosive effects. Modifying erosive foods and drinks by adding calcium and phosphate via milk, yoghurt or cheese is a simple and cost-effective approach; smoothies are a great example—the erosive potential of pulped fruit can be virtually eliminated with the addition of yoghurt [15]. Nevertheless, many commercial smoothies contain large amounts of sugar which pose a dental risk for caries.

Your patient's occupation may have contributed to TSL by exposing them to a particularly erosive or abrasive environment, and it is always worth asking if they often have experienced a gritty feeling between their teeth. Painters, decorators, builders or pharmacists all work in potentially damaging environments—and the list goes on. There is little evidence aside from occasional case reports which link environments to pathological TSL—but it is important not to overlook patient-specific factors that may be contributing in each case. On occasions, intra-oral factors work against the patient too, such as xerostomia, a poor buffering capacity of saliva or thin pellicle formation.

Despite identifying risk factors, often patients are reluctant or unable to change their habits; with any health intervention, the patient must buy into and trust the explanation that you give. Perhaps consider whether the patient can modify their habits rather than change them altogether, for example, attempting to distance behaviours that promote TSL, such as drinking erosive drinks or offering alternatives, e.g. home-made smoothies or preferably eating the whole fruit instead and drinking water. If patients can be persuaded to think of their favourite erosive drink as a special treat only to be consumed occasionally, it will be much less damaging. Where a patient has frequent reflux or vomiting, they need to be persuaded not to brush away the softened tooth afterwards. Recommend instead the use of a fluoride mouthwash to encourage remineralisation. Patients with bruxism or parafunctional habits might be helped with cognitive behavioural therapy (CBT), splints and/or medications as adjuncts [16]. In relation to CBT, patients with an awake-related bruxing habit can be given instructions to self-monitor their parafunction. A small adhesive sticker applied to a patient's watch or mobile phone can provide a recurrent reminder to ensure that the teeth are separated and break one habit with another. In relation to splints, these can be particularly effective with sleep-related bruxism by protecting the teeth from damaging contact. A few patients with bruxism may require specialist medical management, although this is unusual.

Conclusion

If TSL is addressed effectively before it becomes advanced, the need for restoration can often be avoided or at least delayed. Where it is causing the patient significant aesthetic issues, sensitivity or there is a need for protection of the remaining tooth, restoration may be the only viable option. In Chap. 13 we will address restoration and how best to control the risk to restorations from the underlying wear processes.

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7 Immunological Reactions to Materials

Simon Stone, Jimmy Steele, and Robert Wassell

7.1 Learning Points

This chapter will emphasise the need to:

- Distinguish between toxicity and hypersensitivity to a dental material
- Recognise the characteristics of a Type 1 (immediate, potentially life-threatening) reaction and Type IV (delayed). Both can occur in relation to materials used in restoring teeth, but Type IV reactions occur more commonly
- Appreciate that various Type IV reactions may occur with base alloys, and composites but oral lichenoid lesions (OLL) occur most commonly to amalgam
- Assess the need to refer suspected OLL for a specialist opinion as this Type IV reaction is difficult to differentiate from oral lichen planus
- Arrange for appropriate testing to be carried out by a dermatologist to determine which restorative materials can be used for a patient with OLL
- Identify replacement materials not only on the results of immunological testing but also to ensure fitness for purpose.

Whichever materials are chosen for extra-coronal restorations, they should be biocompatible, and attention should be given as to the likelihood of hypersensitivity reactions either to existing restorations needing replacement or to proposed new ones. To ensure a healthy start, the cause of any suspected reaction should be ascertained before placing a new restoration.

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In simple terms, hypersensitivity is an adverse reaction caused by immunological responses to substances. It occurs in individuals sensitised by prior exposure to a substance. Hypersensitivity is different to toxicity where a substance directly poisons cells. In restorative dentistry, toxicity rarely occurs unless a material is used inappropriately, so the focus of this chapter is to consider the clinical relevance of immediate and delayed hypersensitivity to materials used for extra-coronal restorations. Readers needing to know details of the immunological mechanisms involved are referred elsewhere [1].

Considering the number of restorations placed, reports of hypersensitivity reactions in patients are relatively rare although there is likely to be significant under-reporting. Hypersensitivity reactions in dentistry vary in intensity from mild to severe (see Table 7.1). When reactions do occur, it could be because of exposure to the core build-up material, provisional restoration, temporary cement, luting resin or the definitive indirect restoration. In addition, a patient may be allergic to a component of a root filling (e.g. eugenol) or to the impression material (e.g. polyether) [2]. Bear in mind also the potential for natural rubber latex containing gloves, consumables, and local anaesthetic cartridges to cause allergic reactions. Thankfully most practices now are almost universally latex free.

Notwithstanding the long list of potential allergens, alloys and resin composites appear to be the main restorative materials responsible for allergic reactions [3]. This may be because alloys, particularly amalgam and those with low noble metal content, liberate ions through corrosion, marginal breakdown and dissolution into the saliva and surrounding tissues. Composites and bonding agents contain potentially allergenic monomers (e.g. BisGMA, UDMA, TEGDMA, HEMA, MDP) which will be at their greatest concentration before the material is set. Once set composites still contain unreacted and partially reacted monomers, which may leach out of the material causing problems in susceptible patients [2]. Amalgam and composites are used extensively in core build-ups beneath extra-coronal restorations, but in recent years, there have been developments in more biocompatible alternatives made from tricalcium silicate-based materials, e.g. Biodentine™ (Septodont™). So far Biodentine™ has only been tested as a dentine substitute under composite restorations [4], for pulp capping and repair of endodontic perforations [5]. No doubt it would be a good material for blocking out undercuts in the deep parts of tooth preparations, but the manufacturer does not currently recommend it as a structural core build-up for crowns (see Chap. 19).

Table 7.1 Grading of adverse reactions to materials in dentistry, including hypersensitivity reactions

Mild reaction	One requiring only dental treatment
Moderate reaction	One where the signs and symptoms are significant, and the affected person needs specialist referral
Severe reaction	One that leads to death or is life-threatening, causing serious deterioration in health or where emergency treatment is required

Adapted from the national survey of adverse reactions to dental materials in the UK [3]

7.2 Type I and Type IV Hypersensitivity

There are two main types of hypersensitivity reactions that can take place in response to contact with dental materials; these are Type I and Type IV [6]. Type I or immediate immunoglobulin E-mediated hypersensitivity reactions in dentistry are thankfully rare and are more likely caused by natural rubber latex or a local anaesthetic than by an indirect restoration [7–10]. Type I reactions are rapid in onset presenting clinically with swelling (angioedema) of the face, lips, mouth, tongue or throat often accompanied with an urticarial rash. A severe reaction may lead to the airway becoming compromised (anaphylaxis). This is a life-threatening medical emergency requiring where possible immediate removal of the stimulus and urgent medical management. Dental professionals are expected to be trained to recognise and respond to an anaphylactic reaction. Further information is available from the Resuscitation Council (UK) [11, 12]. The likelihood of these intense reactions to indirect restorations is extremely low, but there are reports of immediate hypersensitivities to dental amalgam and resin composite [13, 14]. The latter is of importance with extra-coronal restorations as resin-based cements are frequently used as luting materials. It is most likely the release of unreacted monomer that is responsible for a Type I reaction in a previously sensitised patient.

Type IV, frequently described as cell mediated, or delayed hypersensitivity reactions occur more commonly than Type I reactions. They are seen most frequently with amalgam and to a lesser extent with casting alloys where restorations corrode and elute metal ions [3]. Allergies to gold, palladium and platinum are extremely rare, these metals having very little potential to corrode by comparison to those alloys of low noble metal content [15]. Of the alloys available for crown and bridge manufacture, the base metal and non-precious ones including nickel, cobalt and chromium are associated with higher rates of hypersensitivity compared with those with a high noble metal content. These less expensive alloys are frequently used for both ceramo-metal and all-metal restorations [16].

Fortunately, allergies to titanium appear to be rare but with the increased number of implants being placed, this may increase. In one study of 1500 implant patients, 0.6% showed a positive allergic test result [17]. However, some authorities have questioned the significance of these findings as some of these patients did not have associated clinical issues. Also, where pathology had been associated with an allergic reaction it may have had another cause [18]. Some implants may contain sensitising base metals, so this possibility should be born in mind [2]. If a patient is deemed at high risk for metal sensitisation, patch testing is advised (see below) before embarking on implant placement.

There are several presentations of Type IV hypersensitivity, but the most common is known as an oral lichenoid reaction (OLL) because its reticular appearance resembles lichen planus (see Fig. 7.1). Patients may also experience a burning sensation or swelling (oedema) of the buccal mucosa or both. The other less common presentations also mimic presentations caused by other oral conditions, e.g. mucositis, cheilitis, ulceration or gingival swelling. Occasionally, there may be skin

Fig. 7.1 A unilateral presentation of an oral lichenoid lesion; there are white striations on the right buccal mucosa with an erythematous background. The cause is most likely by the ageing amalgam restorations; it is less likely to be attributed to the full veneer gold crown. Image courtesy of KS Staines, University of Bristol

manifestations (e.g. rashes, urticaria, eczema). So, diagnosis is not always straightforward and specialist referral is advised where dentists are in doubt.

Dentists are most likely to see an OLL, so we will consider this further below.

7.3 Oral Lichenoid Reaction

Most OLLs are caused by amalgam, but milled or cast non-precious/base metal restorations are also implicated [19] as well as a variety of other dental materials [3, 20]. As with any suspected oral allergy, the history is important in determining the causative factor and helps establish if the patient has other symptoms associated with hypersensitivity (e.g. a skin rash from nickel sensitivity).

OLLs are frequently seen in isolation or combination on the buccal mucosa or lateral borders of the tongue adjacent to corroding older amalgam restorations [19, 21]. They generally look very similar to oral lichen planus (OLP) which also has many of the characteristics of a Type IV reaction [6]. OLP varies significantly in severity from asymptomatic reticular white striations to very painful erythematous and erosive lesions. Occasionally, similar presentations are also seen with some systemic medications and conditions such as chronic graft vs. host disease and reactions to some medications. We recommend referring these red or white patches for specialist opinions (e.g. oral medicine or oral surgery) as both OLL and OLP can undergo malignant transformation (estimated rate of transformation less than 0.2% per year with higher risk associated with painful erosive lesions). So the diagnosis should be confirmed histologically and the biopsy checked for dysplasia or neoplasia [22].

If a diagnosis is made of OLL, it is worth asking for patch testing to be carried out. A patch test involves placing an allergen on the skin for 3–4 days. The development of an erythematous reaction indicates a positive result. Patch testing is best done via referral to a dermatology specialist often via the patient's general medical practitioner. In the UK, the British Contact Dermatitis Society recommends a standard series of dental allergens, with further series of metal testing as required. Whilst patch tests are not always effective in detecting sensitisation to an allergen, they can provide some guidance in selecting dental materials for future treatments [23].

Dermatologists may also use other methods to determine sensitisation to specific metals (e.g. nickel, chromium, cobalt, gold or titanium). One such test is the "MELISA" (Memory Lymphocyte Immnunostimulation Assay) [24]. This is an area of ongoing research.

7.4 Dental Management of Lichenoid Reactions

Once the diagnosis is confirmed of a symptomatic OLL associated with a dental restoration they often respond well to removal of the restoration and replacement with a suitable alternative. The choice of material will depend not only on the results of the patch test but also on the size and load bearing requirements of the restoration. Composite is often suitable for direct restorations and resin-modified glass ionomer in non-load-bearing situations [25, 26]. A high strength ceramic is generally a good choice for larger extra-coronal restorations. A conventional cement can be chosen where the patient is sensitised to resins.

When restorations possibly involved in sensitisation are replaced, resolution of adjacent lichenoid reactions often occurs, but patients should understand it cannot be guaranteed [26].

Where possible, amalgam restorations should be replaced under rubber dam to prevent further mucosal irritation [27]. Lesions may also present adjacent to crowns with defective margins, and while it may not be possible to completely determine the aetiology, removal and replacement of the crown that effectively seal the allergens in may suffice. However, it would be sensible to replace an underlying amalgam core, particularly if the patient has a confirmed amalgam sensitivity.

When prescribing indirect metallic restorations, it is worth remembering that nickel sensitisation and contact dermatitis is common; a Danish study reported 11.1% of women and 2.2% of men affected, possibly from wearing inexpensive jewellery [28]. Whilst intra-oral lesions related to nickel are much less common, we advise taking a cautious approach and avoid placing nickel-containing restorations in patients with known nickel sensitivity.

Finally, if a patient or dental care professional has a suspected adverse reaction associated with a dental material (device) current best practice recommends it is reported online to the regulatory agency which in the UK is the Medicines and Healthcare product Regulatory Agency (MHRA) [29].

Conclusion

Whilst immunological reactions to dental materials are not widespread, they do pose significant problems to patients who have them. Type I reactions are rare but life-threatening, so dentists need to be alert to an acute reaction immediately after the patient has been exposed to the sensitising agent. More common are Type IV reactions to base metals such as amalgam alloys and nickel. The reactions have a delayed onset and intra-orally often manifesting as a lichenoid reaction. This reaction requires a specialist opinion to distinguish it from lichen planus. It is wise to refer a patient for immunological testing to determine if they have a sensitivity to the material proposed for replacement restorations.

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Temporomandibular Disorders and Occlusal Disease

8

Pamela Yule, Jimmy Steele, and Robert Wassell

8.1 Learning Points

This chapter will emphasise the need to:

- Provide restorations in harmony with a patient's occlusion
- Check if patients who require extra-coronal restorations have one or more existing temporomandibular disorders (TMDs) or a history of them
- Appreciate that some patients are susceptible to developing TMDs, but the cause is not usually related to the occlusion
- Take care in making occlusal changes because patients with a history of TMDs can react with pain and discomfort
- Diagnose and manage existing symptoms of TMDs before embarking on extra-coronal restorations
- Be aware of patients who complain of occlusal problems but for which there is no underlying occlusal cause. These patients may require specialist management.

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When establishing a healthy start for restorative work, temporomandibular disorders (TMDs) and occlusal issues are sometimes sadly overlooked. Maybe this is because malocclusion is no longer considered the main aetiology for TMDs? Or is it because patients generally adapt to occlusal changes during treatment? Whatever the reason dentists should be aware there is good evidence that sudden occlusal changes may cause patients with a history of TMDs to react with pain and discomfort [1] which may become persistent. So, dentists should understand TMDs, know how to screen for them, and where appropriate provide treatment before embarking on restorations.

The occlusion, like a ridden bicycle, is a biomechanical system which should run harmoniously—if not the ride will be uncomfortable and the bike will soon break down. Occlusal problems are best diagnosed and managed prior to placement of restorations. Restorations should be designed and adjusted to be in harmony with a patient's occlusion. The aim is to provide occlusal comfort and avoid problems due to excessive and misdirected occlusal forces [2]. We will consider these aspects further in Chap. 12. Meanwhile, this chapter focuses on enhancing an understanding of TMDs: a complex collection of conditions, which can have a significant impact on an individual's quality of life.

8.2 Aetiology of TMDs

Clinically, the aetiology of TMDs is best regarded as multifactorial and biopsychosocial [3] with predisposing, precipitating and prolonging factors all playing a part [4]:

- Predisposing factors include structural, metabolic or psychological conditions, which may cause increased risk of developing TMDs by adversely affecting the masticatory complex
- Precipitating factors include trauma due to repetitive loading through parafunction or due to direct injury to the head and neck area
- Prolonging factors include psychosocial problems (e.g. tensions at home or at work), which can perpetuate an existing TMD problem.

Why some individuals are more susceptible to developing TMDs is still not fully understood, although new research is revealing promising biochemical and genetic insights [5, 6].

8.3 Signs, Symptoms and Diagnosis

Patients attending for restorative treatment do not always volunteer they are suffering from, or have a history of, TMDs. It's worth asking 'Do you have or have you had any problems with your jaw joints or jaw muscles?' This can easily be done while carrying out an extra-oral examination. If the answer is yes, follow up by asking about the cause and previous treatments.

The signs and symptoms of TMDs are summarised in Box 8.1, but the most common initial symptom in TMDs is pain, usually in/around the temporomandibular joint (TMJ), or in the muscles of mastication, or both [7, 8]. TMDs are the commonest cause of non-dental orofacial pain, but unexplained persistent orofacial pain (previously termed 'atypical facial pain') can occur both with and without TMDs.

Joint noise, such as clicking, is very common affecting 18–30% of the general population [9], but in the absence of pain is usually of little clinical significance unless it is embarrassingly loud [10]. Patients with TMDs can show a range of difficulties in function, e.g. difficulty opening, closing, chewing and talking which can be intermittent or constant and can range from mild to severe [11]. In making a diagnosis it is important to remember that common dental problems (e.g. caries, periodontal or periapical infections), neuralgias (e.g. trigeminal and post herpetic), systemic disease or neoplasia, although rare, can result in signs and symptoms that mimic those of TMDs [12, 13]. Furthermore patients with fibromyalgia, systemic joint laxity (e.g. Ehlers-Danlos syndrome) or arthritis may also present with TMD signs and symptoms [14].

The diagnosis of TMDs in a clinical practice setting mainly depends on completing and interpreting a thorough history and clinical examination. Imaging techniques can occasionally be helpful but have their limitations.

The Research Diagnostic Criteria for TMDs (RDC/TMD) was developed in 1992 [15] and has been updated recently with the intention of providing a shorter, more pragmatic instrument both for research and everyday use: the DC/TMD [16]. The primary purpose of the RDC/TMD was to facilitate research into TMDs based on well-defined homogenous subgroups that could be identified reliably using operationalised criteria. It has shown fair to good reliability and has been the most widely used diagnostic system for research into TMDs [15]. The DC/TMD also has an excellent research background, but how well it would work in primary care has not been established.

The clinical examination protocol (CEP-TMD) has been shown to produce similar reliability as the RDC/TMD in making a physical (Axis I) diagnosis of TMD which broadly categorises the often multiple issues affecting the masticatory muscles and TMJs. The CEP-TMD is quicker to complete, making it more suitable for the routine clinical practice setting [17]. In a relatively short time, dentists can learn to make reliable TMD diagnoses according to the key findings from the clinical examination (see Table 8.1).

Box 8.1: Six Categories of Signs and Symptoms of TMDs

- Muscular tenderness—in face (masseter, temporalis, posterior digastric, mylohyoid), mouth (medial or lateral pterygoid), neck and shoulders (but remember that cervical problems can occur independently of TMDs).
- Pain—in head (including the TMJs), neck and shoulders.
- Joint noises—clicking, crepitus (grinding).
- Locking—open (dislocation) or closed (inability to open fully).
- Ear complaints—otalgia, tinnitus.
- Psychosocial effects (e.g. chronic pain behaviour, anxiety, depression).

Table 8.1 Diagnostic groupings and key clinical findings used by the Research Diagnostic Criteria for TMDs (RDC/TMD) and the clinical examination protocol (CEP-TMD)

Main grouping	Subgroup	Key findings from clinical exam and history to support diagnosis
Myofascial pain	– Myofascial pain with limited opening	Painful muscles and limited movement
	– Myofascial pain without limited opening	Painful muscles
TMJ disc displacements	– Disc displacement with reduction	Reproducible clicking
	– Disc displacement without reduction with limited opening	Limited opening with no clicking
	– Disc displacement without reduction without limited opening	History of previously limited opening—imaging needed to confirm disc displacement
TMJ arthritides	– Arthralgia	Painful TMJ, no crepitus
	– Osteoarthritis	Painful TMJ with crepitus
	– Osteoarthrosis	Non-painful TMJ with crepitus

A video detailing how to perform the examination plus the accompanying clinical forms which help with history taking, examination, diagnosis and follow-up are available at:

http://www.ncl.ac.uk/dental/AppliedOcclusion/

As mentioned previously, TMDs frequently have a large biopsychosocial element (Axis II) which can be quantified using forms to evaluate chronic pain (graded chronic pain scale), oral behaviours (clenching, grinding, bracing, etc.), amount of somatisation (medically unexplained pain affecting various parts of a patient's body), depression, anxiety and impact on quality of life. Alternatively, dentists may wish to interview patients keeping these aspects in mind and note relevant findings. It is helpful to record the location of a patient's pain on a simple outline diagram which can be referred to as treatment progresses.

Importantly, if a patient has had multiple previous treatments which have been unsuccessful, they are not well suited to management exclusively in general dental practice. It is also worth remembering that a proportion of TMD patients will have symptoms of persistent orofacial or dento-alveolar pain which again are not easily managed solely in primary care.

8.4 Management of TMDs

Due to the wide variety of both the methodology and outcome measures used in trials, good quality, clear evidence for the management of TMDs is lacking [18]. Nevertheless, conservative, reversible therapies have been shown to be at least as effective as more invasive treatments in producing symptomatic relief but with less potential for harm [19, 20]. Thus the American Association for Dental Research reissued and reaffirmed their policy on TMDs management, stating that initial treatment of TMDs should focus on conservative, reversible treatment [19].

Managing TMDs starts with reassuring the patient that they do not have a sinister cause for their pain and that in many cases TMDs are self-limiting. Thereafter cognitive behavioural therapy [21], physiotherapy [22, 23] and the use of intra-oral splints (soft splints or hard stabilisation splints [24]) can have a role. The stabilisation splint (Fig. 8.1) is useful not only to manage TMD symptoms but if carefully adjusted can indicate when the patient has reached a stable jaw position. This is invaluable when multiple restorations are required or there is a restorative requirement to reorganise the patient's occlusion.

We recommend not proceeding with extensive restorative work until the patient's symptoms have been brought under control with conservative measures.

In cases where a TMD patient fails to respond sufficiently to conservative treatments or during episodes of acute pain, medication prescribed in conjunction with the patient's general medical practitioner can be a useful adjunct. However, the evidence base for the effectiveness of the varied potential pharmacological interventions for pain caused by TMDs is limited, and continued research in this field is required [25, 26].

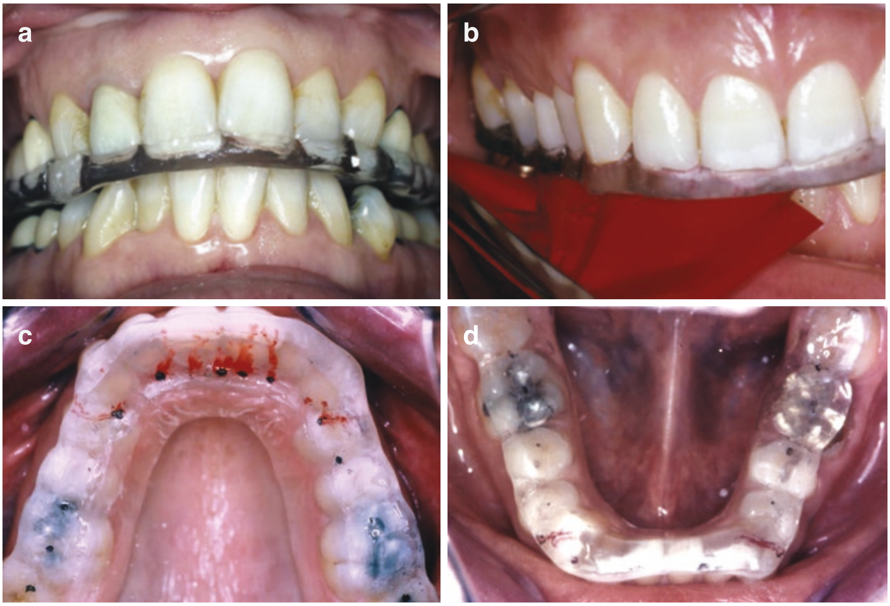

Fig. 8.1 (**a**) Upper stabilisation splint fitted prior to its occlusal adjustment. (**b**) Occlusion marked with articulating foil—red (shown) and black (not shown). (**c**) Occlusal markings indicating even black contacts on the retruded arc of closure with red guidance tracks in protrusion and lateral excursions. (**d**) Alternatively, stabilisation splints can be made in the lower arch

A reasonable approach to managing TMDs at the initial point of contact may be:

- To advise on jaw exercises to be completed twice daily
- To provide a soft splint (but tell the patient to stop using it if, after a couple of weeks' acclimatisation, the symptoms worsen)
- To advise the use of simple over-the-counter analgesia for a short period (subject to no contraindications to the analgesic's usage).

Patients suffering from TMDs should always be reviewed and followed up carefully once treatment is instituted. This is to ensure that progress is as would be expected. The patient should be referred for further advice if after 3–6 months problems persist, *but much sooner if there are concerns of a more sinister cause for the patient's pain (e.g. malignancy)*. Look out particularly for increasing trismus [27], epistaxis and neurological changes.

8.5 TMDs and Occlusal Disorders

It is worth re-emphasising that for most patients there is little to support the popular notion that TMDs are caused by the occlusion [28]. In addition, there is no evidence that occlusal adjustment is more or less effective than placebo in treating TMD symptoms [29]. In certain circumstances though, it may seem sensible to undertake an occlusal adjustment, for example, if the patient's TMD pain began after placement of a restoration and this restoration is shown to be causing an occlusal interference [6]. Care must be taken, however, as adjustment may result in worsening of symptoms. So, if a TMD patient also requires restorative treatment that necessitates altering or reorganising the occlusion, this should be carried out carefully, and the patient needs to understand that while the treatment may improve occlusal function, its effect on TMD pain and other symptoms is not predictable: It would be unwise to suggest or promise an occlusal cure for the underlying TMDs.

Patients with 'occlusal hypervigilance' must also be treated with caution. Occlusal hypervigilance, which can happen spontaneously or after a new restoration is placed, is when patients are 'obsessively focused on the way their teeth meet' [30]. Patients may complain of discomfort or pain (in the absence of any pulpal or periodontal cause for their symptoms) and may also be highly distressed.

In 1976, Marbach described the term 'phantom bite' as a patient's perception of an irregular bite when a clinician could find no such discrepancy [31]. Typically, patients present with a hyperawareness of occlusion and a persistent uncomfortable bite, often in the absence of pain. 'Phantom bite' is notoriously difficult to treat effectively, but in a search to resolve their symptoms, affected patients often undergo lengthy, expensive, irreversible and unnecessary invasive treatments. The condition is remarkable for the nature of the involved explanations and interpretations that patients give and for their persistence in trying to find a dental solution to what is most likely a psychological problem.

If occlusal hypervigilance or phantom bite is suspected, then referral to a specialist is indicated to check the patient's occlusion mindful of a likely need for appropriate psychological management. It is best to decline these patients' requests and resist the impulse to adjust teeth or place restorations which irreversibly alter the occlusion. The resulting change often makes no difference or makes matters worse.

Conclusion

While some dentists cling to the notion that TMDs are caused by the occlusion, current evidence does not support this. Nevertheless, patients with a history of TMDs are more susceptible to adverse effects from sudden occlusal changes. Dentists should therefore screen for TMDs prior to providing extra-coronal restorations. If restorations are to be provided conformatively, patients should have their TMDs treated beforehand. Research shows that dentists can effectively provide simple and effective treatment of TMDs for most patients. If the reconstruction is to a reorganised occlusion, treatment with a stabilisation splint is recommended before embarking on restorative treatment. Patients who do not respond to treatment after 3–6 months should be referred for specialist opinion/management, but an urgent referral is needed for those few patients where a more sinister cause is suspected. Similarly, patients who have unusual symptoms which they blame on their 'bite' but for which a causative occlusal discrepancy cannot be found, should also be referred for advice. Of course, occlusal discrepancies, their adverse effects and their management are important when providing extra-coronal restorations. These are considered in Chap. 12.

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Part III

Managing Future Risk

Preserving Pulp Vitality

9

Simon Stone, John Whitworth, and Robert Wassell

9.1 Learning Points

This chapter will emphasise the need for risk management to minimise pulp damage and its consequences:

- Informed consent—the risks of preparation should be discussed with patients and documented. In the case of crown and veneer preparations extended into dentine, this should routinely include the risk that the pulp may devitalise over time, along with the likely consequences and need for remedial treatment
- Tooth preparation—should be carried out with effective water coolant and with light pressure to reduce frictional heat and vibration. Avoid desiccating preparations by the overenthusiastic use of compressed air
- Restoration margins—both for provisional and definitive restorations should be optimally fitting and sealed
- Oral hygiene—patients may need instruction in controlling the biofilm around the roots and margins of restored teeth, not only for periodontal reasons but also for pulpal health.

In the previous part ‘A healthy start’, we considered what dentists and patients can do before embarking on restorative treatment to ensure a successful outcome. The importance of effective prevention was emphasised in relation to caries control and periodontal disease. Those measures should of course be continued during treatment and beyond.

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In this part *Managing Future Risk* we explore what can be done to reduce the risk of failure when restorations are provided. This chapter considers how to reduce the risk of iatrogenic pulp damage which can cause patients considerable distress and difficulty.

9.2 Risk of Pulpal Damage

Vital teeth are at risk of pulp damage at all stages of their preparation, temporisation and restoration with indirect materials, so it is wise to be mindful of these risks from the outset. Injuries to the dental pulp are cumulative, and few teeth planned for crown preparation will have escaped earlier cycles of caries, tooth wear, trauma and restoration (see Fig. 9.1) [1]. In Chap. 5 we emphasised the importance of removing existing restorations to inspect the cavity walls as well as a thorough preoperative clinical and radiographic assessment with pulp sensibility tests. Inspection of the volume and distribution of remaining coronal dentine will help determine the feasibility of placing a core build-up or other means of retention for your planned extra-coronal restoration (see Chap. 19).

Sadly, tooth preparation for your extra-coronal restoration may be the final straw beyond which the pulp may not recover; a full crown preparation may remove around 60% of coronal tooth tissue with even more removal for conventional bridge preparations to achieve parallelism [2]. Data suggest between 3 and 25% of teeth prepared for full coverage crowns will lose vital pulp functions within 15–20 years, with previously compromised teeth fairing worse than those that are more intact [3–8]. A sensible estimate to discuss with patients is that around 15% of teeth prepared for a single ceramo-metal crown may have pulpal complications at 10 years—but the outlook may be worse if teeth need to be prepared more heavily

Fig. 9.1 Many teeth prepared for extra-coronal restorations have already endured cycles of disease and direct restoration. They should be evaluated carefully before preparation to minimise the risks of unexpected pulp breakdown. In this case we see a prepared lower premolar with multiple amalgam restorations and a buccal composite repair that make up the core

(e.g. as needed for some high-strength ceramic restorations) or are subject to increased occlusal loading (e.g. with bridgework) [8].

Crown preparation presents risks to the pulp because dentine and pulp are intimately related and because crown preparation involves the extensive opening of dentinal tubules. Tubules cut by a bur are covered by a tenuous smear layer—but from a microbe's perspective they are open for business. This is in contrast to dentine affected by caries or tooth surface loss where tubules are narrowed by tubular sclerosis or occluded by tertiary dentine deposition. The more dentinal tubules are opened, the more vulnerable the pulp is to injury. Equally, the deeper the preparation into dentine, the wider the tubules become, and the greater the risk of physical injury to odontoblast processes; a transected process may result in odontoblast death and the formation of defenceless dead tracts vulnerable to microbial ingress [9]. Pulpal damage may also occur after desiccating dentine by the overzealous use of compressed air [10, 11].

The extent of tooth preparation influences a pulp's ability to repair and recover. On the one hand, cavity preparation for a routine filling may simply result in hydraulic effects on the pulp dentine complex (e.g. aspiration of odontoblasts partly or completely into their dentinal tubules) [11, 12] with localised and transient pulp inflammation, followed by repair. On the other hand, with extensive crown preparations, injuries may be so widespread that the pulp is unable to recover fully. In some cases, overheating (most often due to insufficient or misdirected water spray), vibration and deep cutting may result in significant pulpal trauma and haemorrhage, sometimes seen as reddening of the dentine (the so-called blushing pulp) or even frank pulp exposure (Fig. 9.2). Another potential source of pulp overheating is the exotherm from provisional crown and bridge resins which are left to cure fully against a tooth (see Chap. 23).

Fig. 9.2 A patient referred for advice following pulp symptoms after crown preparation and temporisation. Removal of the provisional restoration reveals a heavy crown preparation and frank pulp exposure. The tooth was diagnosed with symptomatic irreversible pulpitis and scheduled for endodontic treatment before restoration. The periodontal condition also required attention

Many of the key changes are associated with disruption of the pulp's vasculature leading to reduced blood flow, vascular stasis, thrombosis and ultimately local tissue necrosis. In a sterile and otherwise irritant-free environment, such injuries may not in themselves result in catastrophic pulp breakdown, but are compounded by ongoing insults, particularly bacterial ingress. Impression taking and cementation/luting may cause further hydraulic disruption of the dentine-pulp complex or drive microorganisms into the pulp. In addition, the cement itself may cause chemical irritation, particularly during setting. Poorly fitting provisional or definitive crowns may allow for cement dissolution, microleakage and ingress of microorganisms. In the longer term, further threats are posed by microleakage or caries developing unseen beneath imperfect and suboptimally maintained crown margins. The challenges from these insults may prove insurmountable, promoting infection of necrotic and defenceless pulp tissues.

Although symptoms and signs of pulp breakdown can arise soon after crown preparation or cementation, these processes are usually more gradual. Often teeth remain remarkably symptom-free until a routine examination reveals an apically related soft tissue swelling or a discharging sinus tract. At that stage dentists will need to consider root canal treatment and whilst accessing the pulp chamber may ponder on the wisdom of having prescribed an impenetrable occlusal surface made from a thick layer of high-strength ceramic.

9.3 Reducing the Risk of Pulpal Damage

It is often said that you cannot make an omelette without breaking eggs, and it is certainly the case that some teeth are best restored with crowns and bridges accepting the risk of damage to the pulp and possible weakening of the remaining tooth structure. But nowadays there are often more conservative options, so it is important to think how damage can be limited and how risks can be communicated to patients as they consider all their treatment options. Only through sensible discussion and shared decision-making can patients properly provide informed consent, which of course should be documented [13–15].

In an increasingly litigious and cosmetically aware society, dentists are often under pressure to prioritise aesthetics over tooth tissue conservation. This is particularly the case when exploring the alternatives to manage tooth discolouration and irregularities in tooth position. Understandably, patients want to look good in the shortest time possible, but they need to appreciate that aesthetic, perfectly aligned, porcelain enriched smiles may not be synonymous with strong healthy tissues. So it is the profession's responsibility to educate and sometimes temper patient expectations whilst prioritising approaches that conserve tooth tissue, including the option of no restorative treatment, where this is in the patient's best interest. These ethical issues are explored further in Chap. 17.

Where there is a need for extra-coronal restorations, it may be wise to at least consider delaying the provision of a full coverage crown in favour of less destructive restorations including veneers, onlays and partial coverage crowns. Don't delay if a full coverage crown is the best option for protecting what remains of the underlying tooth, particularly if other less destructive options have already failed and a retentive crown preparation can be assured.

Further pulpal insults may be reduced by immediately sealing dentine with a dentine-bonding agent following preparation, thereby reducing the potential for bacterial microleakage and post-operative sensitivity [16, 17]. Interestingly bond strength between dentine and the resin-bonded definitive restoration may be improved in this way although long-term clinical outcome data are missing [17, 18]. This concept seems sensible but requires care during the bonding procedure to eliminate pooled, uncured resin and prevent interactions with impression materials or the accidental bonding of the preparation to self-cured provisional materials [17, 19].

Conclusion

This chapter highlights what can be done to reduce the risk of iatrogenic pulp damage during tooth preparation and other procedures involved in providing extra-coronal restorations.

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10 Periodontal Considerations and Surgical Options

Louise O'Dowd, Arindam Dutta, Angus Walls, and Robert Wassell

10.1 Learning Points

This chapter will emphasise the need to:

- Consider viable methods of aesthetically managing the gingivae, including gingival veneers, and obtain informed consent to avoid unrealistic patient expectations
- Avoid gingival recession in patients with a thin biotype by respecting and not traumatising the gingival tissues or extending a margin too far subgingivally
- Place subgingival margins well above the epithelial attachment to avoid invading the biologic width. If possible, use a supragingival or equigingival margin where aesthetics or retention is not critical
- Consider using crown lengthening to improve aesthetics or crown retention, but be aware of the factors which determine the type of procedure, and unless confident of a satisfactory outcome, refer for specialist opinion/treatment
- Be aware of surgical procedures to treat recession or to augment the width of keratinised gingiva. Both are best undertaken in a specialist setting

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- Manage risk of periodontal damage at every stage of providing extra-coronal restorations and ensure patients understand the need for supportive periodontal care provided at an appropriate recall interval.

In Chap. 4 we established the importance of optimising periodontal health and ensuring patient compliance with home care prior to providing fixed restorations. However, to ensure prosthetic success, the periodontal tissues must be respected from planning through to tooth preparation, fitting and beyond.

In planning for extra-coronal restorations, thought must be given to how the gingivae will influence the final aesthetics, maintenance of periodontal health and whether surgery is needed to expose a greater clinical crown height to ensure the restoration remains cemented.

Where teeth are being replaced, there is often an issue as to whether pink ceramic or acrylic is needed as part of a prosthesis to replace a resorbed edentulous region. Where only extra-coronal restorations are needed, an important issue may be black triangles caused by loss of interdental papillae because of loss of attachment, which may pose a prosthodontic challenge. While surgery may be used to cover exposed root surface, it is not a predictable method of replacing missing papillae. So, during planning, patients should be made aware of viable options including acrylic gingival veneers [1], modifying the emergence profile of the restoration to partly fill the space or in selected cases using pink ceramic as part of the restoration [2]. If this is not addressed before treatment starts, patients may have unrealistic expectations which lead to disappointment.

The response of periodontal tissues to perioperative insult is variable, but governed largely by the gingival biotype and the location of the preparation finishing line, particularly when it is placed subgingivally. Added to that will be the operator's skill in preparing the finishing line (see Chap. 20), recording it (Chaps. 21 and 22) and making a well-fitting provisional restoration (Chap. 23). When restorations are fitted on a deep subgingival preparation margin, the results may be catastrophic to gingival health—even if the restoration appears well fitting. Distressed patients may return with erythema (Fig. 10.1), bleeding, swelling and discomfort. Others may suffer recession exposing restoration margins. To prevent these problems, it is important to work with nature rather than against it. This can best be explained via the concepts of gingival biotype and biologic width.

Fig. 10.1 Gingival inflammation at 11 as result of impingement of biologic width by the crown. Recession at 21 revealing the previously subgingival margin

10.2 Gingival Biotype

Based upon the thickness of the gingival tissues, the gingival biotype is described as either thick (>2 mm) or thin (<1.5 mm) [3]. Thick-flat periodontal biotypes are usually associated with square-shaped teeth, large proximal contact areas and short papillae (Fig. 10.2). By contrast, thin tissue displays a delicate, scalloped architecture often with a thin band of keratinised tissue and tooth shapes that are triangular with narrow contact areas and long interdental papillae (Fig. 10.2b) [4, 5]. Many patients fall in the boundary between thick and thin biotype, making the distinction unreliable on a scientific basis [6]. Clinically, however, it is worth distinguishing patients who patently have a thin biotype or where a tooth to be restored has a thin gingival cuff. This is because crowns and veneers placed in these patients are more likely to experience aesthetic complications, particularly recession, than in patients with a thick biotype [7]. This is an important consideration when planning restorations in the aesthetic zone. In consenting to treatment, patients should be made aware of the risks, particularly for subgingival preparations.

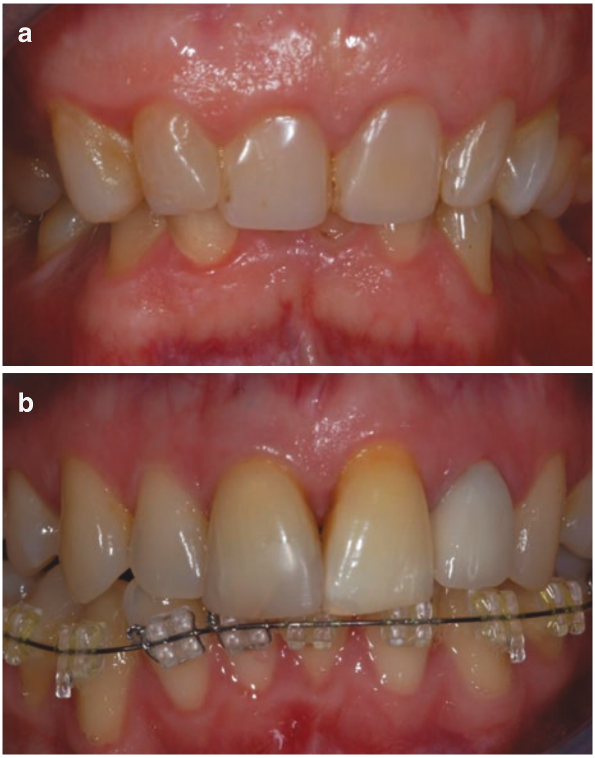

Fig. 10.2 Thick periodontal biotype (**a**) and thin periodontal biotype (**b**)

10.3 Biologic Width

The concept of biologic width mystifies many dentists, so it is worth providing some explanation. The gingival apparatus (see Fig. 10.3) has three main components which must be accommodated between the alveolar crest and the free gingival margin: the connective tissue, junctional epithelium and crevicular epithelium. The classical study of Gargiulo et al. (1961) measured these components in an autopsy study of 30 individuals and found the height of connective tissue almost constant at 1.07 mm with a similar mean height of junctional epithelium, but the latter component showed much greater variation [8]. The term "biologic width" was coined 16 years later to define the dimensions of gingival attachment as the combined height of the connective tissue and junctional epithelium [9]. More recently a meta-analysis of six studies reported mean biological widths of between 2.15 and 2.30 mm, but individual measurements ranged hugely between 0.2 and 6.7 mm, reflecting significant intra- and inter-subject variation. Factors affecting biologic width include tooth type and site, the presence of a restoration and periodontal diseases/surgery [10]. In addition, the measurement method (clinical versus autopsy study) may affect dimensions.

Biologic width is relevant to dentists placing preparation margins in two circumstances. Firstly, subgingival margins, often needed in the aesthetic zone, should not invade the biologic width (again, see Fig. 10.1). This means the finishing line should be placed in the sulcus well above the epithelial attachment. In many cases the probing depth of the sulcus is about 1 mm, so the finish line should be placed 0.5 mm subgingivally. Where patients have a deeper but healthy gingival sulcus, there is capacity to go further subgingivally but generally not more than 1 mm. This is because of the practical difficulties in visualising and recording the margin and the difficulty patients have in keeping the margin clean. Preoperative probing of sulcus

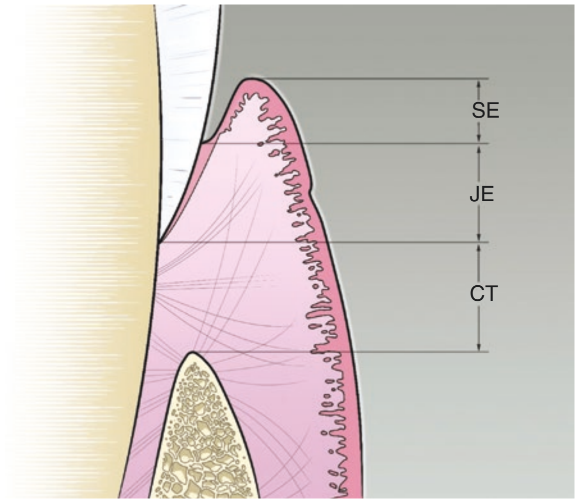

Fig. 10.3 Biologic width represents the gingival attachment and is the combined height of JE + CT. *SE* sulcular epithelium, *JE* junctional epithelium, *CT* connective tissue

depth must be done carefully to avoid penetrating the epithelial attachment and gaining an untrue reading.

The second reason for respecting the biologic width is when carrying out crown lengthening surgery—this is discussed later.

10.4 Margin Placement

Clinicians need to ensure their choice of margin placement not only respects the biologic width but is also compatible with the aesthetic needs of the patient. A supragingival margin does not affect the periodontium and affords an excellent opportunity for the patient to achieve good plaque control at home [11]. Additionally, impressions for the indirect restoration are easier and more predictably made, without the associated trauma of using retraction cord. Supragingival margins are often possible in the posterior dentition away from the aesthetic zone.

An equigingival margin is often acceptable in terms of plaque control but may not always be able to provide adequate aesthetic outcomes, particularly when teeth are discoloured and require an alteration in their emergence profile.

A subgingival margin is often necessary to address various clinical situations such as subgingival decay, discoloured teeth and short clinical crowns that need minor enhancement of resistance and retention features. However, deep subgingival margins are associated with an adverse histological response [8] which may lead to periodontal attachment loss and gingival recession [12–15]. These aspects are considered further in Chap. 20.

There are occasions when mucogingival procedures are required for aesthetic or functional reasons prior to starting fixed prosthodontic treatment. These include correction of defects in morphology, position and/or amount of soft tissue and underlying bone support [16] There are many classifications of mucogingival procedures, but crown lengthening and gingival augmentation surgery (with or without root coverage) are perhaps the most commonly used.

10.5 Crown Lengthening

Crown lengthening is a mucogingival procedure designed to increase the extent of supragingival tooth structure for restorative or aesthetic purposes by apically positioning the gingival margin or removing the supporting bone or both [16]. In the context of aesthetic implant dentistry, it has been said that "tissue is the issue, but bone sets the tone" [17] and this concept is true of crown lengthening procedures too. In other words, the soft tissue follows the contour of the bone, and repositioning of the soft tissues position is frequently unstable unless the underlying bone is similarly adjusted.

Teeth planned for fixed prosthesis are likely to have been subject to tooth decay, fracture or both. When this damage extends subgingivally, then functional crown lengthening surgery can be used to expose solid tooth structure and thus increase

Table 10.1 Surgical crown lengthening techniques related to clinical situations shown in Fig. 10.4

	Clinical situation	Technique advised	Procedure overview
1.	Periodontal bone loss (or false pocketing) + Wide band of keratinised tissue	Gingivectomy	No flap Removal of soft tissue No bone removal Achieved by scalpel, electrosurgery or laser
2.	Periodontal bone loss + Narrow band of keratinised tissue	Apically repositioned flap	Elevation of a mucoperiosteal flap No soft tissue removal No bone removal Tissues replaced further apically on tooth
3.	Normal periodontal probing depths + Wide band of keratinised tissue	Gingivectomy + osseous recontouring	Elevation of a mucoperiosteal flap Removal of soft tissue Bone removal Flap replaced at same level
4.	Normal periodontal probing depths + Narrow band of keratinised tissue	Apically repositioned flap + osseous recontouring	Elevation of a mucoperiosteal flap No soft tissue removal Bone removal Tissues replaced further apically on tooth

retention of the final prosthesis. Aesthetic crown lengthening may be considered when there is excessive gingival display which is disproportionate to the clinical crown height resulting in alterations to the ideal tooth proportions. This is often a concern for patients with a high lip line. Aesthetic crown lengthening surgery may be required in isolation or in combination with functional crown lengthening surgery.

Success with crown lengthening procedures depends on careful case selection and preoperative planning, as well as surgical and prosthodontic skill. Radiographic and clinical assessment of the tooth, bone, soft tissues and facial profile will guide the practitioner on the case complexity, appropriateness of the procedure and the most suitable surgical technique. In planning each case, it is important to have a vision of the final prosthesis design from the outset so that the surgical technique is tailored to complement this desired endpoint. Model surgery can be carried out on diagnostic casts to establish where the gingival margin is wanted. Complications such as excessive root exposure, sensitivity, black triangles and rebound tissue growth can therefore be minimised.

There are several surgical procedures available to lengthen a clinical crown. The choice of technique will depend on the indication for treatment (functional or aesthetic), site in the mouth and preservation of biologic width. Critical to the assessment are the width of the band of keratinised tissue, periodontal probing depth and bone levels—assessed radiographically. Table 10.1 gives an outline of the main surgical options with a schematic diagram of the related clinical features shown in Fig. 10.4.

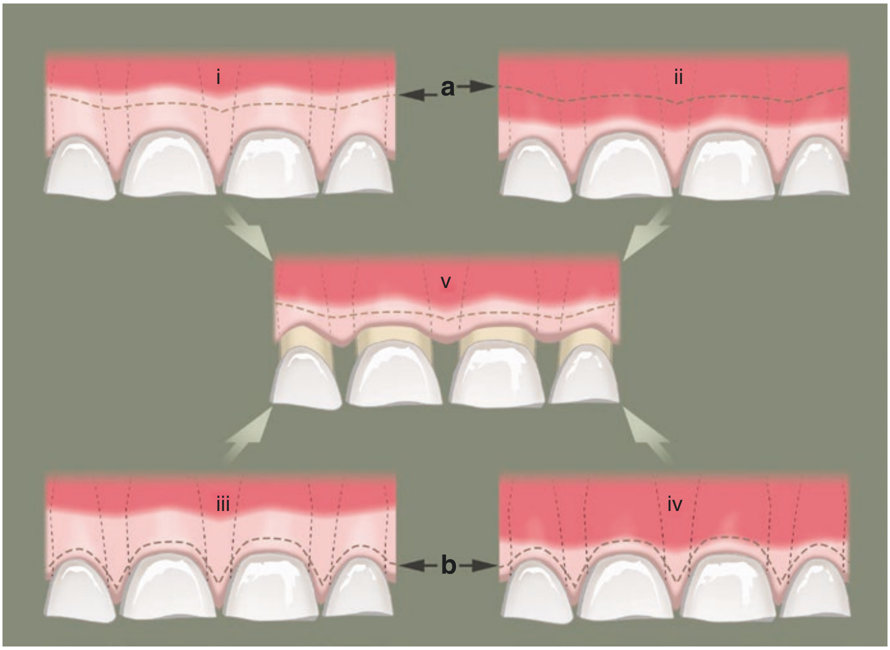

Fig. 10.4 Decision-making for crown lengthening surgery. Teeth with short clinical crown height may require crown lengthening to obtain restorations which are sufficiently retentive and aesthetic. A similar result (v) after crown lengthening surgery follows various procedures. The choice of procedure (see Table 10.1) depends on alveolar bone height, sulcus depth and height of keratinised gingiva. Situations (i) and (ii) have bone loss and pocketing leading to a reduced bone height indicated by the dashed line (a). In (iii) and (iv) there is good bone height (b) requiring surgical bone removal. The choice of soft tissue surgery technique (see Table 10.1) depends on the bone level and height of keratinised gingiva. A low height of keratinised gingiva (ii and iv) necessitates flap surgery to conserve keratinised tissue. A high bone level (iii and iv) also requires flap surgery to access the bone and allow recontouring

As mentioned earlier, the biologic width is important, so dentists undertaking any form of crown lengthening must keep in mind the need to accommodate a fibrous attachment, an epithelial attachment and have the crown margin finish just within the sulcus. As a rule of thumb, a 3 mm gap is recommended between a restoration margin and the alveolar crest [9]. Periodontists use this dimension during flap surgery when gauging the amount of bone to remove during osseous recontouring. Even so, the attachment apparatus is not obliged to adhere to average values and will remodel over the ensuing 3–6 months.

The simplest form of crown lengthening is a gingivectomy which periodontists prefer to carry out with a scalpel. However, gingivectomy may also be performed using electrosurgery [18] or laser. There are a few electrosurgery technique papers [19, 20] but strangely a paucity of research describing clinical outcomes. This is surprising given the significant numbers of dentists who use electrosurgery for impression procedures [21, 22] and the relatively few reports of adverse events [18, 23].

Fig. 10.5 Localised electrosurgery: loss of crown at 13 with gingival overgrowth (**a**). There is *sufficient sulcus depth and zone of keratinised mucosa* for electrosurgery to reveal the preparation margin (**b**). The margin will be extended onto sound tooth to give a ferrule and a well-fitting provisional restoration fitted to allow the gingival position time to stabilise

At one time, there were worries about causing significant damage to the bone and cementum [24], but this was related to first generation electrosurgery machines which are now outmoded.

Dentists wishing to carry out electrosurgery must choose cases carefully ensuring:

- Sufficient sulcus depth to leave at least a 1 mm sulcus following gingivectomy
- Sufficient keratinised mucosa so at least 2 mm remains following gingivectomy
- No requirement for altering the crestal bone contour.

If using electrosurgery, safety precautions must be observed in the same way as when a trough is created for gingival displacement prior to recording an impression (see Chap. 21). A thin wire tip electrode is generally used. This tip must not be brought near metal restorations or implants or bone; otherwise electrical arcing can occur resulting in pulpal or osseous damage.

Two gingivectomy cases treated using electrosurgery are shown in Figs. 10.5 and 10.6. For gingivectomy on the buccal aspect of teeth, the tip should be held at an angle of around 45° (see Fig. 10.6). This is to give a bevelled cut on the outer aspect of the keratinised gingiva and should finish just below where the preparation margin is planned. The bevelled cut appears to help reduce rebound growth as may occur when a cut is made perpendicular to the long axis of the tooth.

Fig. 10.6 Electrosurgery to crown lengthen six worn anterior teeth: Gingivectomy *indicated by false pocketing of 2.5 to 3 mm plus a wide zone of keratinised mucosa* (**a**). The electrosurgery cuts away 1.5–2 mm—note angulation of tip to give bevelled cut, precisely following scalloped outline (**b**). Cut made to centre line (**c**) to allow contour to be matched for the remaining teeth (**d**). Direct composite restorations will be used, so no need to wait months for the gingivae to stabilise

Electrosurgery may appear a simple solution, but, crown lengthening is not always straightforward—flap surgery and bone recontouring may be essential to a satisfactory outcome (Figs. 10.4 and 10.7).

Details of surgical techniques for crown lengthening are beyond the scope of this chapter and are best learnt via a recognised training programme. Case types vary considerably in complexity; so, if in doubt, seek the expertise of a periodontist prior to restoration. This may either be for advice or to carry out the crown lengthening. Alternatively, patients may require gingival augmentation surgery, designed to prevent recession or treat localised recession.

10.6 Gingival Augmentation Procedures

The field of mucogingival surgery is a skill-intensive domain that usually requires advanced postgraduate training, often with periodontal specialist competencies. Dentists without this training are best advised to refer patients requiring these procedures to an appropriate practitioner, before considering the placement of indirect restorations.

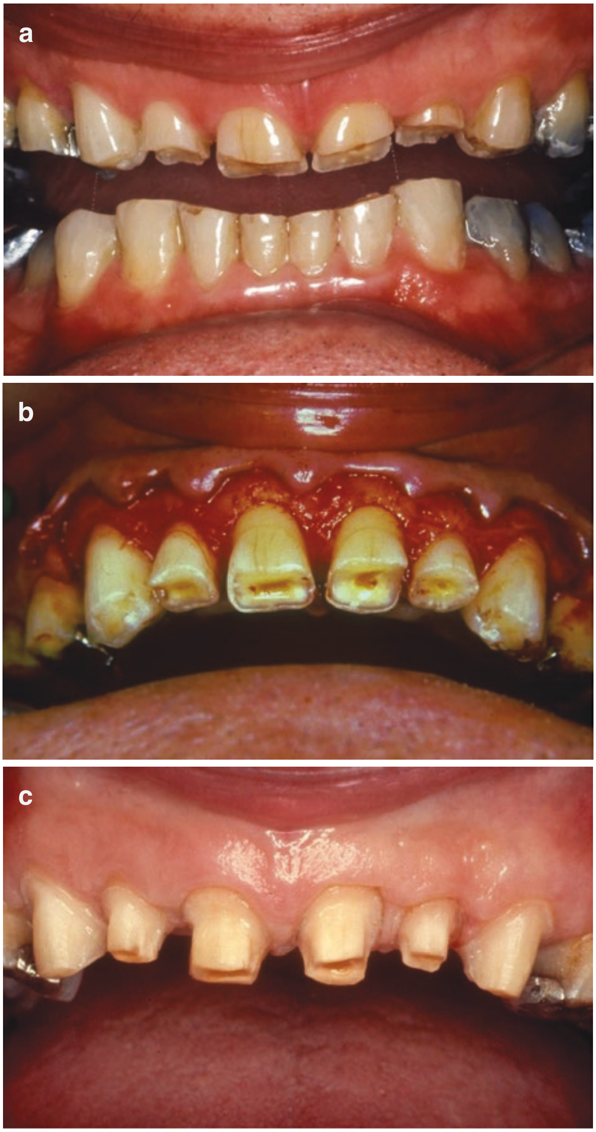

Fig. 10.7 Flap surgery and osseous recontouring to crown lengthen six worn anterior teeth: Note the wide zone of keratinised tissue, but sulcus depth was only 1 mm (**a**). Full-thickness mucoperiosteal flap raised revealing bone which must be recontoured to move the crest 1.5–2 mm apically to give sufficient crown height (**b**). Six months later showing good healing and ceramo-metal preparations (**c**)

Following a mucogingival procedure, it is advisable to wait a minimum of 3 months before provision of definitive restorations [25], but this should be extended to 6 months in the aesthetic zone. This delay allows for tissue maturation and establishment of the final gingival position [26, 27]. Provisional crowns can be provided earlier but require careful maintenance and may need adjustments to the margins and emergence profile as healing proceeds. During the healing phase, patients must actively be given supportive care to ensure good oral hygiene.

10.6.1 Non-root Coverage Surgery

This involves augmenting a zone of keratinised gingiva which is narrow or non-existent. While the health benefits of having a zone of keratinised and attached gingiva can be argued, these tissues are undoubtedly important adjacent to crown and restoration margins, particularly those placed subgingivally [28]. So, non-root coverage surgery is designed to:

- Facilitate plaque control
- Improve patient comfort
- Increase the zone of attached gingiva for restorative dentistry or orthodontics
- Help prevent future recession [29].

The gold standard for this augmentation involves autogenous gingival grafting (AGG) with tissue harvested from the patient's palate. Clinical studies made over 10–25 years show this approach can halt recession, but the procedure is uncomfortable for some patients, and the new keratinised tissue is not always a good aesthetic match with the surrounding tissues. Aesthetics and shrinkage can be controlled by ensuring the graft is neither too thick nor too thin with a recommended thickness of 1 mm or just over [6].

Tissue-engineered materials offer a promising alternative to AGG but are not yet supported by long-term clinical trials. These materials include a variety of matrix materials and membranes derived from human, porcine and bovine sources [6].

10.6.2 Root Coverage Surgery

Recession defects around teeth are relatively common [30], frequently asymptomatic and often not an issue when restored with supragingival margins. However, in some situations they can compromise aesthetics, cause sensitivity and predispose to root caries. When the affected teeth need veneers or crowns, dentists may wish to place the finishing line either equigingivally or subgingivally. However, doing this may compromise the width of the restoration margin, affect pulpal health and look unaesthetic. There may also be further unwanted gingival recession. In such situations, it is worth considering pre-prosthetic root coverage procedures.

Recession defects are often classified per their extent and whether they have a residual band of keratinised tissue at the free gingival margin. Miller's classification [31] is commonly used, and the outcomes of surgery are predicted by the severity of the recession defect (see Table 10.2). There are several surgical techniques involving a variety of flap designs which, as mentioned in the previous section, may additionally require the use of a graft material (Fig. 10.8) [32].

Table 10.2 Miller's classification of gingival recession

Class	Description of recession
Class I	Does not extend to the mucogingival junction (MJ)
Class II	Extends to or beyond the MJ but without loss of interproximal clinical attachment (CA)
Class III	Extends to or beyond the MJ, with either loss of interproximal CA or tooth rotation
Class IV	Extends to or beyond the MJ, with either severe loss of interproximal CA or severe tooth rotation

The chance of correcting a defect recedes with higher levels of classification

Fig. 10.8 Root coverage surgery: 16 with a Miller's Class III Recession Defect (**a**). The tooth was re-root treated and restored with a composite core and lithium disilicate crown. One year after a palatal connective tissue graft and coronally advanced flap (**b**). Courtesy of Mr Matt Garnett

10.7 Periodontal Precautions when Providing Restorations

At each of the stages of providing extra-coronal restorations, there are risks to the periodontium. These are summarised in Table 10.3 but will also be addressed in Chaps. 20–24.

Table 10.3 Periodontal risks from restorative procedures and how to avoid them

Risk	Remedy
Tooth preparation (Chap. 20)	
Gingival trauma	• Protect tissues from trauma
Invasion of biologic width	• Avoid deep subgingival preparations
Gingival displacement (Chap. 21)	
Incorrect, heavy handed or prolonged retraction procedures leading to pain, tissue necrosis and recession [33]	• Careful handling of tissues, particularly thin biotype • Ensure retraction cords are removed from the sulcus before dismissing the patient
Impression (Chap. 22)	
Impression material retained in exposed furcation areas or other periodontal defects	• Block out furcation areas before recording impression • Check deep pockets for retained impression material
Provisional restoration (Chap. 23)	
Overhanging or negative margins and rough, plaque retentive surfaces	• Allow sufficient time for finishing and polishing to create smooth surfaces and generate accurate margins on the provisional restoration
Inadequate gingival embrasure space, especially beneath the connectors linking provisional restorations	• Open embrasures sufficiently to allow patients to clean interdentally. Show interdental cleaning with devices such as Oral B Superfloss™ (Procter & Gamble UK) and how to pass the gingival to the connector between adjoining provisional crown units
Loss of retention of provisional restorations particularly when used in the medium or long term to develop gingival contour	• Ensure oral hygiene methods do not displace provisional restorations: Tooth preparations must be retentive and the temporary cement sufficiently strong
Fitting and cementation (Chap. 24)	
Poor marginal adaptation and restoration contours	• A try-in prior to final glazing/polishing can sometimes be helpful to check fit and contours [34]
Bulky emergence profile leads to biofilm accumulation [35]	• No more than 0.5 mm bulge adjacent to the buccal and lingual aspects of the gingival margin [36]
Open proximal contacts	• Tight contacts can improve gingival health by helping prevent food impaction [37]
Poor gingival embrasure contour beneath the proximal contacts leaving too much or too little space for the papilla	• Too small a space will suppress the papilla • Too large a space may collect debris and biofilm
Deflective contacts and interferences	• If not adjusted may lead to overloading of the periodontal tissues (trauma from the occlusion—see Chap. 12) [38]
Residual excess cement	• If not cleared away, it will act as iatrogenic calculus

Provisional restorations are particularly important in maintaining periodontal health between appointments. In addition, provisional restorations have another important role—to support and develop the soft tissues when replacing defective crown and bridgework or following periodontal surgery or as part of implant placement. Careful adjustments of the provisional restorations establish the desired emergence profile and gingival contour. The resulting shape will then guide final prosthesis design, so it is important this information is carefully and accurately communicated with the laboratory. An impression of the provisional restorations can be invaluable to show the desired crown contour, emergence profile, embrasure shape and the position of proximal contact relationships [34].

Providing the periodontal tissues have been considered at the restoration design stage and carefully handled throughout treatment, then the definitive restorations should pose minimal periodontal challenge. This of course assumes the laboratory is given adequate information and instructions and provides what is asked for. It has been shown that quality control criteria following production of bridgework can be poor [39]. Reasons for this include poor communication [40] and poor quality records provided by the dentist to the laboratory [41] This highlights the importance of ensuring thorough and systematic checks on all extracoronal restorations prior to cementation.

Finally, after restorations have been fitted, there is a need for supportive periodontal care (see Chap. 24) [42]. The same applies with implants where a minimum of 5–6 months between peri-implant maintenance appointments has been proposed, but clearly the interval should be guided for each patient by their disease susceptibility [43].

Conclusion

In planning and placing extra-coronal restorations, the periodontal tissues must be respected. Patients with a thin gingival biotype or with minimal keratinised tissue are particularly vulnerable to recession. So, care must be taken to avoid unnecessary trauma or placement of subgingival margins which invade the biologic width. There are multiple surgical procedures available for crown lengthening to improve aesthetics or enhance crown retention. Dentists may also wish to consider referring patients for root coverage surgery or to increase the width of keratinised gingiva.

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11 Viability of Posts and Cores

Simon Stone, John Whitworth, and Robert Wassell

11.1 Learning Points

This chapter will emphasise the need to:

- Remove existing restorations prior to root treatment or retreatment to assess restorability, preserving as much tooth tissue as possible
- Consider all options if a tooth is unrestorable, including implants for tooth replacement
- Consider if a post is necessary. Alternatively, use the pulp chamber and to a lesser extent root canal anatomy for core retention
- Determine that if a post is needed, ensure it is retentive but also strong enough to resist distortion or fracture. If it fails, it should be retrievable
- Avoid posts that actively engage dentine and create internal stresses
- Ensure coronal coverage for protection, particularly of the posterior teeth.

The decision whether to attempt restoration in preference to extraction and how to ensure that restored teeth enjoy predictable success will always be influenced by the quantity and quality of the remaining tooth tissue. Teeth scheduled for root canal treatment and those that have already been root canal treated may offer challenges, which often render our restorative efforts difficult and unpredictable [1–7]. These include:

- Tissue loss from previous disease and restoration [7]
- Destructive access cavities

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- Aggressive canal enlargement
- Potential physical changes to dentine.

Nevertheless, care and attention to preserve dentine and perform high-quality, tissue-preserving endodontic treatment can offer rewards in overcoming restorative challenges [8–13].

The decision whether to restore or to extract a tooth and possibly replace it with an implant, bridge or denture is not always easy. Teeth unfit for restoration may be identified at the examination appointment, but sometimes an unrestorable or significantly compromised tooth only becomes obvious as the treatment progresses and existing restorations are removed.

This chapter will firstly consider these issues, and secondly provide an insight into the evidence supporting the use of cores, and posts with cores for restoring root-treated teeth. The practicalities of placing cores and posts and cores are considered in Chap. 19.

11.2 Preoperative Assessment

The decision on restorability should be made before starting root canal treatment or retreatment. Existing restorations may cloud objective judgement, and ideally all should be removed to inspect the quality, volume and distribution of tooth tissue and plan the final restoration before commencing. It is tempting and convenient to root treat through an existing restoration, but this is risky in heavily restored teeth. Embarrassingly, these teeth may be found to be unrestorable after root canal treatment or may fail due to previously undetected cracks or fractures [14, 15]. In summary, preoperative removal of all existing restorations allows for:

- Detection of otherwise hidden caries
- Removal of weak and undermined tissue
- Exploration for cracks and fractures
- Assessment of what remains of the tooth to retain a core or extra-coronal restoration.

In assessing the remaining tooth structure, a circumferential band of sound tissue, with a minimum height of 1.5–2 mm and minimum width of 1 mm, is usually sufficient to form a ferrule to resist occlusal forces [8, 15–18]. Of course some teeth have only sufficient tooth remaining to provide a partial ferrule, but there is in vitro evidence to suggest that a partial ferrule, although not as ideal as a circumferential ferrule, still has value in providing fracture resistance [19]. Clinically, the survival of posts and cores has been associated with the height of the remaining coronal dentine [20].

Teeth that have been decoronated to gingival level, leaving table top-like preparations, often provide inadequate resistance form to build a crown back to full contour. In these cases, alternatives, such as dental implants, may provide a more predictable outcome [21], but the decision whether to extract or retain a

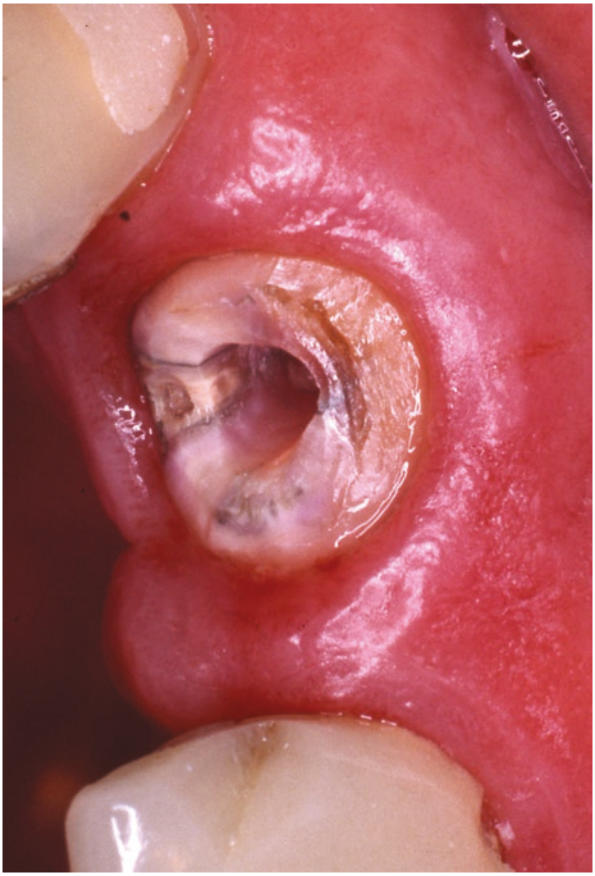

Fig. 11.1 Root fracture associated with post failure. Shown (left) are two asymptomatic cracks on the palatal aspect of a root where a post has recently become decemented—should this be restored, perhaps with a cast post and diaphragm, or extracted and replaced with an implant?

compromised tooth is not always easy (Fig. 11.1) and will be influenced by a dentist's skill, and experience as well as patient preference. However, a decoronated but substantial single root (e.g. a canine or central incisor) with no signs of fracture and with surrounding teeth able to offset the fatiguing effects of non-axial occlusal loading [22, 23] should be considered for conservation, perhaps with crown lengthening and/or orthodontic extrusion [24, 25], rather than automatically replacing it with an implant (Fig. 11.2). While in many cases implants provide an excellent solution, they are not without their own problems (see Chap. 2) and should not be regarded as a "fit and forget".

11.2.1 The Unrestorable Tooth

When a tooth is deemed unrestorable, the options for its replacement should be discussed [15]. For an isolated single tooth in an interested patient, the ideal option may often be an implant retained restoration. If this is not within a dentist's

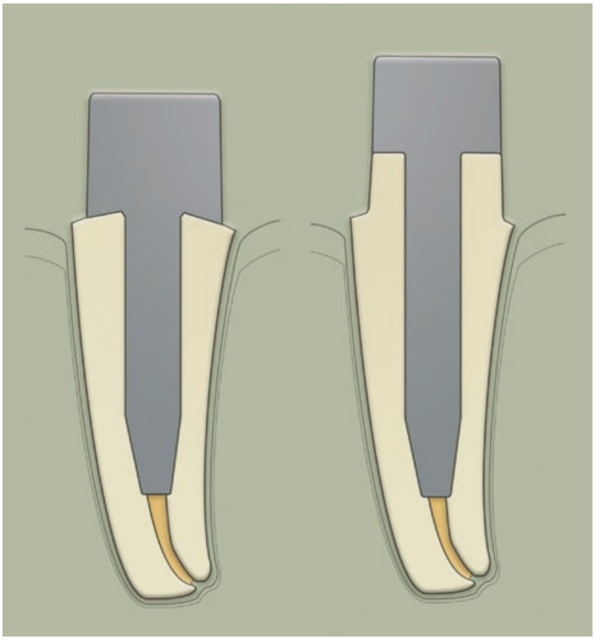

Fig. 11.2 The ferrule: Ideally 2–3 mm of coronal tooth should be preserved so the crown's retention and resistance does not rely entirely on the post. In the left image, there is little or no ferrule remaining coronally, a post and core may still be feasible, but the risk of failure may be reduced if a ferrule can be created by moving the crown margin apically or through forced orthodontic extrusion (right)

competence, a suitable referral should be made. An early referral can be helpful in treatment planning, whether an implant is advised or not. On occasions, an interim restoration may be offered to allow the patient time to consider their options and plan their finances for implant supported restoration.

Where an implant is suitable, the nature and timing of tooth extraction in relation to implant placement may be critical to success. Using an atraumatic and timely extraction technique will help to avoid unnecessary alveolar bone loss (see Fig. 11.3) and the need for complex bone grafting [26]. Immediate or early implant placement allowing for short-term soft tissue healing may be possible even if there is an established endodontic periapical lesion [27–30].

Generally, teeth verging on unrestorable in which symptoms cannot be controlled are best removed, but take care not to confuse tooth-related pain with other sources of pain (e.g. neuropathic pain or pain referred from a temporomandibular disorder).

Implant restorations may not be clinically possible, justifiable, affordable or acceptable to the patient. Alternative replacement options, including bridgework, partial dentures or simply leaving the space, should always consider the status of the remaining dentition and the patient's wishes. Any active dental diseases such as caries and periodontitis should be addressed, risk factors (e.g. smoking) managed, and consideration given to the prosthetic space during treatment planning and workup.

We will return to these important treatment planning issues in Chaps. 18 and 19.

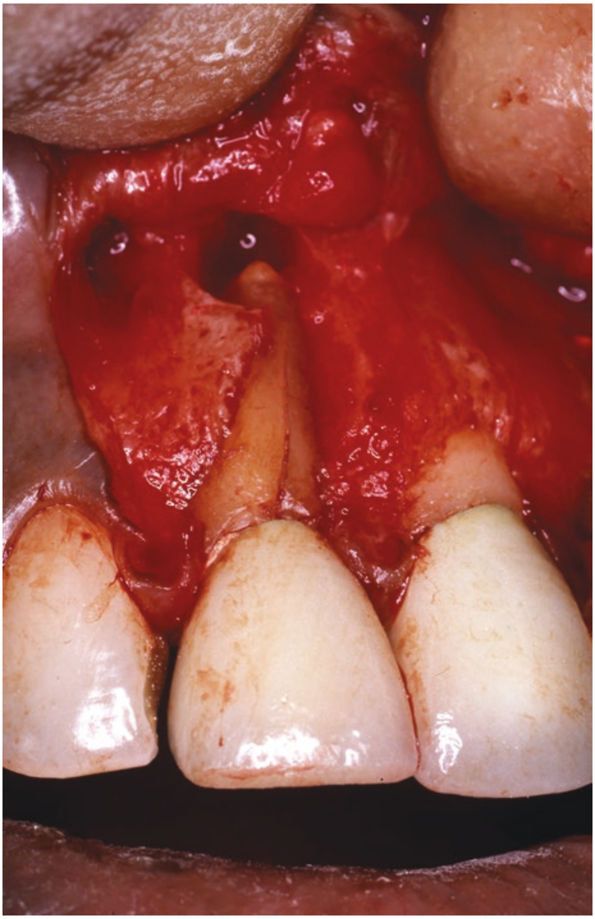

Fig. 11.3 Unfavourable bone loss associated with a symptomatic, catastrophic, unrestorable fracture seen only after flap retraction for an abortive apicoectomy. 3D imaging with cone beam radiography may have revealed the problem earlier

11.2.2 Restoring the Significantly Compromised Root-Filled Tooth

A root-filled tooth always requires restoration to provide a coronal seal. In addition, posterior teeth often need a full occlusal coverage restoration (e.g. a crown) [31, 32], to protect the remaining tooth tissue from fracture [10, 31, 33, 34]. These factors are critical to a root-filled tooth's periapical health and its survival [11, 12, 35–38]. Ideally, the restoration should be planned before commencing root canal treatment, but for any tooth, depending on the quality and quantity of remaining coronal dentine, a core or a post and core may be needed [15, 39]. The types and characteristics of posts will be considered in following sections.

Structurally, a post will provide additional retention and help with stress distribution, but at what cost? The delicate balance between increased retention and risks of

Fig. 11.4 An extracted post-retained lower incisor tooth with a catastrophic perforation because of the lack of control of length during preparation

weakening or perforating the root during post-space preparation must always be weighed carefully (Fig. 11.4) [40]. These risks should be communicated to patients so they can be involved in decision-making. Thankfully, most dentists now realise that a post does nothing to strengthen root-treated teeth [19, 41].

The most conservative way of placing a core in a root-filled tooth is to use a direct restorative material bonded to the remaining tooth tissue, often including the pulp chamber and access cavity. With posterior teeth, further anchorage may be achieved by extending the core into divergent root canal anatomy; this is the "Nayyar" core originally described for unbonded amalgam [31, 42]. Nowadays, such cores can be dentine bonded, and the range of core materials includes amalgam, composite resin and occasionally high strength glass ionomer cements (GICs). Bear in mind that the more brittle nature of GICs requires sufficient bulk of material and sufficient remaining tooth structure. Core placement is explored in depth in Chap. 19.

An important decision before composite core placement is whether a tooth would benefit from internal and/or external bleaching (Fig. 11.5). Where it is necessary to progress crowning or veneering, restoration margins can be particularly noticeable when finished on unsightly and discoloured tooth tissue. Often placing margins subgingivally is only a temporary solution—some gingival recession being inevitable—even in expert hands and with excellent patient compliance. Furthermore, where there is a thin gingival biotype, the discoloured margin and tooth may shine through the soft tissue. In either case, lightening a tooth by bleaching may at least minimise an aesthetic problem. However, bond strengths are affected by carbamide peroxide bleaching [43, 44]. Therefore definitive restorations should be delayed for at least 2 weeks following completion of bleaching for bond strengths to improve and colour to stabilise [45, 46].

Contrary to popular belief, few endodontically treated anterior teeth require a post and core and crowning. Indeed, while crowns made a significant difference to the survival of root-treated posterior teeth, they did not do so for anterior teeth [31]. Nowadays, adhesively retained direct composites and veneers offer a much less destructive approach, although crowning may be needed where severe vertical cracking extends from the incisal edge. As a rough guide, post-retained crowns should be considered where root-filled anterior teeth have lost more than half their natural tooth structure, or there is a patchwork of restorations, including the

Fig. 11.5 A compromised upper central incisor tooth in a patient with a history of trauma and primary endodontics which led to root perforation (**a**). After completion of re-root canal treatment, perforation repair, inside-outside bleaching and core placement (**b**). Conservative management has removed the need for an unnecessarily destructive veneer preparation

endodontic access. However, each case will need to be assessed on its own merits, and there is often a fine balance between using a Nayyar-type core or a post and core.

A cursory glance through any dental supply catalogue will reveal a huge variety of commercially available post systems, with subtle differences in design and varying, sometimes contradictory and possibly biased [47], clinical evidence to support their long-term use [41]. Therefore, it is important to consider some general principles when deciding if a post is absolutely necessary and if so which type to use.

11.3 Characteristics of Post Systems

A post is a device luted into a prepared root canal or pulp chamber or both to retain an indirect restoration. A post may have an integral core or have a core added, usually directly in composite or amalgam. A post may also comprise part of an indirect restoration (e.g. an onlay for a posterior tooth made from alloy, ceramic or composite with a stub post engaging the pulp chamber). Such "endocrowns" show promise in limited clinical studies for 3 years or less [48]. However, a longer-term retrospective study estimates a success rate of only 55% at 10 years [49], so caution is advised in their wholesale use until more evidence is available. There is considerably more evidence for posts that work in conjunction with a core; the two main varieties of which are:

- Custom-made, cast metal post and core: gold alloy or nickel chrome
- Prefabricated posts
  - *Fibre*: glass (quartz) fibre and carbon fibre
  - *Metal*: titanium and stainless steel
  - *Ceramic*: zirconia

Most prefabricated posts have a retentive component to retain a bonded composite core, but in posterior teeth, an amalgam core may also be used. Some prefabricated posts incorporate a core which may require precious tooth tissue to be sacrificed. Posts are either parallel sided or tapered, but to avoid unnecessary stresses, most experienced dentists prefer posts with a passive rather than an active, screw fit [41]. The complex and evolving area of stress analysis associated with different post systems will be considered later.

The traditional approach, which still has its uses, is the custom-made cast metal post and core (see Chap. 14 for alloy selection). Properly performed, these have a strong history of clinical success with retrospective studies indicating 75–80% probability of survival at 10 years [50, 51]. They occasionally may be used with an integral diaphragm to cover all or part of a vulnerable root surface to try and improve stress distribution.

Over the past 10–15 years, dentists have shown a preference for prefabricated posts, largely for reasons of convenience. There is also a belief that fibre posts with a modulus of elasticity similar to dentine pose a lower risk of causing tooth fracture than more rigid metal and ceramic posts [52]. As discussed later, this belief is not well supported by the results of a recent clinical meta-analysis and recent stress analysis studies [47].

One benefit of using a prefabricated post is that immediate placement can maintain the coronal seal, avoiding the need for a temporary post crown, while the definitive post and core is being manufactured. This will reduce the likelihood of poor marginal adaptation or debonding leading to microleakage, although how crucial this is clinically remains debatable [53–56].

Depending how well the prefabricated post fits the prepared root and how well the crown engages with remaining tooth structure, there can be a heavy reliance on luting cement for retention. In addition, there may be limited resistance to lateral forces which can be important for individual crowns but may be critical for bridgework [7].

In the sections below, consideration will be given to the factors important in planning a successful post-retained restoration including reasons for failure, cementation and post preparation to optimise retention, biomechanics and aesthetics. Of course, in the event of problems, a post should be retrievable.

11.3.1 Reasons for Failure

Dentists should be aware of the main reasons for post and cores failing and take steps to avoid them:

- Decementation/debonding
- Caries
- Post fracture
- Root fracture
- Endoperiodontal pathology [57].

In addition, a crown may become decemented if the core is insufficiently retentive or a core may fracture if there is insufficient bulk of material in areas subject to cyclic stresses. Placement technique (considered in Chap. 19) will be as important as post selection in minimising failure. So too will be the occlusion of the definitive restoration which should be managed to avoid cyclic non-axial loads [22, 23].

11.3.2 Cementation

At every stage of post placement, consider how the lute will interact both with the post and the prepared dentine. Any post, whether prefabricated or customised, should be cemented or resin bonded to clean dentine and not residual gutta percha, or smeared root canal sealer, which will compromise seal, retention and restoration longevity (Fig. 11.6). For a lute to be fully effective, the post needs to fit its channel accurately but with sufficient space to accommodate the lute.

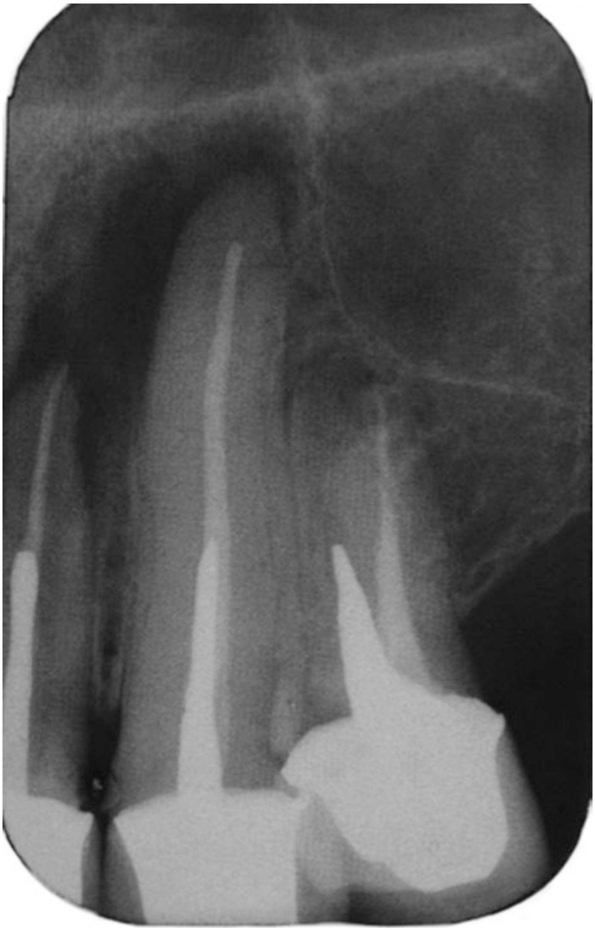

Fig. 11.6 How to build in failure with inadequate endodontics and cast post provision. Look at the upper left canine in the centre of the radiograph, not only is the post relatively short and spindly it also has been cemented ineffectively against residual gutta percha. In the upper left first premolar, a post is cemented into a root with no root filling

A recent survey reports a wide variety of luting materials being used for posts, most frequently resin-modified glass ionomer cements followed by self-adhesive resins—both of which are convenient single stage adhesive materials [41]. Unfortunately, there is no clear guidance as to which material is best, particularly in situations where post retention is compromised. Intuitively, the most reliable dentine bonding system (e.g. an etch and separate bond) should be coupled with a filled dual-cured lute [7, 52, 58]. In addition, there are advantages if the luting material can be used simultaneously and seamlessly to form a core.

Cast metal posts can be luted with conventional cements (e.g. glass ionomer or zinc phosphate) and mechanical adhesion to the post improved using airborne-particle abrasion (APA) with 50 µm alumina. APA also helps create space for the lute by stripping away a thin layer of alloy from the cast post [59].

The surface of any type of metal post can be made chemically active by using APA to apply a tribochemical silane treatment (e.g. Rocatec™ or Cojet™, 3M ESPE—see Chap. 15) [60, 61]. This is an important consideration when luting short metal posts with an adhesive resin system.

Fibre posts and ceramic posts are invariably bonded with a resin lute. Most fibre systems have smooth surfaced posts, but the adhesive properties can be enhanced, again using APA and tribochemical silanation [52].

11.3.3 Safe Post Preparation to Optimise Retention

Long posts will always provide more retention than shorter ones, but this should not be at the expense of a disrupted apical seal or risk root perforation or weakening (Fig. 11.4). Ideally, metal posts should be around two thirds of root length, with care taken to preserve a sealing apical gutta percha plug of 4–5 mm thickness [62, 63]. To avoid root perforation, any post preparation should stop short of root curvatures. A “strip perforation” from a misjudged post channel will often involve a large area of root surface, inaccessible to repair and catastrophic to a tooth’s survival. When fibre posts are adhesively luted, length is less critical than for metal posts, and extension to half root length has been recommended [64].

All things being equal, metal posts that are parallel sided will be more retentive than the tapered ones. Nevertheless, tapered metal posts do have a satisfactory clinical record providing they are adequately extended and effectively cemented. They may be of benefit in narrow roots which otherwise may be perforated by a parallel-sided preparation [7]. Care is needed to ensure tapered posts have a close but passive fit; otherwise they may generate wedging forces promoting root fracture [65, 66].

The manufacturers of fibre posts have gone a stage further and developed posts that are less tapered in the coronal aspect and more tapered towards the apex, reflecting typical canal preparations and therefore preserving precious dentine, e.g. DT (dual taper) illusion light posts XRO™ (RTD, France) [67].

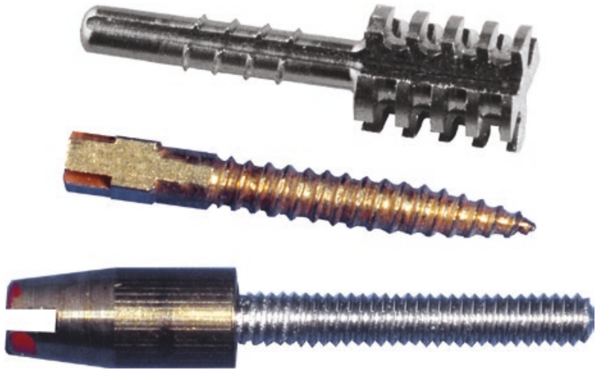

Fig. 11.7 Prefabricated, threaded posts. From top—Radix-Anker™ (Dentsply Maillefer), Dentatus screw™ (Dentatus), Kurer K4™ (Sabre Dental). The first two are self-taping screws. The K4 has the thread pre-cut into dentine before the post is inserted. To accommodate the K4's brass core, a flat recess is cut into the root surface. To spare coronal dentine, the K4 system can also be used with a direct composite core instead of an integral brass core

11.3.3.1 Active Posts

Metal posts that engage the canal walls with a thread (Fig. 11.7) will be more retentive than parallel posts [68]. However, the main risk with an "active" post design is the increase in stress on the canal walls and consequent risk of root fracture [7]. Self-tapping threads can be damaging because they tend to crush rather than cut a thread into dentine, particularly when combined with a tapering post. In an age of adhesive dentistry, there are very few indications for self-tapping screw posts; they are best avoided where possible [69, 70].

There are also post systems which pre-tap a thread into dentine with a thread cutting tool, e.g. Kurer K4™. The risk of root fracture with such posts is not recorded, but a meticulous technique is needed to avoid high stresses developing temporarily during luting. A suggested approach is to reserve them for situations where only a short post can be used (e.g. a short or curved root) but where there is sufficient bulk of dentine to resist root fracture [40]. At one time this was the only way of providing a retentive short post, but adhesive options are now generally preferred.

11.3.4 Biomechanics

The important factors here are post strength, rigidity and stress concentration.

A post's strength and rigidity depend on its diameter, but this must be in keeping with root width. Too wide a post, risks perforating or weakening a root. Sometimes an adequate bulk of post is best achieved with one or more tapering prefabricated posts. Alternatively, a custom-made cast post will also allow for a wide preparation to be engaged coronally and a narrower one apically [71–73].

As mentioned previously, the popular belief is that fibre posts (e.g. quartz fibre and carbon fibre) cause less root fracture than more rigid posts. This belief, is based largely on laboratory tests [34] and early clinical studies. However, a recent meta-analysis of 4752 posts reported no difference in root fracture incidence of cast post and cores versus glass fibre posts after more than 5 years' follow-up. By comparison, prefabricated metal posts and carbon fibre posts both showed twice as much root fracture over the same period [47]. Depending on the type of alloy, metal posts have a modulus of elasticity four to six times greater than fibre posts, so from a clinical perspective, modulus matching the post to dentine does not appear critical in preventing root fracture.

The stresses within post crowned teeth can be simulated using 3D finite element analysis (FEA). FEA involves computer-generated models which mathematically represent a restored tooth supported in its periodontal ligament being subjected to occlusal load. Perhaps suprisingly, recent FEA studies report fibre posts producing higher stresses in dentine compared with much stiffer metal and ceramic posts [74–76]. However, when the cement lute is analysed, FEA shows higher stresses resulting from a metal post compared with those from a fibre post [76]. This suggests metal posts have a theoretically higher risk of debonding than fibre posts and explains why an adequate post length is important for metal posts. In real life, fibre posts often fail clinically due to debonding. This may be less to do with stress concentration and more to the difficulty of bonding to the inside of roots, emphasising the need for a meticulous luting technique [52, 64, 77].

Clearly, avoiding failure due to stress concentration in root dentine and the surrounding lute is important. So too is avoiding post fracture due to stress concentration. Serrations in most preformed metal posts are not cut but rolled into the surface because notches cut into posts tend to weaken them. Notches can also weaken fibre and ceramic posts; we recommend resisting any temptation to cut retentive features into them.

Glass (quartz) fibre posts have been reported to perform well clinically when carefully placed [52, 64, 77] and where sufficient coronal dentine remains to create a ferrule (see Figs. 11.2, 11.8). The ferrule is crucial to help with stress distribution [75]. However, in single-rooted teeth with little remaining coronal tooth tissue and where a long crown is needed, there is a risk of over-flexing a fibre post. Clinically, this can cause it to fracture leaving a "shaving brush" of severed fibres protruding from the root. The fibres fail within the core as predicted by FEA [74]. Cast posts are inherently more rigid and may offer a better choice in this situation [51]—providing they are designed to give adequate bulk in the coronal third of the root (Fig. 11.9) where cast posts generally fracture. Sometimes this is difficult to achieve in small roots (e.g. lower incisors or upper lateral incisors). So, extraction and prosthetic alternatives may need to be considered (e.g. implant, bridge or denture).

Occasionally with more robust roots, incorporating a metal diaphragm into the post may be worth considering, e.g. to help spread occlusal loads, where there is little remaining coronal tooth tissue (Fig. 11.10). The diaphragm can cover all or part of the root surface.

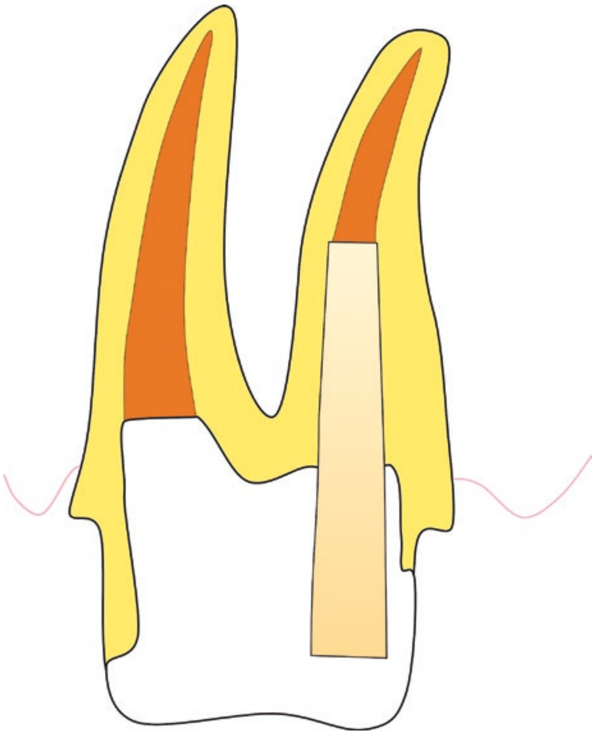

Fig. 11.8 A directly placed prefabricated fibre post and composite core in an upper premolar prepared to receive a crown. The post provides additional resistance and retention in relation to the missing palatal wall. Sound coronal dentine has been preserved to create a ferrule. Practical details are discussed in Chap. 19

Our understanding of post biomechanics continues to improve, but dentists still need to engineer a workable solution for each individual tooth. Where there is sufficient coronal tooth tissue, fibre posts with composite cores will often be a good choice particularly if a composite core by itself would be inadequate. However, fibre posts are not a panacea, and a cast metal post and core should be considered where a more rigid post is needed. Pay attention to obtaining adequate post length, diameter and fit. Design the post channel to avoid weakening the root or cause stress concentration in the post and cement lute.

11.3.5 Aesthetics

Generally, glass fibre posts are preferred as they are more aesthetic and do not have the drawback of “shine though” when used anteriorly with all-ceramic restorations. If black carbon fibre posts are used, it is often necessary to place an opaquing layer of flowable composite around the head of the post to prevent shine through.

To avoid shine through with metal post and cores, either an opaque ceramic restoration or ceramo-metal crown is needed. To reduce the risk of the crown margin or root being stained by corrosion products, a post casting alloy with high noble content is preferred.

Fig. 11.9 A cast post and core for an upper premolar showing how the gold alloy post is gently flared in the coronal aspect of the root providing sufficient bulk to resist fracture. This feature also provides an anti-rotation device without cutting a notch into the root surface. The retentive serrations of the preformed casting pattern can be seen in the apical aspect

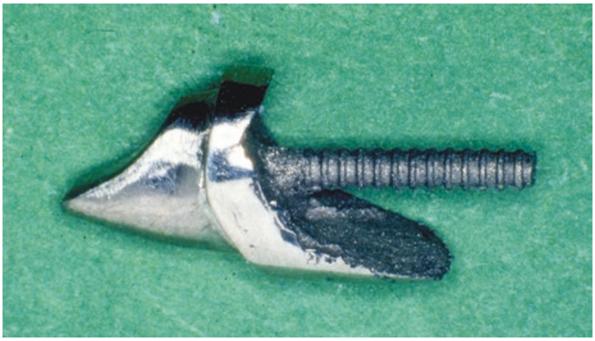

Fig. 11.10 A cast post and core incorporating a diaphragm on its buccal aspect. A diaphragm covering all or part of a root surface may occasionally help tip the balance for an otherwise unrestorable tooth

Aesthetic posts are also prefabricated from ceramics, but there are concerns about the reliability of zirconia resin-bonding to dentine and to composite core materials. Where a ceramic post needs to be retrieved from a tooth this can be particularly difficult [7, 52, 58].

11.3.6 Retrievability

A post may need to be removed to repeat a failed root treatment, but often the reason for removal is a post fracture occurring in the coronal third of the root. Table 11.1 outlines the relative difficulty and methods of retrieving the various types of post. Simply drilling the post out is time-consuming and hazardous, but if a ceramic post is chosen, that may be the only option. For the other types of post, there are effective proprietary post removal systems, but they carry a small risk of root fracture or perforation or both.

With cast metal posts which are properly extended and well fitting there is logic in conventional cementation. This avoids having to wrestle with a tenacious resin bond at a later stage. However, resin bonding is essential with a short metal post and with fibre or ceramic posts.

The reader is directed to Chap. 19 for a detailed discussion of the practical aspects of restoring root-treated teeth.

Table 11.1 Retrievability of posts

Post type	Method of removal	Relative difficulty
Cast or prefabricated metal	Ultrasonic vibration of post used for several minutes to disrupt the cement. If not dislodged, then the *Core* can be gripped and pulled by Eggler type post extractor. *Fractured post remnants* may be trephined, threaded and pulled by the Thomas™ or Ruddle™ post removal systems *Cylindrical post remnant*: Masserann kit™ used to trephine dentine around post	Time-consuming These techniques can remove cemented metal posts much more easily than resin-bonded posts. There may be a small risk of root fracture The Masserann kit removes dentine which can weaken a root and risk of perforation. Caution with ultrasonics not to overheat the tooth, copious water cooling is advised
Prefabricated metal (threaded)	Ultrasonic vibration and attempt to unscrew	Unscrewing may be easy, but if the post is firmly cemented, it may disrupt/fracture root
Fibre post	A small diamond bur creates a pilot hole in the fractured post remnant, the post's fibres are then broken up using a Peeso reamer [78]. Commercially available kits are also available	Once mastered, removing fibre posts is much easier than removing other types of post, but always carries risk of perforation if slightly offline
Ceramic post	Drilling out the resin-bonded ceramic post is often the only option. High strength ceramics, particularly zirconia, are notoriously difficult to grind, and the bur can easily slip off the post and damage surrounding dentine	Currently the most difficult to type of post to remove. With longer posts, there is an increasing risk of root perforation

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Occlusal Control

12

Pamela Yule, Jimmy Steele, and Robert Wassell

12.1 Learning Points

This chapter will emphasise the need to:

- Use occlusal terminology which is unambiguous to avoid misunderstandings with colleagues and technicians
- Examine the occlusion and screen patients for previous or existing temporomandibular disorders (see Chap. 8)
- Look for evidence of occlusal overload and determine if the patient bruxes either during the day, at night or both. Consider fitting an occlusal splint to protect your new restorations
- Distinguish between a conformative and a reorganised occlusion and confirm your choice with casts mounted on a semi-adjustable articulator. Plan occlusal and aesthetic changes and space creation using trial adjustments/diagnostic waxing
- Ensure your new restorations are in harmony with the patient's masticatory system
- Avoid overloading implant-retained restorations by establishing guidance on teeth where possible and ensuring a light intercuspal contact.

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Occlusal control is fundamental to providing restorations with a predictably good outcome. It is a process of avoiding any unwanted occlusal changes and their consequences, but if changes are needed, they must be carefully planned and carried out. Occlusal control all starts at the first appointment with an occlusal examination and screening for a history of temporomandibular disorders (TMDs). Some dentists like to make a detailed record of every aspect of this examination, but others prefer to make a note only of relevant findings which has the advantage of taking less time.

Where there are occlusal and aesthetic issues which merit closer inspection or if multiple restorations are planned, particularly at an increased occlusal vertical dimension (OVD), we recommend supplementing the clinical examination with casts mounted on a semi-adjustable articulator. This allows closer inspection, trial adjustments and any diagnostic waxing to be carried out. Essentially, this is a three-dimensional blue print which allows you to discuss proposed treatment with your patient (see Chaps. 17, 18, and 23). In addition, matrices can be made from the wax-up which are invaluable for gauging preparation reductions (see Chap. 20) and making provisional restorations (see Chap. 23).

12.2 Occlusal Examination Including Screening for TMDs and Bruxism

Begin the process by screening for signs and symptoms of TMDs (see Chap. 8). TMDs are not an issue for most restorative patients, but it is still important to identify those patients who require TMD management before embarking on restorative work.

The intra-oral examination should screen for signs of occlusal overload:

- Pain in and around teeth with heavy occlusal contact
- Wear facets
- Fracture or cracking of teeth or restorations (not associated with caries or trauma)
- Fremitus (vibration of a tooth during occlusal contact detected visually or by palpation)
- Mobility (not simply associated with underlying periodontal disease)
- Drifting (not simply associated with underlying periodontal disease).

Signs of occlusal overload should alert dentists to check for bruxism. Bruxism is a repetitive jaw-muscle activity characterised by tooth clenching or grinding and/or by bracing or thrusting of the mandible typically during sleep but also during wakefulness [1]. Bruxism is centrally mediated, and contrary to popular belief is not caused by occlusal interferences—although the occlusion may well be disrupted by the effects of bruxism [2]. Although many individuals clench and grind, bruxism only becomes a concern when occlusal overload causes symptoms or damage to the teeth, restorations, periodontium and musculoskeletal tissues.

In screening for bruxism, first ask patients if they are aware of tooth clenching or grinding whilst awake and second if they have been heard grinding whilst asleep.

A surrogate marker of sleep-related bruxism but not quite as reliable as the previous two questions is to ask, “Do you have discomfort in your teeth and jaws on waking?” However, it’s worth remembering that unexplained tooth pain is not always attributable to bruxism. If bruxism is identified, there may be restorative implications (see Box 12.1).

Then follows a detailed examination of the tooth contacts both visually and using good-quality ultra-thin (<20 μm) articulating foil held in Miller’s forceps and shimstock (<10 μm thick Mylar™ film) which is used as a feeler gauge to determine if a marked-up contact is tight or loose (Fig. 12.1). These observations allow contacts to be evaluated in the intercuspal position (IP), retruded contact position (RCP), excursive movements (lateral and protrusive) and any deflective contacts or interferences. Occlusal terminology can be confusing, so definitions and their relevance are explained in the next section.

Whilst carrying out the examination, it is always helpful to visualise the restorative options which may improve a patient’s dental condition and whether these might be achieved by largely *conforming* to the existing occlusion or whether a *reorganised* occlusion is required, e.g. when increasing vertical dimension for a patient with tooth surface loss (TSL) or with occlusally related problems. As mentioned in the introduction, this visualisation is improved using casts mounted in a semi-adjustable articulator (see Fig. 12.2). Dentists who are skilful in using semi-adjustable articulators will benefit by having a clearer diagnosis of a patient’s occlusion before starting treatment and benefit from a more predictable outcome when making multiple restorations (see Box 12.2). A centric relation record is recommended if a reorganised approach is anticipated, but the casts can be mounted in IP if a conformative approach is clear from the

Box 12.1: Bruxism and Restorations

Where bruxism is identified as a concern in a patient needing restorations, the role of occlusal management is to reduce or share occlusal loads, thereby limiting future damage. In patients with bruxism and tooth surface loss (see Chap. 13), restorative materials need to be carefully selected which are sufficiently robust not to be fractured, dislodged or wear away an opposing tooth [6]. In addition, the occlusion needs to be carefully designed when multiple restorations are provided. Teeth involved in guiding mandibular movement should be fit for being exposed to heavy, non-axial forces. Root-filled and post-retained crowns are not ideal in this respect. Neither are small teeth with full coverage crowns where the preparation may fracture, e.g. diminutive upper lateral incisors.

Following treatment, a full-coverage occlusal splint may be needed to protect teeth and restorations from protracted sleep-related bruxism. Of the many splint designs, a well-adjusted stabilisation splint is one of the most useful, particularly if patients grind rapidly through soft splints. This splint has already been described in Chap. 8 for the management of TMDs.

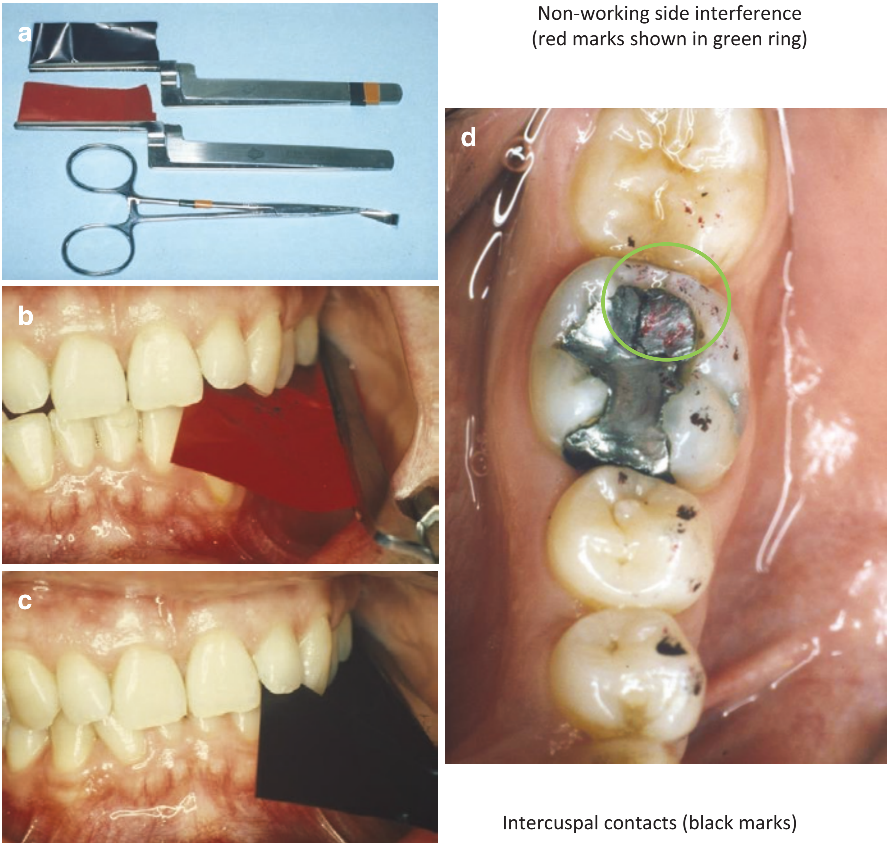

Fig. 12.1 Marking up the occlusion. (**a**) GHM articulating foil in Millers forceps and shimstock in forceps (used as a feeler gauge). (**b**) Red GHM marks excursions. (**c**) Then black GHM marks intercuspal contacts. (**d**) Defective amalgam with heavy non-working side interference causing stress-related defects. It would be unwise to reproduce this interference in a new restoration

outset. An understanding of how to capture a centric relation record can be gleaned from books [3]. Nevertheless, the techniques of jaw manipulation are best learnt practically—a worthwhile investment bearing in mind the fundamental importance of working to a reproducible jaw position which is comfortable for the patient.

An important clinical decision is how to make occlusal space for restorative material. In normal circumstances, this is simply done as part of the tooth preparation. In situations where there has been TSL or overeruption of teeth has occurred, it may be difficult to create sufficient space using tooth preparation alone. To avoid short, unretentive tooth preparations or preparations which are excessively destructive, other techniques of creating space are needed, and these are summarised in Table 12.1.

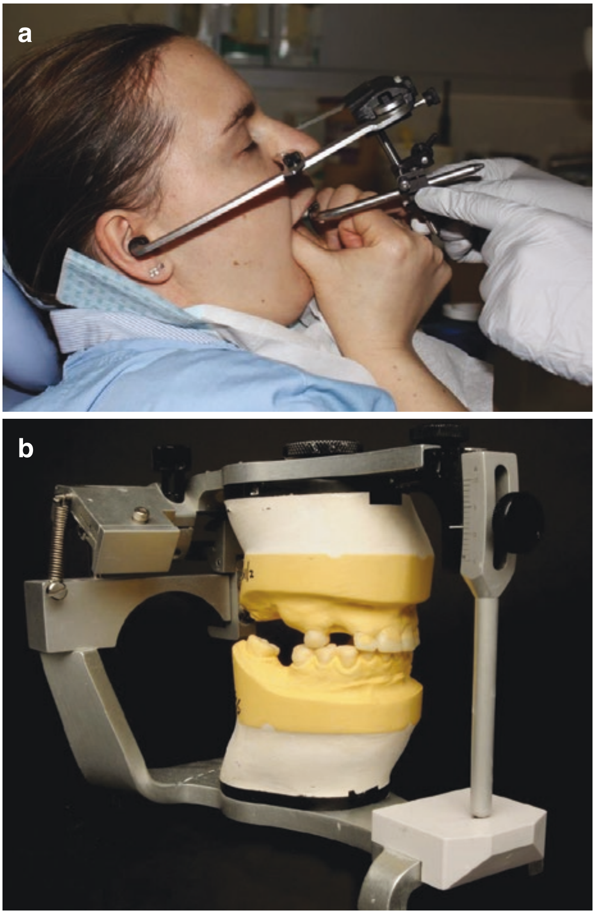

Fig. 12.2 Facebow transfer of the position of the upper arch in relation to the TMJs using an earbow (**a**). Casts can then be mounted in a similar spatial arrangement on a semi-adjustable articulator (**b**). This allows occlusal contacts to be better visualised and any occlusal changes planned e.g. with diagnostic waxing

It is also worth giving careful thought to the choice of material, particularly in bruxists. In using a ceramic occlusal surface, remember it can be very abrasive to the enamel of an opposing tooth. Composite or metal can be a kinder choice for guidance surfaces opposing natural teeth, but composite needs to be sufficiently thick (as a rule of thumb >1 mm) to avoid wearing away too quickly. For a more detailed discussion of occlusal management the reader is referred elsewhere [3].

Where one or more implant-retained restorations are being considered, bear in mind that implants do not have a periodontal ligament and do not have the same adaptive capacity and protective mechanisms as natural teeth. So, implant-retained restorations are potentially at greater risk from occlusal damage than natural teeth. Guidelines for occlusal management of crowns on single implants are given in Box 12.3. A more detailed discussion of occlusal planning for implant-retained restorations can be found elsewhere [3]. An outline of the various implant types and abutments is given in Chap. 16.

Box 12.2: When to Use a Semi-adjustable Articulator in Planning and Making New Restorations

- To ensure appropriate guidance with your new restorations, especially where multiple restorations are involved.
- If you plan to increase the vertical dimension.
- If you plan to reorganise the occlusion for other reasons (e.g. placement of multiple restorations involving removal of multiple existing occlusal contacts so IP will be lost).
- If you plan to remove occlusal interferences associated with occlusal disharmony (i.e. undertake an occlusal analysis and trial adjustment).
- When an occlusal stabilisation splint is required to either stabilise jaw position before treatment or after treatment to protect restorations from the effects of bruxism. NB. these splints can be made on average value articulators providing the occlusal record has been recorded at the intended occlusal vertical dimension prescribed for the splint.

Table 12.1 Techniques for creating space to allow restoration of teeth

Technique	Indications	Advantages	Disadvantages
Increase the vertical dimension	Generalised TSL necessitating longer clinical crowns for aesthetics and improved retention of restorations	No need for occlusal reduction so full axial wall length of preparation can be maintained	All teeth in one or both arches may need restored
Dahl (localised occlusal builds up to give dentoalveolar intrusion of built up and opposing teeth and extrusion of others)	– Localised TSL, e.g. to palatal surfaces of maxillary anterior teeth – Posterior teeth over-erupted into bounded saddle edentate space	– Not destructive to teeth – 2–3 mm space is obtainable	– Tooth movements can take several months – Sometimes teeth do not move
Enameloplasty	One tooth or small number of teeth requiring minor adjustment	Simple	– Sensitivity/ Discolouration from dentine exposure – Limited adjustment can be undertaken
Distalization of the mandible	Localised TSL of palatal surfaces of anterior maxillary teeth	– No (or little) anterior tooth reduction required – Can enable worn teeth to be restored without increasing vertical dimension	Limited to cases where large horizontal RCP-ICP slide exists

(continued)

Table 12.1 (continued)

Technique	Indications	Advantages	Disadvantages
Crown lengthening	– For localised and generalised TSL – Often used in combination with another technique	Increased retention gained by increasing axial wall height	Surgical procedure requiring bone removal if there is no preoperative periodontal pocketing. Loss of gingival papillae may result in black triangles in the gingival embrasures
Orthodontics	Occasionally can aid pre-restorative alignment of anterior teeth	Limits tooth destruction	Time consuming

Adapted from Wassell et al. 2015 [3]
TSL tooth surface loss

Box 12.3: Occlusal Considerations of Implant-Retained Crowns in a Partly Dentate Mouth

- Ensure sufficient space is available to accommodate the implant superstructure and the crown (screw-retained crowns generally need less space than cemented ones).
- Try to avoid non-axial loading, particularly if there is a tall implant superstructure and crown.
- Try to avoid building guidance surfaces on implant-retained crowns. Instead, consider building new guidance surfaces strategically on healthy natural teeth, e.g. using composite. If guidance on an implant-retained crown is unavoidable, ensure it is kept shallow.
- Keep occlusal contacts on implant-retained crowns lighter than between natural teeth. The recommended 30 μm clearance during clenching and excursions can be assessed using shimstock. An implant-retained crown should hold three layers of shim but allow two layers to pass with only light contact—An indication of the attention to detail needed when no periodontal ligament is present.
- Provide patients with sleep-related bruxism with an occlusal splint to protect their implant-retained crowns.
- A two-stage surgical procedure is preferred to allow an implant time to integrate before making an abutment connection and placing a provisional restoration. If using an “immediate” or “early loading” protocol, whereby the provisional restoration is placed at the same time as the implant fixture, be aware this carries a risk of occlusal overload unless the provisional is kept out of contact or multiple implants are linked together.

12.3 Occlusal Terminology

The definitions below are derived from the *Glossary of Prosthodontic Terms* [4] with some explanation of their restorative relevance.

12.3.1 Intercuspal Position (IP or ICP)

Synonyms: centric occlusion or maximum intercuspation.

IP is the comfortable, reproducible position that most dentate patients close into if you ask them to "bite together on their back teeth". This position is where the maximum number of tooth contacts occur and is the most "closed" position of the jaws. The shape of the teeth and neuromuscular co-ordination guide a patient into this position. Physiologically, it is the endpoint of each chewing cycle where the patient exerts maximum force and is the position used to brace the jaw during swallowing. In IP the teeth are most likely axially loaded. This is ideal for the periodontal ligament with its tissue architecture designed to bear vertical occlusal forces most effectively. Importantly from the perspective of the dentist, IP is the position in which most restorations are made in everyday practice.

IP contacts in restorations should provide stability to prevent unwanted occlusal changes (e.g. tilting or overeruption). This can be achieved by ensuring the cusps of restored posterior teeth occlude either against opposing cusp slopes or against opposing fossae. The IP contacts of anterior teeth are often lighter than those on posterior teeth, and this should be replicated in restorations. The cingulum areas on restorations for upper anterior teeth may be enhanced to provide an occlusal table to provide additional stability and function in selected cases.

Occlusal vertical dimension (OVD) is the distance measured between two fixed points with the teeth in IP. However, individuals who are not bruxists have their teeth in contact for less than 20 minutes each day—a fact worth reminding patients with awake-related clenching and grinding habits. In a relaxed individual sitting upright, the teeth are separated by 2–4 mm, and the gap is termed the "freeway space" (FWS). However, FWS is subject to considerable variability, and in some individuals, it may sometimes be as high as 7 mm [5]. Some dentists use FWS to assess loss of OVD due to TSL, but as discussed in Chap. 13, it is not particularly reliable.

12.3.2 Centric Relation (CR)

Synonyms: retruded axis position and terminal hinge position.

Over the years, CR has been defined variously [4], but essentially CR describes the position of musculoskeletal stability provided by healthy TMJs when the condyles are in their most superior position within the glenoid fossae with the discs correctly interposed. The two synonyms, "retruded axis" and "terminal hinge", relate to the mandible in this position being able to open and close in a pure arc of rotation to an interincisal opening of 20–25 mm. CR is relevant to restorative dentists as it provides an alternative position for restoring a patient's occlusion when IP is no longer satisfactory (e.g. when increasing OVD in a case of TSL). Also, where patients have occlusally related problems, dentists may wish to examine the tooth contacts in CR to determine whether deflective contacts between CR and IP are contributing to the problems (see deflective contact below).

12.3.3 Retruded Contact Position (RCP)

Synonyms: centric relation contact position.

RCP is the position of the mandible when first contact occurs between opposing teeth on closing in CR. The mandible then slides from this usually unstable RCP position up into IP (Fig. 12.3). When viewed at the lower incisors, the slide almost

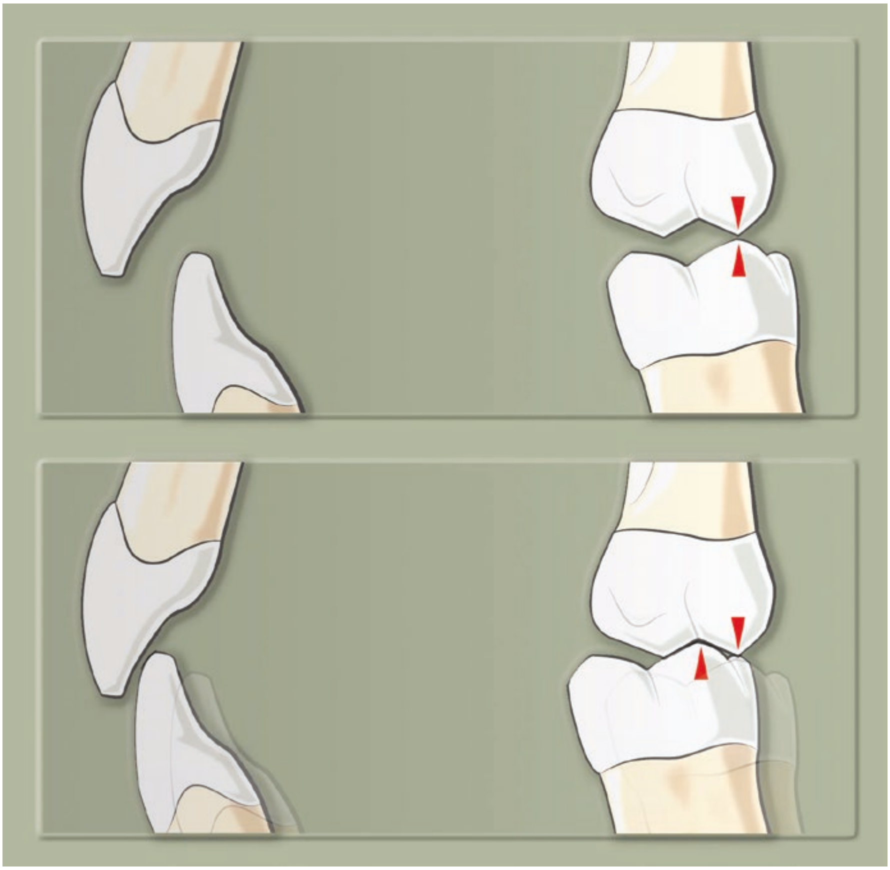

Fig. 12.3 The slide from RCP (above) to the IP (below). Not an issue for most individuals but in some patients may become a damaging deflective contact. Tooth-related damage may occur on the RCP contact (red arrow heads) or on anterior teeth at the end of the slide (anterior thrust)

Box 12.4: RCP and New Restorations: Situations When RCP Is Important

- *If RCP involves a tooth you are about to prepare*, it is best to remove the deflective contact at a separate appointment before preparing the tooth. This is because it is extremely difficult to reintroduce the same contact in the restoration, and patients generally find it easier to adapt to a new deflective contact between other opposing teeth than an arbitrary deflective contact on a new restoration.
- I*f reorganising the occlusion at a new vertical dimension*, the new occlusion should be reorganised at RCP (or around RCP) as CR is the most reproducible position in the absence of a satisfactory IP.
- *If space is needed to incorporate new anterior restorations*, then using an existing RCP-IP slide to "distalise" the mandible may negate the need to change the vertical dimension. However, this is only possible if the slide has a significant horizontal component allowing the mandible to distalise following adjustment of the deflective contacts on the posterior teeth.
- *If anterior teeth to be prepared are affected by a strong anterior thrust* resulting from the RCP-IP slide, the effect of the thrust on the anterior teeth may be detected clinically as fremitus.

always has vertical component, sometimes a horizontal component and occasionally a lateral component. In about 10% of the population, RCP will be the same as IP (i.e. if you hinge the mandible in CR until the teeth are in contact, they will go straight into IP with no deflective contact).

Most crowns and other extra-coronal restorations will be made to conform to the patient's IP, but knowing preoperatively where RCP is and whether there is an RCP-IP slide can be useful when providing new restorations. Specific situations, where adjusting the RCP contact may help with improving the predictability of the restorative procedure, are described in Box 12.4.

The RCP-IP slide may act either like a harmonious guidance contact or a damaging deflective contact. These terms are defined below.

12.3.4 Guidance from the Teeth

"Guidance teeth" are the contacting teeth which provide harmonious guidance to the mandible when the patient moves their jaw to and from IP. Movements may be side to side (lateral excursions) or backwards (retrusion) and forwards (protrusion). This effect of the teeth on mandibular movement is sometimes called "anterior guidance", although the term is a little misleading as guidance is often provided by posterior as well as anterior teeth.

Mandibular movement is also guided by the anatomical shape and function of the temporomandibular joints (sometimes called “posterior guidance”).

When a patient makes a lateral excursion, the side they move the mandible towards is termed the “working side”, and the other side the “non-working side”. So, in right lateral excursion, the right side is the working side, and in left lateral excursion, the left side becomes the working side. Canine guidance is said to exist when the upper and lower canines on the working side are the only teeth in contact during a lateral excursion. When two or more pairs of teeth on the working side are in contact during a lateral excursion, then the patient is said to show group function. The term “disclusion” is used to describe teeth being lifted out of contact by the guidance teeth.

During excursions guidance teeth are repeatedly loaded non-axially. Heavily restored teeth, including those with crowns or posts, may be at risk of fracture if heavily loaded. Prior to providing new restorations, it is therefore best to identify the guidance teeth and decide whether the teeth currently providing guidance can still be used for this purpose following restoration (usually the case) or whether a planned change in the guidance teeth is needed. If a tooth to be restored is thought insufficiently strong in the long term to withstand non-axial forces associated with anterior guidance (e.g. if a post-retained crown is used), it may be best to ensure the new restoration is adjusted so that guidance is shared with, or transferred to, other more suitable teeth.

If a patient has a satisfactory anterior guidance, it is a good practice to copy the guidance features (i.e. the shape of the lingual surfaces of the upper teeth) into the new restorations. Various techniques are available (e.g. custom incisal guide table or “every other tooth technique”) which are detailed elsewhere [3]. If the guidance is unsatisfactory, as may occur in TSL, a harmonious guidance can be developed in provisional restorations and then copied into the definitive restorations.

Where guidance is not carefully controlled, the resulting deflective contacts and interferences may combine with the effects of bruxism and neuromuscular dysfunction to cause problems such as pain, fractured teeth or restorations, accelerated localised TSL, tooth migration/mobility or TMD symptoms.

12.3.5 Interferences and Deflective Contacts

Interferences are tooth contacts which prevent smooth mandibular movement in excursions.

Deflective contacts are contacts which deflect the mandible from one path of closure into another (e.g. from RCP into IP).

There can be huge variation between individuals in the size and number of interferences or deflective contacts and the impact these may have. Some patients may be asymptomatic and unaware of an inharmonious contact, while others experience pain in or around the tooth or teeth concerned. Alternatively, a deflective contact may throw the mandible forwards resulting in an “anterior thrust” of the lower incisors against the upper incisors (see Box 12.3 and Fig. 12.3).

Conclusion

To manage future risk of biomechanical failure, restorations should function in harmony with a patient’s masticatory system and provide stable occlusal contacts and freedom from interferences, particularly on teeth providing guidance to jaw movement. A history of TMDs or damaging levels of bruxism should be identified and managed in conjunction with planning restorative treatment. An occlusal examination supplemented with casts mounted on a semi-adjustable articulator is indispensable to making an occlusal diagnosis and planning occlusal and aesthetic changes.

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Managing Tooth Surface Loss

13

James Field, Jimmy Steele, and Robert Wassell

13.1 Learning Points

This chapter will emphasise the need to:

- Be aware that most patients diagnosed with tooth surface loss (TSL) do not need to be restored, at least in the short term, but need to be advised how best to control causative factors (e.g. extrinsic erosion, intrinsic erosion, and bruxism)
- Liaise with the patient's doctor to manage intrinsic erosion, e.g. gastro-oesophageal reflux disease (GORD) or bulimia. The patient must accept the risk of early failure if restorations are provided before the medical condition is controlled
- Record baseline study models to monitor TSL longitudinally
- Implement restorative treatment where there are major aesthetic concerns and uncontrolled dentine sensitivity or where further TSL would compromise restorability
- Consider restoring anterior teeth using composite. A large composite can later have its buccal surface covered with a ceramic veneer (sandwich technique)

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- Be realistic about restoring posterior teeth and choose an appropriate material to cope with higher occlusal forces, particularly in bruxists. If teeth are to be crowned, patients need to be aware of the risk of pulp damage and its consequences
- Plan reconstructions according to whether TSL is localised or generalised. Generalised wear is more difficult; space is created by increasing the occlusal vertical dimension.

This chapter aims to consider ways of protecting patients from the risks of further tooth surface loss and where rehabilitation is indicated minimising risks of restoration failure. From the outset, it is worth emphasising comparatively few patients with signs of tooth surface loss (TSL) need restoring. As discussed in Chap. 6, the patient's history and the findings of the clinical examination will determine whether a patient simply needs counselling (e.g. to control extrinsic erosive factors) or where there is concern over the amount or rate of TSL a period of monitoring may also be advised before reassessing the need for restoration.

13.2 Monitoring

The purpose of monitoring to determine if the wear is progressing or if symptoms need to be addressed (e.g. application of dentine desensitisation agents). Only occasionally are issues so severe that rehabilitation needs to be implemented urgently.

Many patients are unaware of TSL until told by their dentist; others may have noticed signs and symptoms, but their main concern is these do not get worse. On the other hand, patients with significant aesthetic and sensitivity problems may be keen to embark on treatment but have not addressed the underlying cause. Particularly with erosion of intrinsic origin, perhaps due to suspected gastro-oesophageal reflux disease (GORD) or an eating disorder, a referral for medical investigation and management is advisable. Depending on the services available, a gastroenterologist may arrange for pH monitoring of possible reflux, while psychological management may be required for patients with eating disorders [1]. In the UK, such referrals are best arranged with patients' consent in collaboration with their general medical practitioner.

Baseline records should be recorded; study casts and clinical photographs are the simplest way of making a visual comparison at future reviews which may be scheduled in a few months or a year depending on the severity of TSL and symptoms. To avoid cluttered store rooms, we give patients baseline casts marked with name and date for safe keeping, along with a written explanation to bring them to future review appointments. The purpose of review is to:

- Check compliance with preventative advice
- Check on progress with any medical referral
- Estimate the rate of TSL from appearance of teeth and casts; recognising TSL may not be obvious on casts during early reviews
- Advise on symptomatic treatment
- Discuss treatment options if treatment is indicated.

At an early stage, patients appreciate having an outline treatment plan so they understand what would be involved and their commitment should treatment be recommended.

Clearly, there would be little argument against restoring worn teeth that were symptomatic or if the aesthetics were having a significant effect on a patient's quality of life. Further, many clinicians would *want* to restore teeth with severe TSL, not least to protect the remaining tooth tissue from future loss which may make restoration more difficult. Ideally, the underlying cause should be controlled, but particularly with GORD and bulimia, restorative work sometimes needs to start with medical management in progress. Where erosion continues, there is always a risk of rapid restoration failure, and patients need to understand this when consenting to treatment. Composites are often chosen to cover exposed dentine, but as discussed below some composites may perform better in an erosive environment than others.

13.3 Rehabilitation

Once a decision is made to provide treatment, restorability needs to be assessed on a tooth-by-tooth basis—in much the same way as for a tooth about to undergo root treatment, or teeth severely affected by caries or trauma. This is quite a complex decision-making process and will often be based on a dentist's knowledge, skill, and experience, although there are two published systems which give some guidance [2, 3]. Periapical radiographs are invaluable to assess a pulp's proximity to a worn occlusal surface and to determine if there is sufficient root length when planning crown lengthening. This is in addition to the usual radiographic assessment of bone height and periapical pathology.

Always consider how successful a restoration would be, both in terms of retention and structural durability within a potentially erosive environment or one affected by bruxism. Typically, worn teeth present with little in the way of retention or resistance form, and so there is often a heavy reliance on resin-bonding techniques. Undoubtedly, a resin bond to enamel is superior to that of dentine—however as operators we must ensure that we are *thinking* about the types of tissue present and the ways in which we want to resin bond to it, including adjuncts to bond onto existing but sound restorations, e.g. airborne-particle abrasion and silication followed by silane coupling agents. This is discussed further in Chapter 15.

Another important issue when building up teeth in composite or any restorative material is the occlusion and particularly anterior guidance. Guidance surfaces are often on the upper anterior teeth and need to be carefully developed to provide harmonious jaw movement without interferences (see Chap. 12). If both the upper and lower anterior teeth need to be built up, we advise building the lower teeth first. This establishes the desired occlusal plane on the lower teeth, and then the upper guidance surfaces are developed against them.

Dentists have long used composites to 'patch-up' TSL or more formally as direct or indirect restorations (sometimes in combination with ceramic veneers—see following section), particularly for anterior teeth. Patch-ups often perform poorly on cupped occlusal surfaces. This may be because configuration of the concave cavity allows the setting and shrinking composite to pull away relatively easily from the peripheral enamel. Here, the bond to the sides of enamel prisms is much weaker than the bond to their ends. Another reason is the thin section of the restoration which inevitably occurs after the occlusion is adjusted to conform to the intercuspal position (IP). Clinically, composite performs better when it is built up in sufficient thickness (>1 mm) and where it can be wrapped buccally and lingually over the occlusal surface. In this way, setting shrinkage tends to pull the composite onto the tooth rather than off it. To obtain sufficient composite thickness may require increasing the occlusal vertical dimension (OVD), and this is discussed later.

The performance of composite to restore posterior teeth affected by TSL is less certain. On the one hand, a short-term study has shown reasonable results [4], but another study has shown very poor performance [5]. This may reflect not only the properties of the composite and type of TSL but also the skill of the operator [6].

Surprisingly, not all composites appear to react well to hydrochloric acid exposure. This caustic chemical intermittently corrodes teeth in patients with gastric reflux or eating disorders. Some composites and resin lutes may undergo softening and roughening within an acidic environment [7, 8]; however, these are laboratory studies, exposing materials to relatively harsh conditions for extended periods. The practical benefits of being able to place composites quickly and easily may prove to be the overriding factor for many, but it would be useful to have clear guidance from our materials scientists on which composites are most fit to survive in erosive and occlusally stressed environments.

As discussed in Chapter 2, there is evidence to show adhesively retained onlays made from alloys, ceramics, and composites perform well clinically. However, there is very little specific information regarding onlay performance in TSL patients, but it would be safe to assume continued exposure to acidic attack would do nothing to improve it. Clinically, metal occlusal surfaces exposed to heavy bruxism may occasionally become decemented, but they do not crack or fracture like ceramic or composite and can be used in thinner section (see Fig. 13.1). It is worth noting that current NHS dental charging regulations do not allow onlays providing some cuspal coverage to be made from anything less than 60% fine gold. However, *full-coverage* restorations can from either gold or base metal alloys [9].

While recognising that adhesively retained restorations are conservative of tooth structure and perform well in many TSL patients, there are times when repeated restoration failure and replacement prove frustrating (e.g. of anterior or posterior composites). In these circumstances, Bartlett [6, 10] advises full-coverage crown placement, accepting there may be endodontic consequences, and patients should be made aware of these in consenting to treatment [11].

Ceramo-metal crowns are still an important means of restoring bruxists (see Chaps. 2 and 14). To reduce the risk of ceramic fracture, metal copings should be designed so intercuspal contacts don't fall on a ceramo-metal junction. Empirically, occlusal contacts should either be on metal or ceramic, ideally at least 1.5–2.0 mm from the ceramo-metal junction. A mistake made by some technicians is to extend a metal palatal surface fully to the incisal edge of anterior crowns. The intention is to strengthen

Fig. 13.1 Onlays providing full occlusal coverage can restore posterior teeth of bruxists more conservatively than crowns. Onlays made of gold alloy or CoCrW offer good protection against tooth fracture. MOD onlays (bottom right) used to replace defective amalgams and provide cuspal coverage

the incisal ceramic, but sadly it weakens it making it vulnerable to chipping (Fig. 13.2). Instead, the ceramic should be wrapped sufficiently over the incisal and occlusal surfaces (Fig. 13.3) taking care to keep the intercuspal contact away from the ceramo-metal junction. Remember, the benefit of having a metal occlusal surface is that it is less abrasive to the opposing tooth [12] than most ceramics. In addition, because it is thinner, it requires less tooth reduction. It is also easier to polish after adjustment.

Where there is sufficient space interocclusally (e.g. in class III incisor relationship) to accommodate both metal and ceramic, the ceramo-metal junction can be made close to the lingual margin and the whole occlusal surface covered in ceramic (Fig. 13.4).

Fig. 13.2 The metal backings of the copings at 12 and 22 have been extended too close to the incisal edge resulting in ceramic chipping. Before providing new crowns test the shape with provisional restorations to check occlusion and aesthetics

The ceramo-metal junction should be kept well clear of a proximal contact. It will act as a floss shredder if a technician has inadvertently placed it there. Another disadvantage is that if a proximal contact is deficient, it will be difficult to add to. By contrast a metal proximal contact can be built up in solder, while a ceramic contact can have further ceramic fired to it giving a much better result.

Next, we consider other aspects of risk management in relation to the treatment of localised and generalised TSL.

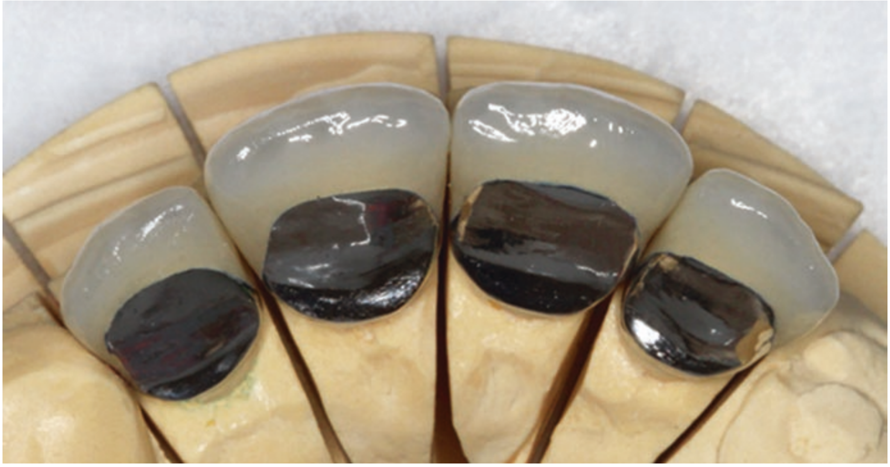

Fig. 13.3 Well-designed metal backs with small palatal shelves for occlusal stability in the intercuspal position—the patient had a deep overbite

Fig. 13.4 Full ceramic coverage on the lingual aspect. The patient had a class III incisor relationship which gave sufficient interocclusal clearance for metal and ceramic

13.3.1 Localised TSL

Erosion frequently causes localised TSL of the anterior teeth. In some patients, the TSL may leave interocclusal space allowing teeth to be restored easily, but in others the dentoalveolar complex extrudes apparently compensating for the TSL with further "eruption" which maintains occlusal contact. This makes conventional restoration of the anterior teeth destructively difficult. Traditionally, it involved elective root treatment, post and cores, and crowns. Sadly, multiple post and core restorations placed in mouths of bruxists may have catastrophic clinical performance [13].

Alternatively, the vertical dimension was increased via full arch restorations of one or both arches—often a massive undertaking, particularly if only the anterior teeth have TSL.

Nowadays, the dental profession and patients with localised TSL are fortunate in being able to benefit from the "Dahl effect" to produce interincisal space [14–17]. The Dahl effect works through a combination of dentoalveolar intrusion of the built-up teeth and dentoalveolar extrusion of the teeth taken out of contact. During the 1970s and 1980s, this orthodontic movement was made by means of a removable appliance with an anterior bite raising platform. Because patients did not always comply with full-time appliance wear, an alternative approach evolved for composite to be bonded to the teeth requiring restoration. This build-up increases the occlusal vertical OVD 2–4 mm—usually on the anterior teeth, leaving the other teeth to erupt back into contact over a period of 3–6 months, but sometimes longer.

Apart from active periodontal or periapical disease, there are no absolute contra-indications to using the Dahl approach. However, in the same way as for any orthodontic tooth movement, caution is urged in several situations (see Table 13.1). If advised in advance what to expect, patients cope well with the build-ups, and any mild discomfort from the teeth generally dissipates within 2 weeks. There may also be a tendency to lisp and mild difficulty with fine chewing. The teeth don't move in less than 6% of cases, but it is still wise to have an alternative treatment plan should this become an issue [14].

The composite build-ups used as a Dahl appliance can provide useful medium-term restorations. A 10-year study of 283 of these composites in 28 patients reported a median survival time of 5.8 years and 4.75 years for replacement restorations. Failure was because of wear, fracture, and marginal discoloration [18]. Clinically if there are repeated problems with composites failing, a useful strategy is to consider replacing them with more robust indirect restorations. The composite will at least have given a guide to the occlusal shape required for the definitive restoration.

Over the past 10 years, various hybrid approaches have evolved for building Dahl-type restorations on anterior teeth. These involve a combination of directly placed composite with an indirectly placed veneer. For example, an indirect composite veneer may be bonded to the lingual surface of the tooth providing a palatal occlusal stop and guidance surface; then an aesthetic buccal veneer is applied with directly placed composite. In the "sandwich technique", the lingual surface is built with composite, either directly or indirectly, and at a later stage, a ceramic buccal veneer is bonded to the composite and what remains of the buccal tooth tissue. This approach is used in conjunction with the Anterior Clinical Erosion (ACE) classification system [19]. ACE defines the appropriateness of using the sandwich technique per the degree of tooth surface loss (see Table 13.2). However, the system assumes that loss of pulpal vitality only occurs when almost all the tooth has been eroded (ACE score 6) which may not always be the case.

In a clinical study of the sandwich technique, each of 12 patients had up to 6 anterior teeth restored as part of a subsequent full-mouth reconstruction using adhesive restorations. Eight patients had some buccal enamel remaining, while the four others had little or no buccal enamel. They were followed up for a mean of 4 years

Table 13.1 Dahl appliance—possible issues and related advice

Possible issues	Advice
Root-treated teeth [29]	
Inflammatory or replacement resorption *but* **Not an issue** when teeth satisfactorily root treated and restored	**Avoid Dahl appliance** where: • Root treatment inadequate • Apical periodontitis not resolving • Teeth already with signs of resorption—particularly if previously severely traumatised (e.g. subluxation)
Periodontally involved teeth [30]	
Bone loss may be worsened if disease still active	**Control periodontal disease** before fitting Dahl appliance
Splaying of anterior teeth	Ensure teeth are axially loaded when periodontal support is reduced
Root resorption in patients with a deep overbite and marginal bone loss	Orthodontic intrusion may cause 1–3 mm of root resorption in these patients. No evidence of resorption with Dahl appliance—proceed with caution
Occlusal issues	
Class III edge to edge incisor relationship and composite fracture	Class III incisor relationships are not a contraindication per se to using a composite Dahl appliance, but if such patients habitually exert high occlusal forces on their anterior teeth, a thin layer of composite may well fracture [31]
Occlusal instability, e.g. associated with gross mandibular asymmetry and prognathism [31]	Patients with unstable occlusal contacts need to be treatment planned carefully. Firstly, to provide sufficient occlusal contact to allow a Dahl appliance a chance to work. Secondly, to provide sufficient occlusal stability in the final restorations
A large horizontal slide between centric relation and intercuspal position (IP)	Theoretically, patients with a large horizontal slide may risk losing the ability to function comfortably in the more anterior position after the disturbance to IP from a Dahl appliance [32]
Recently completed orthodontic treatment [14]	Again, a theoretical concern but best to liaise with a patient's orthodontist if localised axial tooth movement is required for restorations
Lack of eruptive potential [14]	
Poor response to treatment	Teeth with bony ankyloses and dental implants will not be affected by a Dahl appliance—but surrounding teeth will—making it difficult to predict the outcome Patients with anterior open bite may not respond well to a posterior Dahl appliance
Temporomandibular Disorders TMD	
Clinically, symptoms may be made worse in some TMD patients—but improved in others	TMD is not a contraindication to a Dahl appliance, but patients with a history of TMD are best referred to a dentist with recognised experienced both in managing TMD and the worn dentition

(continued)

Table 13.1 (continued)

Possible issues	Advice
Oral or IV bisphosphonates (BP) [33, 34]	
BPs inhibit osteoclastic activity and may prolong any form of orthodontic treatment Ulceration caused by an appliance theoretically may lead to Medication Related Osteo Necrosis of the Jaws (MRONJ). Therefore, avoid a removeable Dahl appliance	Low dose bisphosphonates are not a contraindication to orthodontic or restorative treatment which have a low risk of causing MRONJ. For most patients, there is no evidence that a Dahl appliance causes excessive or heavy occlusal forces [32]. If a patient is under BP treatment or has a history of BP: • BP patients consenting to Dahl treatment must be advised of low risk of MRONJ • Tooth movements may be prolonged or not work and alternative methods of space creation may be needed • Contact the patient's doctor before Dahl treatment to explain dental procedure, the low level of risk, and check ongoing medication Patients on high dose or IV bisphosphonates often have significant underlying medical conditions and would rarely be considered for a Dahl appliance

Table 13.2 The Anterior Clinical Erosion (ACE) classification with suggested treatment strategies

ACE classification	Clinical features	Treatment
Class I	Thinning of palatal enamel	No restorative treatment
Class II	Dentine exposure on the palatal aspect (contact areas), no damage to incisal edges	Direct or indirect palatal composites
Class III	Dentine exposure on the palatal aspect, loss of tooth length (<2 mm)	Palatal veneers rebuilding the incisal edge
Class IV	Extended dentine exposure on the palatal aspect, loss of tooth length (>2 mm), preserved facial enamel	Sandwich technique (see text for explanation)
Class V	Extended dentine exposure on the palatal aspect, loss of tooth length (>2 mm), loss of facial enamel	Sandwich technique (experimental)
Class VI	Advanced loss of tooth structure leading to pulp necrosis	Sandwich technique (highly experimental)

and 2 months. Only one partial failure was reported (a crack in the ceramic veneer), and six veneers showed marginal staining [1]. These are promising results but need independent corroboration to determine how much relies on the expertise of the clinicians and how well the technique works when used as a Dahl appliance. In addition, the influence of a lack of buccal enamel needs to be determined in a larger group of patients over a longer time span.

When bonding only to a dentine root face, many dentists would not be optimistic of their restorations surviving. If surgical crown lengthening is planned to expose more enamel, the possibility of causing unsightly "black triangles" between the teeth and possibly unfavourable crown to root ratios should be born in mind [20]. Onlay dentures or implants or complete dentures may need to be considered instead.

In a small number of patients, the space for anterior restorations may be created by "distalization". As mentioned in Chap. 12, distalization is a process of occlusal adjustment allowing the mandible to drop back distally by the removal of deflective contacts on posterior teeth. It is only effective in patients with a large horizontal component of slide between retruded contact position (RCP) and IP. Where distalization is possible, it not only creates space without increasing OVD but also helps eliminate any anterior thrust of the mandible associated with the RCP to IP slide. A persistent anterior thrust may cause damaging occlusal forces at the end of the RCP-IP slide when the lower incisors impact against the lingual surfaces of the restored upper incisors.

In the following section, we consider methods of managing future risk when restoring patients with generalised TSL.

13.3.2 Generalised TSL

With generalised TSL, many, if not all, of the teeth are affected. Consequently, an increase in OVD is needed in combination with the restoration of either one or both arches. This makes restoration rather more complex but with some careful thought and planning should not be beyond most competent dentists. When first embarking on these more extensive cases, the best option is to have a mentor as a guide. However, textbooks should also be consulted [17] for a more detailed explanation of the various stages.

For the planning stage, carefully articulated study models are essential and should be mounted in centric relation (CR)—see Chap. 12. Recording CR in some patients is relatively straightforward, but in others it can be difficult because the patient postures into an incorrect position. Various means of neuromuscular deprogramming (e.g. Lucia Jig, occlusal leaf gauge, stabilisation splint) can be used to help coax the mandible into the correct position before taking the jaw record in wax or silicone mousse.

Diagnostic alterations of the OVD can be made on a semi-adjustable articulator if a face-bow transfer has been used. As a rule of thumb, OVD is increased to ensure adequate aesthetics anteriorly and sufficient interocclusal space posteriorly. Measurements of OVD and freeway space (FWS) may provide a clue as to whether there is clearly space available for restorations or not, but attempting to make any more detailed analysis [21] is not particularly helpful. This is because FWS measurements in some patients are notoriously variable [22] and FWS generally re-establishes quickly after an OVD increase with only transient, if any, short-term discomfort [23, 24]. If in doubt whether a patient will tolerate an increase in OVD, this can be trialled with a stabilisation splint (see below).

Increasing the OVD may obviate the need for any occlusal reduction which is helpful because with generalised TSL, the teeth are often short, and further tooth reduction may compromise restoration retention as well as the pulp. Sometimes, despite an increase in OVD, there is insufficient tooth length, and crown lengthening surgery (described in Chap. 10) may be planned to improve the resistance and retention form [25]. The gingival margins can be adjusted on the mounted casts and a diagnostic wax-up undertaken to plan the shape and occlusion of the proposed restorations.

There are several occlusal schemes [17], and dentists need to have a clear idea of the pattern of occlusal and excursive contact which will be developed in the final restorations. Where the occlusion is being reorganised for a bruxist, it is worth planning restorations that create almost immediate disclusion of the posterior teeth from ICP both in protrusion and lateral excursions. Ideally, the incisors provide protrusive guidance, and the canines provide lateral guidance. This classical approach of "mutual protection"—where the anterior teeth provide guidance and posterior disclusion while the posterior teeth provide support in ICP—is still considered by many to be important [26]. Nevertheless, it may be necessary to use other guidance teeth where the incisors or canines are absent or for any reason unsuitable.

When undertaking a full-arch restoration at an increased OVD, it is best to avoid building up *some* teeth and leaving others out of occlusion for more than just a few days; otherwise unwanted tooth movements can easily occur, causing an inconvenient loss of interocclusal space. In these situations, an acrylic stabilisation splint may be used to stabilise the entire arch at the intended OVD while restoration takes place. Alternatively, it is becoming increasingly acceptable to build up the anterior teeth to the required vertical dimension (e.g. with composite or provisional restorations), and then place glass ionomer or composite "stops" onto the occlusal surfaces of the separated posterior teeth as a temporary measure. This strategy helps ensure that teeth do not overerupt before they have been definitively restored. There is merit in this approach, which may also serve to "temporise" teeth with exposed dentine that are causing sensitivity.

In bruxists (see Chap. 12), it is worth ensuring your restorations do not cause occlusal instability through differential wear. Differential wear occurs when materials of differing wear resistance oppose one another, and often the softer material is worn away more quickly. It is generally thought that similar opposing materials, and tooth tissue against metals (particularly gold alloys), is acceptable. A laboratory study by Jacobi and Shillingburg in the 1990s [12] demonstrated how destructive ceramic can be to enamel. In contrast, they also showed how sympathetic gold alloys can be, demonstrating 40 times less wear to enamel than ceramic, but as discussed in Chapter 14, polished zirconia, unlike other hard ceramic materials, is not particularly abrasive.

13.3.2.1 Splint Therapy

A rigid stabilisation splint can help to encourage the patient into a more retruded arc of closure and test an increase in OVD where limited space appears available. However, it must be designed with specific features to facilitate relaxation of the muscles of mastication (see Chap. 8) [27]. Splints can also help to guard against TSL primarily due to bruxist or parafunctional habits—but care must be taken to ensure that a splint does not act as a reservoir for erosive components—either intrinsic (regurgitated stomach acid) or extrinsic (acidic drinks). Finally, a rigid splint can be very useful for pre-restorative stabilisation, management of TMD, or to ensure stability *during* rehabilitation.

We do not recommend partial coverage splints as bruxism guards; a partial coverage splint acting as a Dahl appliance over long periods may produce unwanted tooth movement [28].

Conclusion

Many patients with TSL can be managed simply by controlling the causative factors and monitoring, but inevitably some patients will need to be restored. Restoration of TSL can be demanding particularly where there are high occlusal forces associated with bruxism. Adhesive dentistry is often a good option but needs to be carried out meticulously and in harmony with the occlusion. Crowning requires further tooth destruction and can cause pulpal problems but may be needed, particularly where composite restorations fail.

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Part IV

Materials and Aesthetics

14 Material Choice

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14.1 Learning Points

This chapter will emphasise the need to:

- Be aware of the capabilities of modern CAD/CAM technology for making extra-coronal restorations from all types of materials
- Choose alloys carefully when prescribing metallic restorations (e.g. for bruxists) to reduce problems with biocompatibility and corrosion
- Check your laboratory heat treat cast posts and cores made from gold alloy to ensure optimum stiffness
- Choose reputable high strength ceramics which can be etched for optimum resin bonding
- Cut retentive preparations for zirconia restorations to ensure retention
- Prescribe direct and indirect composite restorations which are fit for the intended purpose.

This is the first chapter in the part "Materials and Aesthetics". It includes materials for making extra-coronal restorations, luting agents, implant abutments and aesthetics. All these areas have had major developments, and, like a rich fruit cake, each chapter is best consumed in manageable slices.

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The range of materials and manufacturing techniques facing dentists is bewildering. So, let's start simply and put them under three broad headings: metallic (all-metal and ceramo-metal), ceramic and resin composite. Critical to the success of any luted restoration are cements and cementation [1]. Both conventional and adhesive materials are considered in the next Chap. 15, while cementation techniques are covered in Chap. 24.

Over the past two decades, there have been considerable advances particularly for ceramics, but of importance to the production of all types of restoration is the coming of age of computer-aided design/computer-aided machining (CAD/CAM) technology.

Ceramics are now better and stronger, but despite their aesthetic appeal, there is still an important place for conservative all-metal and ceramo-metal restorations, particularly when restoring bruxists. Indeed, the ceramo-metal crown is still the "gold standard" against which the durability of all-ceramic restorations is measured [2].

Each material has its advantages and limitations, but ultimately it is the clinician's responsibility to guide the patient and laboratory as to which material should be used. The aim of this chapter is to provide a broad overview to help as guide. We will indicate which materials we use—not because we think they are the best but simply because they reflect our position as neither early nor late adopters. As such, we draw upon the experience and evidence of others rather than being seduced by untried developments with unforeseen risks.

Before considering the metallic, ceramic and composite options for individual restorations, we will give an overview of dental CAD/CAM as it is increasingly used for all types of restoration.

14.2 Dental CAD/CAM

Nowadays CAD/CAM engineering is commonplace, but its development within dentistry was a massive achievement. One of the pioneers was Dr Duret. In 1971, he started work on an optical impression system linked to a series of electronic systems allowing a crown to be designed and then milled. Sadly he was before his time, and the resulting Sopha™ system failed commercially because it was too expensive and too complex [3]. The current generation of dental CAD/CAM has evolved from this sunken ship buoyed up by increasingly powerful and increasingly inexpensive digital components. Accuracy of fit and the ability to machine the occlusal surface have evolved considerably over the years [4, 5].

All CAD/CAM systems involve the three main stages of *data acquisition*, *data processing* and *machining* [6]. Importantly, tooth preparations can either be recorded directly using an intra-oral scanner (see Fig. 14.1) or via a hybrid route. With the hybrid route, a conventional impression is recorded and the resulting stone cast or die scanned in the laboratory (Fig. 14.2). Although laboratory scanners are incredibly accurate, a well-fitting restoration still requires excellent impressions, well-trimmed dies, and properly articulated casts!

Fig. 14.1 (**a**) *Data acquisition* via digital scanning to record an optical impression followed by information transfer; (**b**) *data processing* to design a virtual form of the restoration/coping using computer software; (**c**) *manufacturing*—a machine receives the processed data and manufactures the restoration/coping. This Cerec™ machine can mill blocks of alloy, ceramic or composite. Its size is mid-range suitable for laboratories. There are smaller machines for chairside use and much larger ones weighing several tonnes for milling centres (Courtesy of Andrew Keeling)

There are several workflow options for dental CAD/CAM. To give the reader a clear idea of what is involved these are outlined separately for metallic restorations (Fig. 14.3) and for ceramic restorations (Fig. 14.4). We will consider ceramics in greater detail later, but at this stage it is enough to know that either ceramic blocks can be milled to create a high strength core (which is then veneered with another type of ceramic) or a monolithic restoration can be milled from a single type of ceramic.

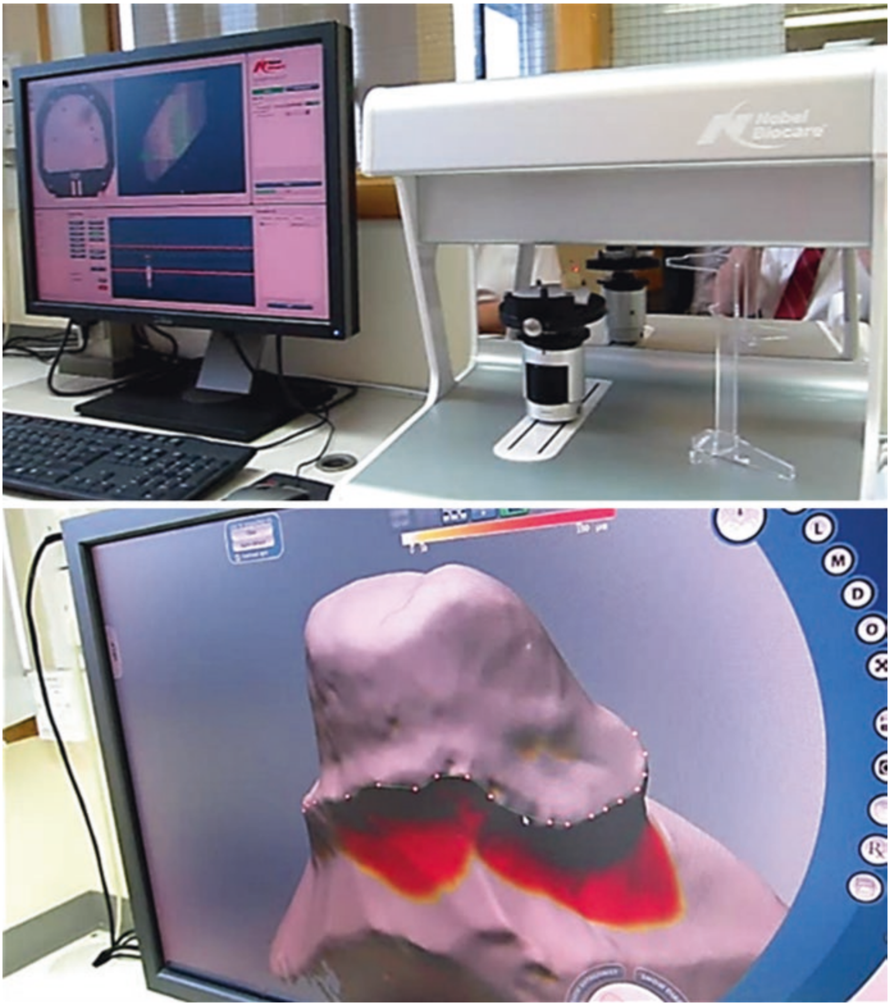


Fig. 14.2 A conventional impression may be used instead of an intra-oral digital impression. The resulting die is laser scanned in the lab (top right) and data processed (top left). The finish line is identified with linked white dots with the undercut area highlighted in black and red (bottom)

Restorations and copings can either be designed virtually using a 3D image on a computer screen or in the hybrid route by a technician using a conventional wax up on an articulator which is then scanned. Some CAD/CAM systems offer virtual articulators, but it is unclear if they are any better or worse than the mechanical ones they simulate.

After restoration design and following data transfer, machining of restorations can take place in one of the three locations: chairside, laboratory or industrial milling centres.

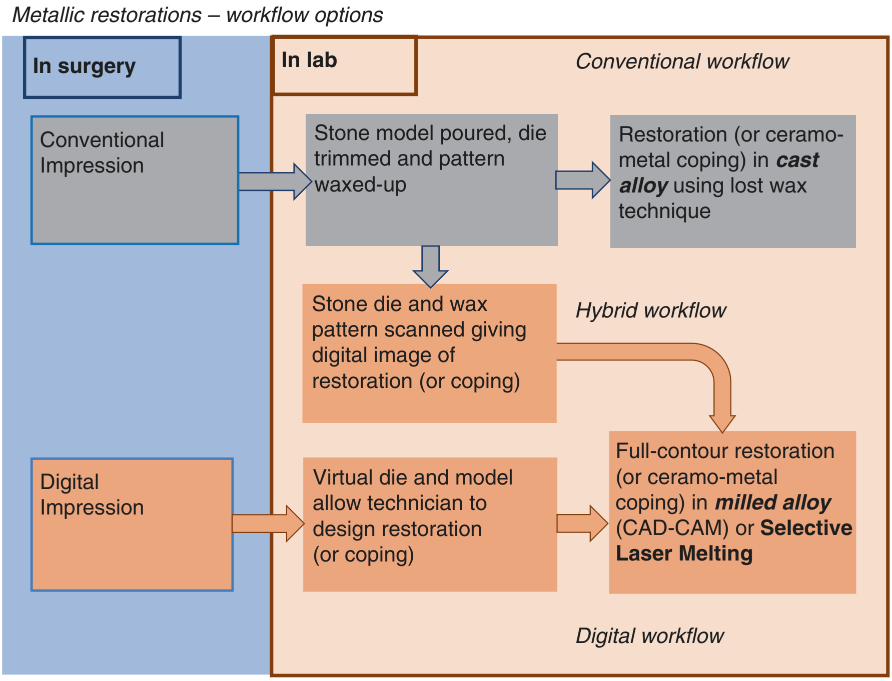


Fig. 14.3 Workflow options for metallic restorations—conventional path in grey and digital path in orange. The hybrid approach allows the lab to 3D scan a conventional die and wax pattern for subsequent CAD/CAM production. Alloy copings for ceramo-metal restorations generally have the ceramic applied manually (discussed later in the chapter)

14.2.1 Chairside Milling

The Cerec™ system, developed by Dr Moermann and launched by Sirona in 1987, was the first commercially successful dental CAD/CAM system. It comprised an intra-oral scanner, a computer for virtual restoration design and a chairside milling unit [3]. Initially only simple ceramic inlays were possible, but nowadays a remarkable range of ceramic and alloy restorations can be produced in the surgery or more conveniently in a local lab (see Fig. 14.1). In 2015 Sirona amalgamated with Dentsply giving further impetus to the development of CAD/CAM restorations.

14.2.2 Laboratory Milling

Laboratories may of course serve more than one dental practice and invest in their own 3D scanner, CAD computer and in-house milling equipment. Two such CAD/CAM systems in the UK are Cerec™ (Dentsply Sirona [7]) and Planmeca

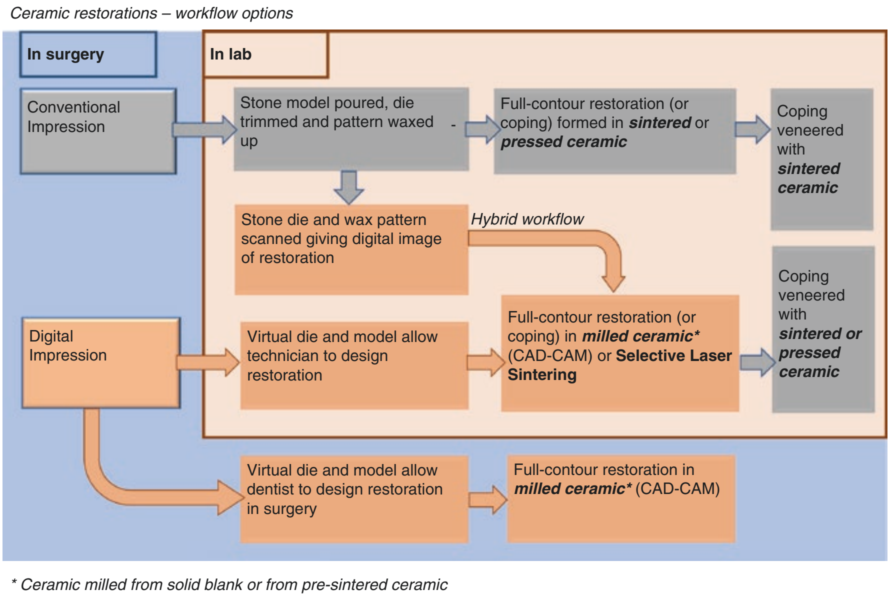


Fig. 14.4 Workflow options for ceramic restorations—conventional path in grey and digital path in orange. Again, a hybrid pathway involves scanning of the cast or impression. Restorations may be made in a lab/milling centre but also at the chairside

PlanMill™ (Planmeca [8]). Initially manufacturers supplied ceramic blocks and discs which could only be milled with one of their own machines. Nowadays there is a trend to standardise dimensions allowing a wide variety of ceramic materials be machined.

14.2.3 Industrial Milling

Alternatively, laboratories may outsource milling to an industrial milling centre and restrict their involvement to scanning, restoration design and finishing of the milled restoration. Finishing may simply involve polishing or the application of ceramic veneers to metallic or ceramic cores.

These industrial milling centres are networked in a global "hub and spoke" configuration with factories sometimes thousands of miles from the dental laboratories they serve. The laboratories send CAD design information via the Internet, and the milled restorations or copings are delivered a few days later. Some milling centres also offer a cast scanning and prosthesis design service, particularly for implant-retained prostheses.

The foundations for industrialised dental CAD/CAM were laid in the 1980s by Dr Matts Anderson, who developed the Procera™ (Nobel Biocare) system for machining cores and frameworks made from titanium or ceramic [3].

Initially the focus of these milling centres was implant-retained crowns and prostheses, but nowadays they deal increasingly with tooth-retained restorations in a variety of metallic and ceramic options. Examples of companies currently sponsoring industrial milling centres producing crowns and bridgework include Nobel Biocare, Dentsply, 3M ESPE, and Straumann.

14.2.4 "Closed" and "Open" Systems

Any dentist considering moving over to a digital work flow will need to be aware of the concept of "closed" and "open" systems, particularly if they are buying an intraoral scanner for recording 3D digital impressions (see Chap. 22). The same applies to laboratories investing in benchtop digital scanners. With a "closed" system, companies only provide milling machines or milling services for their own scanning products and software. Other companies use "open" CAD software allowing compatibility with the scanners and restorative materials of other manufacturers. This is a changing field, and dentists and technicians are advised to check before buying if they would rather not be locked only into one system.

14.2.5 The Milling Processes

Modern CAD/CAM milling uses a selection of computer-controlled burs held by collets in a milling machine. The computer selects an active bur best suited to milling the internal or external aspects of the restoration. The workpiece consists of a block or disc of material from which either single or multiple restorations are cut. The most recent milling machines offer four or five axis milling capability. Each axis defines a rotation or translation carried out by the assembly of the milling bur and the workpiece being milled. Having four or five axes helps optimise the milling of axial and occlusal contours, surface detail and restoration margins. If this all sounds rather complicated, there are several fascinating videos on YouTube: just google "dental five axis milling".

The materials being milled are homogenous alloys or ceramics or composites. Alternatively, a precursor to the metal or ceramic may be used. One precursor is the material itself, but in a partly sintered form easier to mill—called "green machining" [9] (see Box 14.1). Another precursor is a resin or wax pattern for conventional casting.

Initially, ceramic blocks only came in single shades giving restorations a bland appearance. Several materials are now also available in double or triple layers better simulating tooth colours and translucencies. However, getting a good result requires skill and experience to align the 3D outline of a crown into the best position within a block.

Obtaining good results with CAD/CAM restorations requires tooth preparation to comply with the limitations of the milling process. For example, Cerec™

Box 14.1: Material Precursors to Facilitate CAD/CAM Milling

- Alloy precursor—Partly sintered Co-Cr consisting of blocks or discs of fine alloy particles part-sintered together. An oversized restoration is milled which shrinks to the correct size after fully sintering in a small furnace with an argon atmosphere. The advantage of this seemingly complex "green machining" is that partly sintered Co-Cr is easier to machine than solid Co-Cr reducing production time and bur wear. Example: inCoris CC™ from Sirona.
- Ceramic precursor—Partly sintered zirconia for cores, frameworks, monolithic restorations and custom-made implant abutments. Again, an oversized piece is "green machined" which then shrinks after fully sintering. Example: NobelProcera™ from Nobel Biocare.
- Wax or polyurethane burnout material which is used to mill burnout patterns for the lost wax technique using a computer-generated design. The pattern is invested allowing alloys to be cast or ceramics to be pressed onto a zirconia coping or framework. Example: Cercon base cast™ from Dentsply.

(Dentsply Sirona) recommends dentists to prepare teeth taking into account the dimensions of the milling bur. The bur is 10.5 mm long, is stepped at 4 mm from its tip and has a minimum diameter of 1 mm. So whilst preps up to 10 mm high can be accommodated, ideally prep wall height should be <4 mm to avoid internal fitting discrepancies [10]. In addition, the prep's axial walls should have a minimum total occlusal convergence of >6% with rounded internal line angles. If the prep has an inlay component, the occlusal outline form should be rounded; otherwise excess ceramic will be left after milling which must then be ground away manually. To enhance the appearance of the occlusal surface, the ceramic can be adjusted manually with fine grooves and pits after milling.

14.2.6 Other Computer-Aided Machining Options

So far, we have focused on CAM milling which is a *subtractive* process, but there are other CAM options relying on *additive* manufacture which may be used for making all-metal restorations and copings for ceramo-metal crowns, ceramic crowns and dentures. With additive manufacturing, incremental layers of material (polymers, ceramics or metals) are laid down using a 3D printer and then fused together using a high-powered laser to build up a restoration [11]. This process is called selective laser sintering (SLS), but some authors prefer the term SLS for non-metallic materials (polymer, ceramics) and use DMLS (direct metal layer sintering) or SLM (selective laser melting) for alloys [12]. A review of SLM notes it can be used with most types of alloys, but in dentistry titanium and Co-Cr alloys are favoured. Co-Cr restorations made via either milling or SLM are more homogenous and with less microstructural porosity than those made by casting. Porosity can have a major impact on the strength and corrosion resistance of the alloys. Most reviewed studies show internal and marginal fit of SLS restorations made from Co-Cr to be equal to or better than cast restorations with milled restorations less accurate. However, the clinical significance of these differences is unclear, and the accuracy of milling is likely to improve further. The quality of bond between ceramics and Co-Cr copings made by the three manufacturing techniques is similar. SLM produces restorations faster than milling or casting and is claimed to provide consistent high-quality by reducing human involvement in the process [12]. Currently, SLM equipment is more expensive than milling, and the production of metal fumes is potentially more hazardous to health than grinding debris [11].

The alternative to building restorations directly in metal with SLM is to use SLS to print a wax or polymer pattern and then invest and cast conventionally with the lost wax process. This approach may be useful where expensive gold alloys are prescribed.

This is an exciting technology with great future potential.

14.3 Metallic Restorations

As mentioned in the introduction, metallic restorations still provide an important treatment option. Please see Table 14.1 for the alloys we use at Newcastle Dental Hospital and School.

Traditionally, metallic restorations are cast using the “lost wax” technique; a wax pattern is invested in a refractory material, so the wax can be burnt out leaving a space for the molten metal. The resulting casting is then broken out of the investment and finished. This technique dates back five millennia and is not just specific to dentistry [14]. It works particularly well with alloys containing high percentages of noble metals, principally gold, palladium and platinum. Two important examples are the high gold/low palladium and high palladium/low gold alloys. These alloys have a high density which helps molten alloy reach the more detailed parts, such as fine metal margins, during casting.

Around the turn of the millennium, commodity prices for gold and palladium rocketed boosting the adoption of less expensive casting alloys. These alloys contain low concentrations of noble metals or consist entirely of base metal. Low noble metal alloys have small amounts of gold or palladium or both alloyed with various combinations of silver, copper or tin. The main base metal alloys comprise cobalt chromium (Co-Cr), cobalt chromium tungsten (Co-Cr-W) and nickel chromium [15]. These alloys can all be cast, but CAD/CAM milling options are increasingly available for Co-Cr and Co-Cr-W.

At Newcastle, we routinely use a Co-Cr-W alloy (see Table 14.1) formed by CAD/CAM both for all-metal and ceramo-metal restorations. A hybrid workflow is used, and the restorations and copings are milled by an industrial milling centre. Gold alloy posts and cores for restoring endodontically treated teeth are still cast.

Table 14.1 Alloys used for metallic restorations at Newcastle Dental Hospital and School

Metallic restorations				
Clinical use	Method of construction	Alloy	Main constituents (>2%)[a]	Minor constituents (<2%)
All-metal and ceramo-metal restorations and copings	CAD/CAM milled or cast base metal	Cobalt, chromium, tungsten (W) [1]*"remanium star"*	Co (61%) Cr (28%) W (9%)	N (<1%) Mn (<1%) Nb (<1%)
All-metal restorations	Cast in noble metal alloy	Gold, silver, copper, palladium [2]*Dentalor 60*™	Au (60%) Ag (23%) Cu (12.5%) Pd (3%)	Zn (1.50%) Pt (0.45%) Ir (0.05%)
Ceramo-metal copings	Cast in noble metal alloy	High palladium, low gold alloy [2]*Cerapall2*™	Pd (79%) Cu (7%) Ga (6%) In (5%) Au (2%) Sn (2%)	Ru (0.5%) Zn (0.1%)
Post and cores	Cast and heat treated	Silver, gold, copper[b] [3]*Yellow Special*™	Ag (45%) Au (41%) Cu (11%)	Pd (1.7%) Zn (0.70%) Pt (0.45%) Sn (0.20%) Ru (0.05%)

"Product trade names": [1]Dentaurum, Germany; [2]Cendres + Métaux, Switzerland; [3]Type 4 alloy having gold/platinum content 60–75% (ISO 8891:2000) [13]
[a]Rounded to nearest percent
[b]Requires heat treatment

Whilst generally considered safe, the release of metal ions, particularly from less expensive alloys, may be a concern for patients, dentists and technicians.

14.3.1 Biological Aspects of Metallic Restorations

In comparison with some of the cheaper cast alloys, high gold or palladium alloys appear to offer some clinical advantages over and above providing reliably fitting restorations. A high noble metal content makes alloys less susceptible to corrosion and the release of metal ions [13]. Although a causal link between release of corrosion products from dental alloys and cellular response has not yet been clearly established, lichenoid reactions (see Chap. 7) similar to lichen planus have been associated with copper ions released by corrosion of alloys having low noble metal content [16]. Some patients with amalgam worry about mercury exposure which may result from galvanic corrosion of amalgam restorations when in combination with other metallic restorations (polymetallism or galvanism). However, evidence to support a toxic effect from amalgam and most dental alloys is sparse. There are also diagnostic difficulties as non-specific symptoms (e.g. unexplained pain when biting, metallic taste, general malaise) [13] may be unrelated to metal ions.

An important background factor for many of these patients is a chronic anxiety disorder [17].

Contact dermatitis is commonly linked with wearing nickel-containing jewellery, but reports are rare of restorations causing an oral reaction or of an existing dermatitis being exacerbated [18]. Ni-Cr and Co-Cr alloys "passivate", meaning they rapidly form a thin oxide barrier layer which protects the underlying alloy. Nevertheless, on a precautionary basis, nickel-containing alloys are best avoided in patients with known nickel sensitivity [19].

Dentists and technicians may also suffer adverse occupational effects, including carcinogenic changes from grinding nickel chromium alloys containing beryllium, particularly if dust extraction and ventilation is inadequate [15]. Adequate ventilation is important not only for grinding metals: Inhaling ceramic dust may eventually cause silicosis [20].

14.3.2 All-Metal Restorations

These consist entirely of alloy and include crowns, partial-coverage crowns, onlays and shims (onlays relying solely on adhesive retention). All-metal crowns generally require less tooth preparation than ceramo-metal and most all-ceramic crowns. With suitable surface conditioning, metallic restorations can be bonded to enamel and dentine using resin cements (see Chap. 15). Clearly, unless a patient prefers an intra-oral display of gold or "silver", these restorations are restricted to being used on posterior teeth, particularly molars. Nowadays Co-Cr-W or Co-Cr is often used for milled individual metallic restorations. Cast Co-Cr has been reported to require more adjustment and remakes than gold restorations [21], but this is not something we have experienced with milled Co-Cr-W. Readers should note that within the UK NHS Dental Services, the use of non-precious alloys is only permissible in full-coverage restorations and resin-retained bridges [21].

Titanium is mainly reserved for implant bars and customised implant abutments (Chap. 16).

At Newcastle University School of Dental Sciences, we prefer to use a Co-Cr-W alloy with CAD/CAM milling (see Fig. 14.5) but resort to casting when necessary. Casting is reserved for when:

- The finishing line can be visualised on the die but is difficult to scan digitally
- Gold alloy (see Table 14.1) is preferred by the dentist or the patient or both. Some of the reasons include:
  - Aversion to base metal
  - Hypersensitivity to a base metal alloy constituent (also an indication for all-ceramic restoration)
  - Gold-coloured alloy desired
  - Avoiding multiple metals in a restored mouth with the potential for corrosion and, rarely, as already mentioned possible signs or symptoms
- Cast posts and cores—considered at the end of this section.

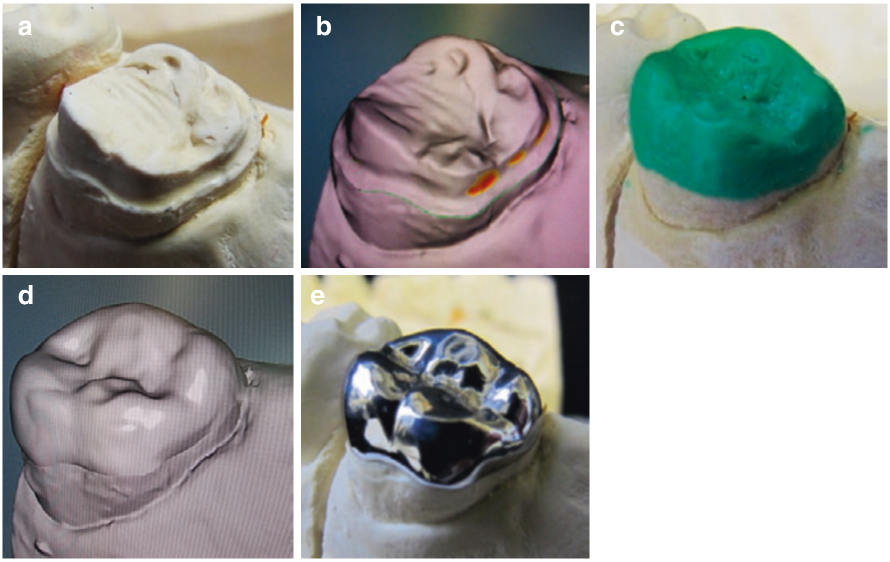


Fig. 14.5 Production stages for CAD/CAM Co-Cr-W onlay: (**a**) stone die ready for scanning; (**b**) scanned 3D image; (**c**) onlay waxed up using casts mounted on articulator; (**d**) scanned 3D image and data transferred to milling centre; (**e**) milled and polished onlay (Courtesy of Stuart Graham-Scott)

14.3.3 Ceramo-Metal Restorations

Ceramo-metal restorations comprise crowns (and bridges) with a metal coping or framework veneered either completely or partially in feldspathic ceramic. This method of strengthening feldspathic ceramic was patented in 1962 [22]. It was well received by dentists who were often confronted by patients whose feldspathic all-ceramic crowns had fractured, often soon after fitting. The problem with all-ceramic restorations is to prevent cracks propagating outwards from the fit surface of the restoration. One way of doing this is to bond the ceramic to a metal coping. Of course, other methods have also evolved to strengthen ceramics, and these will be considered below in the Sect. 14.4.

As mentioned in the introduction, ceramo-metal is still the "gold standard" against which the durability of all-ceramic restorations is measured [2]. Furthermore, the use of metal allows restorations to be designed with less aggressive tooth reduction. This is an important consideration for bruxist-prescribed crowns as part of their management. A metal occlusal surface is not only conservative of tooth tissue but also it won't fracture like ceramic. Metal also allows for the occlusion to be adjusted and polished more easily. In addition, it is less likely than some ceramics to wear away the opposing tooth [23].

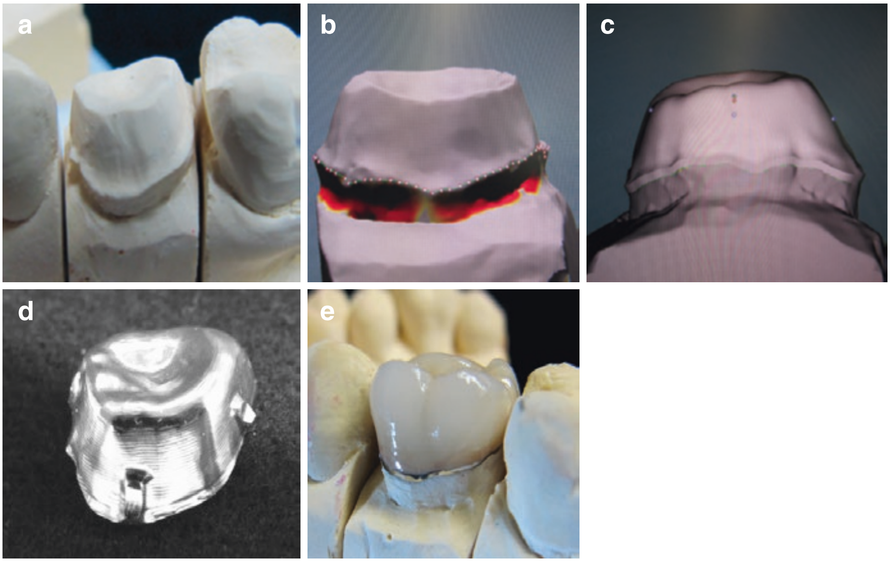


Fig. 14.6 Production stages for CAD/CAM Co-Cr-W coping: (**a**) Trimmed stone die on mounted cast ready for scanning; (**b**) scanned 3D image; (**c**) coping design (metal collar) specified with software and data transferred to milling centre; (**d**) milled coping displaying connectors used to hold it in the metal disc whilst milling and which are ground off prior to ceramic application; (**e**) ceramic sintered to coping (Courtesy of Stuart Graham-Scott)

We make our ceramo-metal copings using a Co-Cr-W alloy with CAD/CAM milling (see Fig. 14.6). Casting is still used occasionally for the same reasons as for all-metal restorations. Where the use of base metal is unacceptable, a cast high palladium low gold alloy is used (see Table 14.1). This alloy contains gallium, indium and tin. During firing, these elements form an oxide layer to which the ceramic bonds. Other high noble content alloys are similarly formulated for the same reason and to resist slumping during ceramic firing [24]. The bond strength of the ceramic to the coping is particularly important, and minimum requirements are defined in the EN ISO 9693:2000 [13].

With a skilled technician, ceramo-metal restorations can be as beautiful as all-ceramic ones, but creating the illusion of tooth structure (see Chap. 17) is technically more demanding for three reasons: firstly, the thickness of the metal coping gives less space for translucent ceramic; secondly, the crown's optical properties are affected because the metal is opaque; and thirdly, the metal has to be masked partially or completely by an opaque ceramic layer to prevent or limit "shine through" of the underlying coping. Most ceramo-metal copings are made in alloys which are "silver" in appearance when polished (Table 14.2). Yellow-coloured alloys with a very high gold content (Table 14.3) can make the overlying ceramic veneer more aesthetic but are very expensive.

Table 14.2 Ceramo-metal copings can be made from a variety of alloys having a silver appearance when polished

Ceramo-metal copings			
Alloy	Method of production	Ceramic	Comments
High gold and platinum	Cast	High fusing	First alloy used for ceramo-metal restorations. With 98% noble metal content, it was good for single restorations but needed a minimum coping thickness of 0.5 mm and too easily flexed for long-span bridges where ceramic fracture can occur. The addition of leucite to the ceramic to match the alloy's coefficient of thermal expansion prevented stress build-up in the ceramic during cooling after firing causing fracture
High palladium low gold	Cast	High fusing	Became popular in the 1980s when palladium was relatively inexpensive. Having a higher modulus of elasticity allowed thinner 0.4 mm copings to be made for crowns. The greater rigidity was more suitable for bridge frameworks
Silver palladium	Cast	High fusing	Good mechanical properties but silver corrosion products can diffuse into the ceramic sometimes giving it a greenish hue
Nickel chromium	Cast	High fusing	Inexpensive alloy popular for many years in the USA but not used in Sweden because of concerns over nickel content and beryllium toxicity [25]. Good physical properties, ceramic bonding and resin bonding allow thin copings and retainers for resin-bonded bridges
Titanium	CAD/CAM milled	Low-fusing ceramic	Titanium alloys have a high melting point but form thick, bluish-coloured oxide layers at high temperature which is why low-fusing ceramics are used [26]. Ceramic bond strength is not as good as for other alloys putting the ceramic at risk of fracture [27]. Whilst extremely biocompatible, titanium needs to have sufficient bulk to avoid deformation
Cobalt-chromium-tungsten	CAD/CAM milled, SLM or cast	High fusing	Copings made of Co-Cr-W alloy can be fashioned by traditional casting and modern CAD/CAM methods. It is much less expensive than noble alloys so increasingly popular for making metallic restorations: our experience with using this alloy for more than 4 years has not highlighted any specific problems (e.g. poor fit, ceramic debond or fracture, allergies, galvanism), but it would be useful to have a formal comparison with other alloys

Tables 14.2 and 14.3 also outline manufacturing techniques. We have excluded techniques which contributed to the development of ceramo-metal restorations, but are now rarely, if ever used, for example, the use of thin metal foils made of tin-plated platinum [29, 30], palladium [31], gold-coated platinum [17, 32] and gold [33]. Sadly, these foil copings gave questionable improvements to the strength of the overlying ceramic [26, 34], suggesting a certain coping thickness is required for strength.

Table 14.3 Ceramo-metal copings with a golden hue can be made from high gold alloys or pure electroformed gold

Ceramo-metal copings—gold coloured			
Alloy	Method of production	Ceramic	Comments
High gold (77–87% Au), platinum and palladium	Cast	High fusing	A range of high Au + Pt group alloys (96–98%) which offer fine-grained, detailed castings and having low or no Ag or Cu content are claimed by the manufacturers to be extremely biocompatible [28]. Depending on the gold content, the colour of the cast alloy ranges from yellow (87%) to bright yellow to pale yellow (77%). With a 75% gold content the alloy colour is described as white. The advantage of the high noble metal content is that it avoids a dark oxide layer, and consequently the yellow hue of the alloy enhances the dentine colour of the overlying ceramic [13]
Electroformed gold	Electroplating up to 0.3 mm thick	Low or high fusing	The GES system plates with 24 carat gold, so copings are relatively soft, but there are no adverse reports of clinical durability for single crowns. The manufacturers claim the copings to be highly biocompatible. The almost pure gold surface shows little oxidation after firing which in selected clinical cases may provide similar or greater aesthetic enhancement as cast high gold copings. The lack of oxides is also claimed to avoid the black line that sometimes occurs at ceramo-metal crown margins. Surprisingly good ceramic bond strengths can be obtained to the pure gold by first firing a slurry of gold and ceramic particles [13]
Captek™ (88% Au, 4% Pt, 4% Pa)	Metal composite	High fusing	The technique involves the fabrication of a metal composite coping [26]. A metal-impregnated wax sheet is adapted over a refractory die and sintered in a porcelain furnace, and the resulting granular structure infused with molten gold. The coping thickness is 250 μm for anterior teeth and 350 μm for posterior teeth. Like electroformed gold, it only produces copings for full ceramic coverage and does not allow for metal occlusal surfaces

14.3.4 Post and Cores for Endodontically Treated Teeth

Cast posts and cores are still used to restore endodontically treated teeth, despite the increasing use of fibre/composite post systems (see Chaps. 11 and 19). To avoid a cast post bending or breaking under occlusal load, the alloy chosen should be stiff and strong. These qualities will be indicated on manufacturers' product sheets as showing in relation to other alloys a higher Young's modulus, hardness, proportional limit, and ultimate tensile strength.

To get optimum mechanical properties, manufacturers recommend their gold post alloy (see Table 14.1) to be heat treated at 400 °C for 20 min. Our technicians avoid the need for a separate heat treatment by allowing the hot-casting ring to bench cool slowly to room temperature after casting. Laboratories may unwittingly produce soft posts simply by quenching the hot-casting ring in water so the investment can be easily removed. If quenched a casting must be heat-treated per manufacturer's specifications.

It is false economy to choose a cheap alloy for posts. The resulting corrosion, porosity and weakness can cause post fracture with unfortunate consequences, particularly in posts of narrow diameter. Cast post and cores can equally well retain metallic or ceramic crowns. There are now hundreds of ceramic systems, and in the next section, we will try and make sense of what is available.

14.4 Dental Ceramics and Porcelains

Dental ceramics are defined by ISO 6872:2015(en) as "inorganic, non-metallic material which is specifically formulated for use when processed according to the manufacturers' instructions to form the whole or part of a dental restoration or prosthesis" [35]. The same standard defines dental porcelain as "predominantly, glassy dental ceramic material used mainly for aesthetics in a dental restoration or prosthesis". Clearly, dental porcelain is just one type of ceramic. It is easiest to think about porcelain having a composite structure comprising a crystalline phase or phases within a glassy matrix. Other types of ceramic are mainly crystalline, and this is reflected in the classification of materials discussed in the next section.

Dental ceramics are most commonly used to make veneers, crowns, onlays and inlays. The improvement in strength of more recent ceramics also allows for the construction of implant abutments, bridgework and orthodontic brackets.

Dental ceramics consist of metallic and silica oxides and are often considered inert, but we should be aware that most glassy matrix porcelains can be attacked by acids such as acidulated phosphate fluoride (APF) gel and prolonged exposure to acidic fruits [36]. On the other hand, crystalline ceramics composed of alumina or zirconia are more resistant to acid attack.

Ceramics are rigid, brittle and crack sensitive. They are vulnerable to stress corrosion at the crack tip when the wet environment of the mouth interacts with cyclic occlusal loading [37]. Under these fatigue conditions, cracks can grow continuously, classically starting at the fit surface and extending outwards to interact with cracks that may be propagating inwards from the region of occlusal contact. Hence ceramics in clinical service may fail catastrophically at loads well below their flexural strength and fracture toughness (K_{IC}) as measured with a single cycle load [36]. The problem of crack propagation is exacerbated because ceramics are difficult to process without incorporating flaws on the surface or in the bulk of the material. These flaws become stress concentrators when a restoration is under occlusal load.

Modern methods of manufacture include pressed ceramic, CAD/CAM machining and slip casting with glass infusion. These minimise flaws but rarely succeed in eliminating them completely. Indeed, machining may introduce surface flaws into an otherwise flaw-free ceramic block requiring further heat treatment to reduce the risk of fracture. There have also been other improvements in quality control resulting from the move away from naturally occurring ceramic components (e.g. feldspar) to those made synthetically [38].

There has been a natural evolution with some materials being withdrawn from the market as newer materials with better clinical performance are introduced [36]. Redundant ceramic trademarks now mainly of historical interest include the castable glasses, Dicor™, Cerapearl™ and Cerestore™ [39]. Readers interested in their composition are referred to the first edition of this book [15].

We have already described how the alloy core in a ceramo-metal restoration enhances the strength of the overlying ceramic. Similarly, all-ceramic restorations may combine a strong ceramic core with a weaker (but more aesthetic) veneer ceramic. Alternatively, the restoration may be made as a monolithic structure featuring a crack-resistant ceramic microstructure (e.g. made of lithium disilicate or zirconia). The trade-off for the stronger monolithic restoration may be less good aesthetics because of a limited range of ceramic colours or reliance on coloured surface glazes which may be impermanent.

The most conservative method of utilising ceramic restorations is to resin bond them to sound underlying tooth structure. This allows ceramic to be used in relatively thin section (0.3–0.5 mm) particularly for veneers supported by underlying enamel. Of course, reliable resin bonding is only possible if the intaglio (fit) surface of the restoration can easily be etched with hydrofluoric acid. It usually can be if made from a glass ceramic, but not so if made from zirconia.

14.4.1 Classification of Dental Ceramics

Over the years there have been several classifications of dental ceramics [9, 40]. A recent classification [38] sensibly and simply divides ceramics into two main categories:

1. Glass matrix ceramics
2. Polycrystalline ceramics.

A third category was also proposed—“Resin matrix ceramics”—to include resin composite blocks with a heavy ceramic filler loading specifically for CAD/CAM use. These materials comply with the ADA’s revised definition of a ceramic as containing “predominantly inorganic compounds” [20]. However, this category is not universally recognised. Many would regard them resin composites—albeit for indirect use. However, there is one type of CAD/CAM material called a “polymer-infused glass ceramic” which is very much a hybrid of composite and ceramic. This is discussed later in the Sect. 14.5.

To make informed clinical choices, clinicians should have an insight into how glass matrix and polycrystalline ceramics are strengthened, how they are made, whether they can be etched/resin bonded, how abrasive they are to opposing teeth and how they perform clinically.

14.4.2 Strengthening Agents of Glass Matrix Ceramics

Glass matrix ceramics are largely "dispersion" strengthened so that cracks through the glass are stopped by stronger polycrystals or crystalline structures within the material. An important clinical distinction is whether the strengthening is provided by a core, which is then veneered with aesthetic but weaker porcelain, or if the strengthening extends all the way through to give a monolithic restoration. Clearly, if extra space is needed to accommodate a strengthening core, this can result in a more destructive tooth preparation.

Examples of polycrystals used for strengthening glass matrix ceramics are leucite, lithium disilicate, fluorapatite and alumina. Zirconia is hugely important with *polycrystalline* ceramics (discussed in the next section) but plays a smaller role within glass matrix ceramics.

In recent years, to avoid inherent variability of natural mineral materials, the ceramic industry has moved towards synthetic precursors composed of a variety of compounds including potassium oxide, sodium oxide and aluminium oxide [9].

14.4.2.1 Leucite

Leucite consists of potassium-aluminium-silicate crystals and is found in varying quantities depending on the type of ceramic.

Feldspathic Ceramics

Prior to the 1960s, these were the only available ceramics for making "porcelain jacket crowns". Feldspathic ceramics contain three naturally occurring minerals: feldspar (potassium and sodium aluminosilicate), kaolin (hydrated alumina silicate) and quartz (silica). Only when the porcelain powder is sintered in a porcelain furnace does some of the feldspar form leucite crystals (<5% mass) within the alumina-silicate glass matrix [38].

Feldspathic ceramic crowns were aesthetically pleasing but extremely brittle. The poor physical properties were associated not only with the low leucite concentration but also with the flaws inevitably found in a sintered material. Consequently, in the 1980s and 1990s with the introduction of CAD/CAM technology, blocks of fine-grained feldspathic ceramic were manufactured (Vita MKI and II™, VITA Zahnfabrik) to provide a flaw-free material which could be machined using the Cerec™ system (Dentsply Sirona). This material has been further developed to incorporate multiple dentine shades and translucencies within the block (Cerec CPC™, Dentsply Sirona) to simulate polychromatic tooth shades better [41]. Despite the relatively high strength of the ceramic blank, machining may weaken the restoration through the introduction of surface flaws [42].

Another important development to improve clinical performance of feldspathic ceramics occurred in the early 1960s with ceramo-metal crowns.

Ceramo-Metal Ceramics

Metal copings for ceramo-metal crowns were considered earlier in the chapter. Critical to success is an effective bond between metal and ceramic which Weinstein

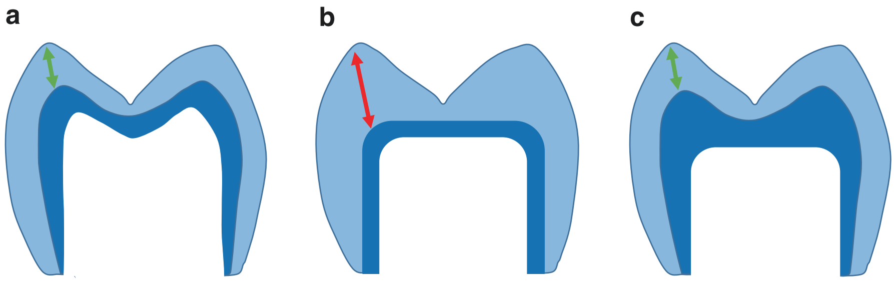


Fig. 14.7 Anatomical prep allows for optimum thickness of ceramic on metal coping (**a**). A short prep results in a thick layer of ceramic predisposing to ceramic fracture (**b**). Risk of fracture reduced by thickening metal coping to support cusps (**c**)

achieved by adjusting the coefficient of thermal expansion (CTE) of feldspathic ceramic to be slightly higher than that of the metal coping [22]. After firing, the differential in CTE controls cooling stresses at the vulnerable ceramo-metal interface so that the interfacial ceramic is loaded tangentially in compression resulting in less cracking and failure. Leucite has a relatively high CTE, so by adding specific concentrations (17–25% mass) of leucite to feldspathic ceramic, Weinstein was able to create ceramics for alloys with different CTE [9]. The strength of the ceramic veneered onto the metal coping will to a large extent depend on the veneer's thickness. Clinical experience suggests the veneering ceramic should be about 1–2 mm thick for adequate strength and aesthetics. To avoid having a ceramic veneer which is too thick, the metallic core should be contoured anatomically, so it is thicker in areas where the ceramic needs support (see Fig. 14.7). This concept is supported by a limited number of laboratory studies that show greater amounts of chipping with thicker layers of ceramic [43, 44].

High Concentration Leucite

During the 1980s and early 1990s, stronger glass matrix ceramics were developed with increased concentrations (40–55% mass) of leucite. Materials were formulated both for traditional sintering and as ingots to be pressed in their molten state into a refractory mould (e.g. Empress™, Ivoclar Vivadent). Although not a particularly strong material (160 MPa flexural strength), leucite ceramics continue to be a popular choice with dentists, particularly for resin-bonded veneers. This is most likely because of its excellent aesthetics resulting from the close match in refractive index between leucite polycrystals and the surrounding glass matrix [9].

Leucite veneers also come preformed in various sizes (Cerinate One Hour™, Denmat). These need to be fashioned by grinding before fixing to a tooth. One in vitro study showed early bond strength between preform and composite to be only half that of the comparator materials [45]. No clinical trials of these restorations are reported, so we don't know if there are any issues with fit or retention.

14.4.2.2 Lithium Disilicate

Empress II™ (Ivoclar Vivadent), the first dental ceramic to incorporate lithium disilicate (70% vol), was introduced in the 1990s. In terms of flexural strength, it was almost three times stronger than the leucite-containing Empress™. Empress II™ underwent a minor reformulation and was replaced in 2006 by IPS e.max™ (Ivoclar Vivadent) [40]. IPS e.max™ can be formed both by pressing and CAD/CAM. At Newcastle, we prefer to use the pressed ceramic (see Fig. 14.8).

To allow for machining, blocks of IPS e.max CAD™ (Ivoclar Vivadent) contain only 40% lithium disilicate and are coloured blue. The blueness is to ensure machined restorations are tempered at 850 °C. Tempering increases lithium disilicate content to 70% and at the same time removes the blueness to give a tooth-coloured restoration. It is worth noting that restorations made using press and CAD/CAM have different microstructures and different mechanical properties. IPS e.max press appears to have more complete crystallisation, possibly because of the heating and pressing. This may explain why it has higher fracture toughness (KIC 2.5 c.f. 1.8) and greater reliability in resisting fracture as shown by Weibull analysis [46]. However, there is insufficient data to show whether IPS e.max Press performs any better clinically [47]. Nevertheless, a meta-analysis based on eight studies of single crowns showed excellent early results for all types of lithium disilicate. Only one study, carried out in private practice, provided long-term data reporting 97.8% survival at 5 years and 96.7% at 10 years [47]. Clearly, further studies are needed to corroborate the long-term performance.

The nano-fluorapatite layering ceramic, IPS e.max Ceram™ (Ivoclar Vivadent), is used to create a sintered aesthetic veneer onto an IPS e.max™ core. Alternatively, monolithic e.max restorations can be made which may offer improvements in strength, but less opportunity for matching aesthetics of adjacent teeth.

IPS e.max™ can be used for all types of extra-coronal restorations both anteriorly and posteriorly. In common with feldspathic and leucite ceramics, it can be etched with hydrofluoric acid allowing restorations of thin section, for example, veneers, to be bonded directly to enamel. The manufacturers consider it sufficiently strong for three-unit bridges back to the second premolars, providing there is adequate connector height. However, a meta-analysis reports relatively poor survival rate for lithium disilicate bridgework at 5 and 10 years (78.1% and 70.9%) [47].

To illustrate ongoing ceramic development, a lithium disilicate reinforced with zirconia has recently been introduced for CAD/CAM production (Suprinity™, VITA Zahnfabrik). This material was compared in vitro with IPS e.max CAD™ and showed better flexural strength but greater brittleness suggesting poorer machinability [48]. Another manufacturer has used zirconia to reinforce lithium silicate (Celtra Duo™, Dentsply), again for CAD/CAM milling. It had a similar flexural strength to IPS e.max CAD™ and similar amounts of edge chipping after machining [49]. However, Celtra Duo™ had a lower Weibull modulus indicating a possible higher probability of failure at lower levels of stress [50]. We await clinical data for these and similar materials with interest.

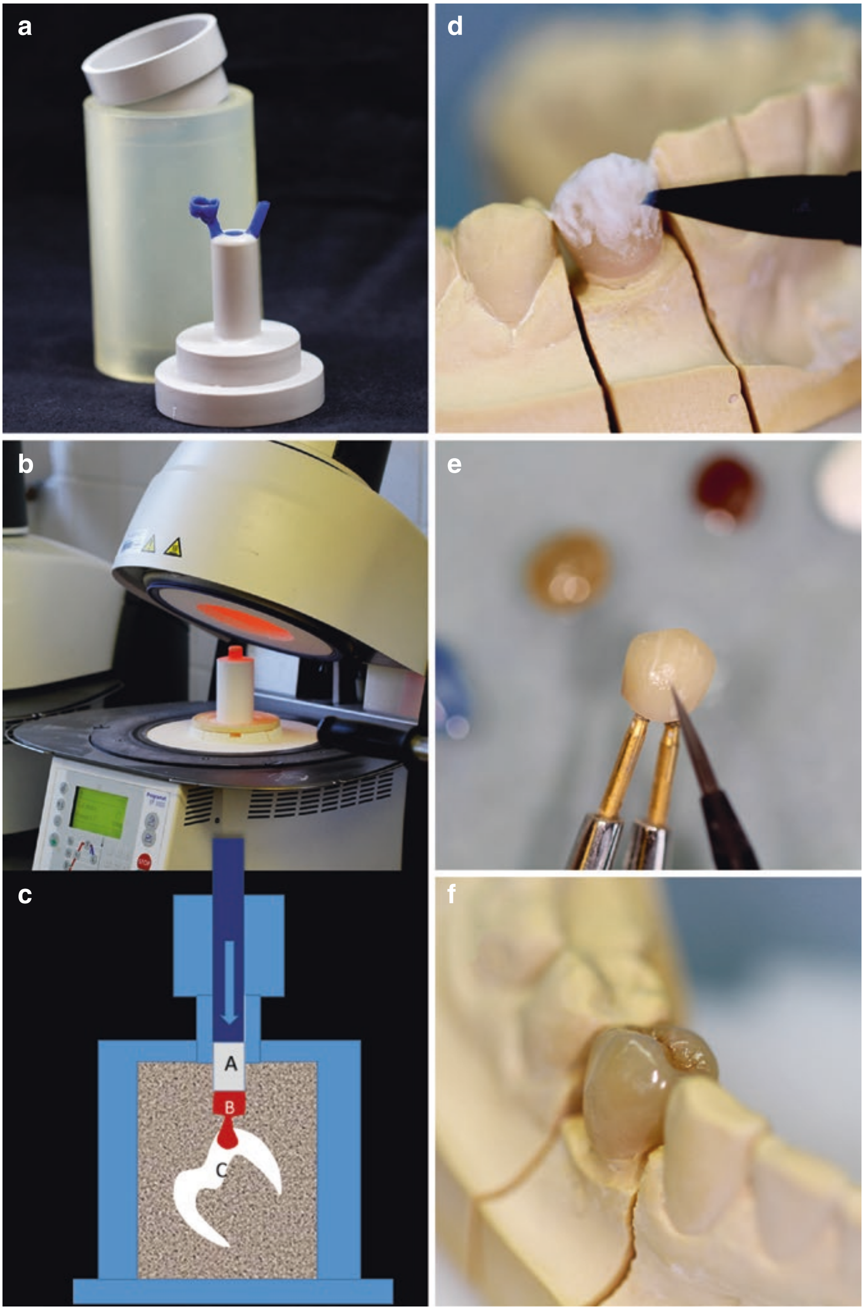


Fig. 14.8 IPS e.max Press production: (**a**) premolar waxed and sprued prior to investing; (**b**) investment cylinder preheated to burn out wax placed under the ceramic furnace hood (note the protruding red hot allox cylinder beneath which is a softened ceramic ingot); (**c**) hot-press schematic—the furnace plunger (dark blue) pushes the allox plunger (*A*) onto the softened ceramic (*B*) which is extruded into the investment mould (*C*); (**d**) after removing investment the lithium disilicate crown is cut back and a slurry of sintered ceramic applied to simulate enamel; (**e**) stains for a more natural appearance can either be incorporated within the sintered build-up or applied after sintering (as shown); (**f**) the final restoration

14.4.2.3 Alumina

Alumina is both hard and strong and can be used in several ways for dispersion strengthening of glass matrix ceramics; all of them involve having a high strength aluminous core. Aluminous porcelain developed in the early 1960s by John McLean has been largely succeeded by glass-infiltrated alumina (In-Ceram Alumina™, VITA Zahnfabrik) and derivatives which supplement the alumina content with either magnesium spinel (In-Ceram Spinell™) or zirconia (In-Ceram Zirconia™). The magnesium spinel imparts improved aesthetics but decreased flexural strength [51]. It is unclear whether zirconia imparts any useful improvement to the material [52].

In-Ceram™ cores are still popular with some dentists. However, where a strong core is required, many dentists prefer densely sintered zirconia [38], a polycrystalline ceramic which we will consider below.

14.4.3 Strengthening Agents of Polycrystalline Dental Ceramics

Zirconia and alumina are the principal polycrystalline compounds used to create high strength cores, although pure alumina is now used much less because zirconia is much stronger. Indeed, zirconia has a greater yield strength than many dental alloys but is not as tough [53]. Zirconia undergoes "transformation toughening" which is a fascinating concept quite different from dispersion strengthening used in the glass matrix dental ceramics (see Box 14.2). Cores are formed using CAD/CAM to mill the ceramic in its "green state" and then densely sintered. This produces a structure which in microscopic cross section looks like meticulously laid crazy paving.

As discussed in Chap. 2, zirconia cores rarely fail, but the overlying ceramic veneer is prone to unexplained chipping [2]. Possible reasons include a mediocre ceramic bond to the core, mismatch in coefficient of thermal expansion between core and veneer and stresses due to micro-expansions associated with the transformation toughening process [36]. It should also be remembered that the flexural strength of the veneering ceramic is an order of magnitude weaker than the zirconia

Box 14.2: Transformation Toughening of Zirconia

Pure zirconia exists in three different allotropic forms depending on temperature:

- <1170 °C "monoclinic" (think of a rectangular block pulled out of shape but still with straight sides)
- Between 1170 °C and 2370 °C "tetragonal" (think undistorted rectangular block)
- >2370 °C "Cubic" (think Picasso!).

Box 14.2 (continued)

Transformation toughening requires a substantial proportion of tetragonal zirconia (T) in the material at room temperature making it metastable. When exposed to external stress, e.g. at a crack tip, T undergoes transformation to the monoclinic phase (M). This TM transformation is accompanied by a localised 4% increase in volume, and the accompanying compressive stresses can block or close the crack tip (see Fig. 14.9). To obtain sufficient T phase at room temperature, the zirconia is stabilised (more correctly partially stabilised), usually with yttria, but ceria is showing great promise. The proportions of the various zirconia phases and their microstructure (at both the micro- and nanoscale) depend on the amount and type of stabilising agent used. Most dental zirconia products have been based on yttrium tetragonal zirconia polycrystals (Y-TPC). These products are sufficiently strong and crack resistant following sintering and machining to be used for dental restorations [38], providing the amount of T to M transformation is controlled. Typical flexural strength and fracture toughness values are 900–1400 MPa and 5–10 MPa $m^{1/2}$, respectively [54].

Y-TZP is also used for prosthetic joints, and a well-recognised problem in orthopaedics is low-temperature ageing degradation (LTAD) where continued and excessive T to M transformation particularly in the presence of moisture weakens rather than strengthens the material [53, 55]. This continued transformation is also seen in dentistry with Y-TZP but has not as yet shown itself clinically to be a problem. This may be because zirconia restorations have not been followed up for that long. However, a mean reduction in crown crush strength of more than 30% resulted from autoclaving specimens at 135 °C for 2 h which the authors claimed simulated 10 years of LTAD in vivo [56]. However, the validity of such accelerated ageing has been called into question [57]. Unwanted T to M transformation can also result from stressing the material as may occur during airborne particle abrasion (sandblasting), particularly with larger 120 μm grit particles under high pressure [36].

By contrast LTAD is not seen in ceria-stabilised zirconia combined for extra strength and toughness with nano- and micro-sized alumina particles. Typical flexural strength and fracture toughness values are 1400 MPa and 19 MPa $m^{1/2}$. We can expect to see more of these stronger materials in the future [54, 58].

core. To reduce the risk of veneer chipping, technicians are advised to allow restorations to cool slowly to room temperature after firing [9]. Another suggested strategy to reduce chipping is making copings with localised thickening to help support the veneer in the same way as advised for ceramo-metal restorations (Fig. 14.7). Unfortunately, this method has met with only limited clinical success [59].

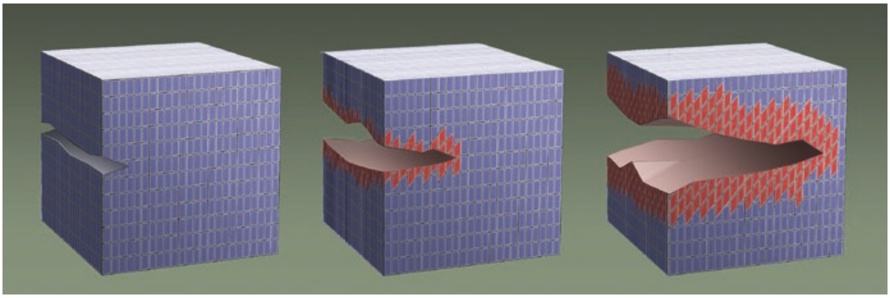


Fig. 14.9 Transition strengthening in zirconia ceramic: crystal transition at the crack tip from tetragonal to monoclinic (shown in red) produces a small localised expansion. The resulting compressive stresses impair further crack growth

Improvements in the translucency of zirconia have allowed production of monolithic restorations. By eliminating vulnerable veneer ceramic, these monolithic zirconia restorations appear less prone to chipping [60].

There are many different zirconia manufacturers, but it would be unwise to assume that all zirconia products perform similarly [61]. Variations in constituents, grain size, purity, CAD/CAM processing and sintering may have good or bad effects. The best advice is to use material from reputable companies, preferably with an established record of accomplishment in high strength dental ceramics. Dentists choosing to prescribe zirconia restorations should also bear in mind the need for retentive tooth preparations because the lack of a glass phase means zirconia is difficult to etch with HF to secure resin bonding.

Ongoing research is focusing on providing greater resistance to cracks propagating from the intaglio surface of the zirconia core or restoration. The potential problem of airborne particle abrasion producing defects and stress transformations in the material has already been mentioned in Box 14.2. One suggested remedy is to "anneal" the restoration afterwards by heating to 1200 ° for 2 h to "heal" the surface by reversing the T-M transformation. This is only partly successful as the surface defects still remain which may become future sites of crack propagation [36]. A clever alternative under development is to glass infiltrate the zirconia surface to a depth of 120 μm. Not only does this help with healing defects, it also helps dissipate stresses by creating a graded transition between the relatively compliant glass and the more rigid core. The glass infiltrate may also provide a better substrate to bond veneer ceramic and for etching prior to resin bonding [38].

14.4.4 Ceramic Production Methods

14.4.4.1 Sintered Porcelains

Sintered porcelains are made by condensing an aqueous slurry of porcelain particles onto a platinum foil matrix or a refractory die. Sintering occurs at a temperature above the softening point of porcelain whereby the glassy matrix partially melts and the particles coalesce. The volume shrinkage is 30–40%. Porosity can be reduced from 5.6 to 0.56% by vacuum firing [62]. Sintering is the oldest method of constructing ceramic restorations but is still used by some laboratories, mainly for feldspathic or leucite-reinforced veneers. It is also used to apply ceramic veneers to an underlying high strength ceramic core. For example, the nano-fluorapatite layering ceramic, IPS e.max Ceram™ (Ivoclar Vivadent), is used to veneer both hot-pressed glass ceramic and zirconia cores.

14.4.4.2 Hot-Pressed, Injection-Moulded Ceramics

Hot pressing differs from casting in that the ceramic ingot is not liquefied but softened by heating so it can be pressed as shown in Fig. 14.8. IPS e.max Press™, a lithium disilicate glass ceramic, and IPS Empress™ (now renamed IPS Esthetic™, Ivoclar Vivadent), a leucite-containing glass ceramic, are two ceramics which can be formed in this way.

Ceramic ingots are available in a wide variety of shades and translucency. Previously, there were only three translucencies available, but this has recently been extended to five to include a high opacity ingot. There are also two additional ingots: one which allows for a pressed monolithic restoration with multi-layered tooth colours; the other provides for opalescent veneers on thin teeth [63]. With translucent ingots it is particularly important for dentists to record the shade of the underlying tooth as the technician will factor in this “stump shade” to create the desired aesthetics. All but one of the pressed ingots provides just the basic shade, so restorations are either characterised externally through glazing or alternatively cut back and, as mentioned above, veneered with IPS e.max Ceram™—a compatible fluorapatite-sintered ceramic (see Fig. 14.8). The cut-back can be done either during waxing or after pressing. To ensure compatibility the pressed ingots have a lower coefficient of thermal expansion (14.9×10^{-6}/°C) than those for the fluorapatite veneering material (18×10^{-6}/°C). The application of veneer porcelains may require multiple firings, but this can enhance the strength of the material [64].

IPS e.max Ceram™ is also available as a pressable ingot instead of sintered fluorapatite particles. This allows an aesthetic veneer to be pressed onto zirconia crown copings or bridge frameworks (e.g. IPS e.max ZirCAD™, Ivoclar Vivadent). The concept is to enhance restoration strength in more clinically demanding situations such as posterior crown and bridgework. There is some encouraging, but limited, clinical evidence to show that on a zirconia coping/framework, pressed ceramic is more resistant to chipping than sintered ceramic [65].

14.4.4.3 CAD/CAM-Machined Ceramics

A full range of all-ceramic restorations can now be made using CAD/CAM, and an outline of the workflow options was shown at the start of the chapter in Fig. 14.4. Nowadays most types of ceramic material can be formed using a purely digital workflow from scanner to milling machine including those that might otherwise be made manually using hot-press or sintering technology. Nevertheless, CAD/CAM is essential for zirconia cores and zirconia monolithic restorations. An important consideration is where the ceramic milling takes place: chairside, dental laboratory or industrial milling centre.

Materials that can be machined chairside include:

1. Feldspathic ceramic
2. Leucite ceramic (e.g. IPS Empress CAD™, Ivoclar Vivadent)
3. Lithium disilicate (e.g. IPS e.max CAD™, Ivoclar Vivadent)
4. Zirconia (partly sintered) for monolithic restorations and short-span bridgework.

Feldspathic, leucite and lithium disilicate restorations are generally milled to the required size from fully sintered blocks of ceramic. Restorations are then either polished or glazed in a small ceramic furnace, although as mentioned previously, milled lithium disilicate must be tempered at 850 °C to improve its physical properties and remove the blue colouration. Zirconia restorations are generally milled to an oversized dimension from a partly sintered block. They are then fully sintered in a furnace allowing them to shrink to the required size. One manufacturer claims that their ten available zirconia shades does away with the need for an aesthetic surface glaze.

The above ceramics can of course also be used in the lab with a larger milling machine which can accommodate larger ceramic blocks and discs. This allows multiple crowns to be milled simultaneously or the production of long-span monolithic zirconia bridgework (up to eight units). Laboratory fabrication is more suited to materials that need extra time and skill (e.g. application of sintered ceramic). These include:

1. Zirconia (partly sintered) for cores intended for crowns and short-span bridgework
2. Zirconia (partly sintered) for custom-made implant abutments.

Industrial production of all-ceramic CAD/CAM restorations involves heavy-duty milling machines weighing several tons. Some manufacturers confine ceramic production to zirconia cores, bridge frameworks (up to 14 units) and monolithic crowns for teeth/implants and custom-made implant abutments (e.g. NobelProcera™, Nobel Biocare). Others (e.g. CARES CADCAM™, Straumann), in addition, offer the full range of materials mentioned above.

It is worth noting that the original Nobel Biocare production method for both alumina and zirconia cores uses CAD/CAM milling twice. First, a pressing tool is formed in the shape of an oversized die of the tooth preparation. This tool compacts the ceramic powder and binder. The excess is then milled away with a second CAD/CAM operation to create the outer coping shape which is then densely sintered in a furnace. Copings can be made 0.6, 0.4 and 0.2 mm thick. The 0.6 mm copings are best for molars, while 0.4 mm cores are used for aesthetically critical crowns on anterior teeth and first premolars. The 0.2 mm thickness was for veneers but is rarely indicated because of problems with resin bonding to zirconia and the deeper tooth preparation needed to accommodate the core.

A clinical survey in 2010 reported the majority of restorations fabricated with milling systems were partial-coverage ceramic restorations, including inlays, onlays and ¾ crowns [66]. With the more sophisticated range of colours and translucent monolithic zirconia options now available, it would be surprising if more full-coverage restorations were not being produced by milling.

14.4.4.4 Glass-Infused Ceramics

The In-Ceram™ technique patented by VITA Zahnfabrik involves infusing lanthanum glass into a porous core made of partly sintered polycrystals consisting of alumina or magnesium spinel or zirconia. These are all core materials and require a sintered veneer for aesthetics. The production method which is similar for all three materials is shown in Fig. 14.10. The process features shrinkage of the refractory die during firing allowing it to drop away from the sintered polycrystals. This is called "slip casting"—and is also used in the manufacture ceramic lavatory pans!

14.4.5 Tooth Wear and Ceramics

Traditional teaching says that ceramics are abrasive to opposing enamel, and this is borne out by clinical observation and early in vitro studies [67, 68]. It was therefore expected that monolithic zirconia, which is much harder than feldspathic, leucite and lithium disilicate ceramics [3], would be at least as abrasive. Surprisingly, quite the opposite has been found with wear rates from mirror-polished zirconia consistently low and similar to gold [68]. The reason for this low abrasivity is the homogenous and fine grain microstructure of modern zirconia ceramics. This microstructure mirror polishes well using a suitable sequence of diamond burs and diamond-polishing pastes. However, zirconia is not always kind to enamel. Glazed zirconia is similarly abrasive to other ceramics. This is because the thin glaze wears away

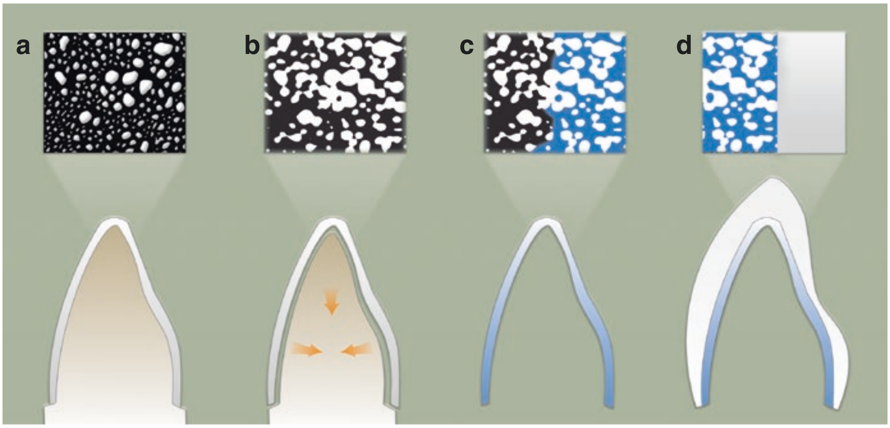


Fig. 14.10 Slip cast technique (from left to right): (**a**) alumina particles applied to refractory die, (**b**) fired to partial fusion whilst die is shrunk, (**c**) slurry of lanthanum glass flowed onto coping and refired causing glass to infuse by capillary action, (**d**) glass-infused coping veneered with compatible sintered ceramic

leaving a hard, rough surface. Zirconia is also abrasive if it is ground with a diamond bur but not polished. Despite these encouraging in vitro results supporting the use of polished monolithic zirconia, it would be unwise to expect it to perform in the same way clinically, and further research is clearly needed. Meanwhile, dentists should consider asking technicians for a mirror-polished occlusal surface when prescribing these restorations but more importantly spend time repolishing after occlusal adjustment.

Whilst in vitro wear studies of ceramics are notoriously variable in their findings [68], they do indicate that some ceramics are prone to roughening if placed under repeated occlusal loading. These surface changes may predispose opposing tooth wear under heavy occlusal loads [3] and have been found in some feldspathic, fluorapatite and lithium disilicate ceramics [69]. Furthermore, dietary acids may cause erosion and roughening particularly of low-fusing ceramics which in turn may wear away the opposing tooth [23]. Clinically, it would be best to avoid using these ceramics when creating guiding (gliding) occlusal contacts in bruxists. Current best practice would be to use an alloy guiding surface for restorations (e.g. with a ceramo-metal crown), although polished monolithic zirconia shows promise both in terms of low abrasivity and fracture resistance.

14.4.6 Choice of Ceramic System

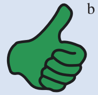
Advising dentists on which ceramic system to use is not so easy. We now have limited 10-year follow-up for individual crowns made from lithium disilicate systems [47], but, as mentioned in Chap. 2, there is only 5-year follow-up data comparing different ceramic systems [2], and this may well be subject to various study biases. Nevertheless, that 5-year study reported similar performance of all the systems, at around 95% survival, except for the weaker feldspathic/silica-based ceramics which performed less well both anteriorly and posteriorly [2]. The veneer ceramic of densely sintered zirconia cores was also seen to fail significantly more often when used posteriorly. However, the meta-analysis did not include monolithic zirconia. Furthermore, it should be remembered that ceramics are constantly evolving, so published clinical data may not always be relevant to current materials.

The generic types of ceramic available and their clinical indications are shown in Tables 14.4 and 14.5. These recommendations are largely based on advice from manufacturers and clinical observations. To choose between the systems, we can reflect on the guiding principles evolved by others who reviewed the literature albeit almost 10 years ago [70, 71]. The important clinical parameters are:

14.4.6.1 Type of Restoration

Most ceramic systems have a limited number of clinical applications, but pressed lithium disilicate (IPS e.max™) can be used for most types of single tooth restorations (see Tables 14.4 and 14.5). It can also be resin bonded which may enhance the strength of the restoration [72] and, providing the restoration is finished in enamel, reduce the need for conventional retention and resistance form in the tooth

Table 14.4 Glass matrix ceramics and their clinical indications—these can all be etched with HF making them suitable for adhesive dentistry (Table derived from Gracis et al. [38])

	How made	Coping (C) Monolithic (M) Veneer (V)[a]	Etchable	Veneer restoration	Partial coverage	Full crown (anterior)	Full crown (posterior)	Implant abutment
Glass matrix ceramics								
Feldspathic	Layered slurry on investment or platinum foil	M/V	**Y**					
Synthetic								
Leucite-based	Press, CAD/CAM	C/M	**Y**					
Lithium disilicate	Press, CAD/CAM	C/M	**Y**					 [b]
Fluorapatite-based[c]	Layered slurry, Press	V	**Y**	–	–	–	–	–
Glass-infiltrated								
Alumina	CAD/CAM or slip casting	C	**Y**					

(continued)

Table 14.4 (continued)

	How made	Coping (C) Monolithic (M) Veneer (V)[a]	Etchable	Veneer restoration	Partial coverage	Full crown (anterior)	Full crown (posterior)	Implant abutment
Alumina and magnesium spinel	CAD/CAM or slip casting	C	**Y**			👍		
Alumina and zirconia	CAD/CAM or slip casting	C	**Y**			👍	👍	

[a]Veneer for alloy or ceramic coping or framework
[b]Hybrid implant abutment resin bonded to titanium base
[c]Only used to veneer lithium disilicate or zirconia framework

Table 14.5 Polycrystalline ceramics and their clinical indications—these cannot be etched with HF (Table derived from Gracis et al. [38])

	How made	Coping (C) Monolithic (M) Veneer (V)	Etchable	Veneer restoration	Partial coverage	Full crown (anterior)	Full crown (posterior)	Implant abutment
Polycrystalline ceramics								
Alumina	CAD/CAM	C	**N**	👍[a]		👍[b]	👍[b]	
Stabilised zirconia	CAD/CAM	C/M	**N**		👍[c]	👍[b]	👍[b]	👍
Zirconia-toughened alumina Alumina-toughened zirconia	CAD/CAM	C/M	**N**		👍[c]	👍[b]	👍[b]	👍

[a]Not the first choice of material for a veneer restoration as sufficient space to accommodate both the coping and veneering ceramic may result in destructive tooth preparation
[b]Again, retentive tooth preparation needed but preparation for monolithic crowns less destructive
[c]Retentive tooth preparation needed to avoid bonding issues which may result from not being able to etch and bond the intaglio surface

preparation (e.g. with an onlay or veneer). Furthermore, if the restoration is effectively resin bonded to the underlying tooth, additional strength will be conferred to a relatively weak ceramic as occurs with leucite ceramic veneers and crowns. Indeed, the strength of an intact tooth can be re-established with resin-bonded restorations—again providing the finishing line is in enamel. If the restoration is finished in root dentine, its strength is markedly reduced [73]. Currently, only the glass ceramics, with the exception of glass-infused ceramics, can effectively be etched with HF to create a reliable resin bond.

However, there may be clinical demands for additional strength (including wear and abrasivity resistance) or aesthetic demands which dentists feel more confident meeting with other ceramic systems. Dentists are reminded not to forget metallic restorations which may sometimes be the most reliable option for patients prepared to accept them.

14.4.6.2 Sufficient Strength

Flexural strength measurements are not always a good guide to the clinical performance of restorations. For example, zirconia cores have strengths often exceeding 1000 MPa, but restorations still fail from chipping of the weaker veneering ceramic. Unlike the glass ceramics, zirconia appears not to rely on the luting cement to give it strength [74].

Bruxists need strong restorations to bear the heavy occlusal loading during clenching and grinding. Biomechanically these patients are best persuaded to have a metal occlusal surface, but understandably some patients may insist on a completely tooth-coloured restoration. Monolithic zirconia may offer a promising alternative as in vitro as it has good wear characteristics [68] and resistance to chipping [75, 76]. However, translucent zirconia has a lower flexural strength than zirconia core material [77]. A trial comparing the clinical performance of ceramo-metal restorations with monolithic zirconia and lithium disilicate restorations in these more demanding patients is most certainly needed.

In vitro studies suggest that for monolithic zirconia an occlusal thickness of 0.5 mm and chamfer depth of 0.5 mm—as might be used for all-metal restorations—are sufficient to survive occlusal loading on molars [78]. Unfortunately, in vitro testing provides conflicting results [56, 57, 79] because of differences in testing regime and often lack of adequate fatigue loading. Again, this needs to be resolved with a clinical trial, but there are also practicalities with providing adequate clearance during tooth preparation which are considered in Chap. 20.

Nevertheless, monolithic zirconia crowns may hold promise where aesthetic requirements are not absolute but strength is (e.g. for posterior teeth or lower anterior teeth) [60].

14.4.6.3 Aesthetic Demands

Some clinicians consider that there is an inverse relationship between ceramic strength and aesthetics. In other words, the weaker glass ceramics look better than the strong crystalline ceramics [9]. This opinion may have originated because of the opaque cores used for high strength alumina and zirconia crowns. Crowns with opaque cores, including ceramo-metal crowns, may look artificially bright because of the way light is reflected to the observer rather than some of it being refracted and transmitted through the restored tooth. The weaker feldspathic, leucite and lithium disilicate ceramics are much better at mimicking translucency of enamel and dentine (see Chap. 17), particularly when luted with a translucent resin cement.

On the other hand, crowns with opaque cores have a major advantage in masking tooth discolouration not amenable to bleaching. In these circumstances, if a leucite ceramic is chosen, it would need to be up to 2.0 mm thick [70]—most likely resulting in a massively destructive tooth preparation. To get round this problem with lithium disilicate, Ivoclar Vivadent has recently introduced a pressable ceramic with high opacity for masking dark teeth or an underlying zirconia framework [80].

If a zirconia restoration is chosen both for strength and masking capabilities, the decision should be tempered by the need to have a resistant and retentive tooth preparation.

14.4.6.4 Resistance and Retention

Conventionally cemented restorations need tooth preparations with adequate resistance and retention to prevent them being dislodged (see Chaps. 15 and 20). With ceramo-metal crowns, there is often the opportunity with short/tapered preparations to incorporate grooves and boxes, should there be sufficient tooth remaining. These features when reproduced on the restoration's intaglio surface can reduce the risk of it being pulled or rotated off the tooth. However, they are difficult to reproduce with CAD/CAM milling, particularly if the groove diameter is smaller than that of the milling bur [71]. Furthermore, whilst the marginal fit is generally acceptable for most ceramic systems, the internal gap width (between the axial wall of the prep and the intaglio surface of the restoration) of many milled ceramic restorations is not as close as for cast metal. This may have biomechanical implications for the ability of a thick cement lute to resist functional forces [70].

Zirconia crowns have been reported to fail more often than other types due to loss of retention [2]. The reason for this is unclear but may be due to unretentive tooth preparation, a misplaced faith in the resin bond to zirconia or a thick cement lute acting either singularly or in combination. To improve retention and resistance, dentists may need to consider extending the axial wall height. The restoration margin may then be placed subgingivally or kept supragingival via a crown lengthening procedure (see Chap. 10). The implications of margin placement on the choice of ceramic system are considered next.

14.4.6.5 Margin Placement

Deciding where to place the ceramic margin can have consequences for moisture control, restoration strength and microleakage which may impact the choice of cement and ceramic. With a subgingival margin, moisture control may be insufficient for resin bonding but sufficient for glass ionomer cementation. The decision to use a water-based glass ionomer cement means the strengthening effect from resin bonding [72] is lost, so a stronger ceramic is needed (lithium disilicate, zirconia core or monolithic zirconia).

Resin bonding is not so effective where the finishing line is extended onto dentine beyond the cemento-enamel junction. This is because without enamel loss of adhesion and microleakage inevitably result [71]. This makes for a difficult clinical choice—whether to use a conventionally cemented full-coverage restoration or select an adhesively bonded glass ceramic. The adhesively bonded ceramic may be much more conservative of tooth structure but more prone to leakage. No doubt the development of newer more effective dentin bonding agents will make this decision easier both for ceramic and composite restorations.

14.5 Resin Composite

The use of resin composite as a dental restorative material has increased dramatically over the last couple of decades to a point where it has largely become the restorative material of choice for direct restorations in many situations, including replacement of amalgam fillings [81]. The clinical reasons for this rise in popularity include good aesthetics, command set, bonding and reparability. There have also been improvements in the physical properties of resin composites resulting in more durable direct restorations. However, large complex composites may be difficult to place clinically, so indirect composites continue to be developed allowing restorations to be formed in the comfort of the laboratory. This section gives an overview of both direct and indirect composites.

14.5.1 Direct Composite Restorations

The use of resin composite for large complex restorations sometimes makes a lot of sense (see Fig. 14.11). Of course, the teeth for this patient could have been restored with indirect restorations, but she had recently undergone a crown lengthening procedure, and as a short-term option, to allow gingival maturation, direct composite restorations were placed. The teeth were prepared with a chairside airborne particle abrader (CoJet™, 3M ESPE) and following acid etching augmented directly with resin-bonded composite (Filtek Supreme™, classified by 3M ESPE as a “nanocomposite”). The resulting restorations proved to be technically and aesthetically acceptable and were maintained as a longer-term option. A patient of this nature is consigned to a lifetime of indirect restorations, and so delaying this with direct restorations that are conservative to the limited underlying tooth tissue and easily repairable is preferable. Indeed, in a similar common clinical scenario, the worn dentition, direct resin composite augmentations may provide a very useful medium-term solution particularly, as discussed in Chap. 2, when combined with strategic occlusal restoration with more durable metal or ceramic materials.

Every dental student should know that resin composite consists of organic resin matrix containing inorganic filler coated with silane to couple the two together. Also well-known are the options for curing: light, chemical activation or dual cure. The trend with filler particles is to increase filler loading with nanometre-sized silica

Fig. 14.11 A case suffering from amelogenesis imperfecta. Images (**a**) and (**b**) show the initial presentation with worn remaining teeth and some minimal composite augmentations. Images (**c**) and (**d**) show direct composite augmentations after 6 months of service. These were provided at an increased vertical dimension with the aid of a diagnostic wax-up. At a social distance, a pleasing result is achieved. The case highlights the challenges of providing extensive direct composite restorations: multiple lengthy appointments, difficulties of obtaining optimal tooth morphology and contour and any surface irregularities prone to picking up staining

particles. Other particle types include silica and barium glasses, zirconia and alumina. A high filler loading makes for a strong material with good wear resistance, but too high a loading (much above 60% by volume) can make it unworkably stiff incorporating voids which weaken it when set. The filler also imparts radiopacity.

There have been many composite classifications based on filler characteristics (e.g. conventional, microfil and hybrid), but disappointingly there is no agreed classification system for current materials. Nevertheless, modern materials are often described as “nanocomposites” or “nano-hybrids” to distinguish them from the older microhybrid materials which also contained the same nano-sized particles but less of them!

The properties of a composite are controlled not only by the filler but also by the organic resin. Many composites continue to use either BisGMA resin diluted to a workable viscosity with TEGDM or UDMA resins or derivatives of these. However, newer silorane resins which have less polymerisation contraction are showing promise [82]. Composites designed for anterior and posterior restorations, including large coronal build-ups, are called “universal composites”. For other applications, there are less viscous “flowable composites” and more viscous “packable composites”. Viscosity is largely controlled by reducing or increasing filler loading.

The “new kid on the block” is bulk-fill composites. These aim to eliminate the incremental placement normally required for light-cured materials. Whilst showing promise in the laboratory, there are marked differences between materials, and clinical evidence is lacking [83].

Direct and indirect composites share similar resins and fillers. However, as discussed in the following section, the way indirect composites are processed can improve physical properties. Dentists should also be aware that indirect composites also have disadvantages.

14.5.2 Indirect Composite Restorations

Indirect composite restorations can be made using a variety of techniques (see Box 14.3).

A review by Nandini [84] discussed the types of laboratory resin composite available, categorising them into first-generation—some of which are no longer available—and second-generation materials. Second-generation materials, e.g. Artglass™ (Heraeus Kulzer), BelleGlass HP™ (Kerr Dental), Solidex™ (Shofu), Charisma™ (Kulzer), Gradia Indirect™ (GC) and Sinfony™ (3M ESPE), have higher filler contents. Additionally, they utilise improved polymerisation techniques to ensure the degree of conversion is as high as possible to optimise flexural strengths and stiffness (elastic modulus). Polymerisation techniques include extended periods of light curing, heating, pressure, oxygen-free environments and vacuums. Fibre reinforcement is available for strengthening bridgework but is not a common feature in restorations for individual teeth.

Box 14.3: Methods of Making Indirect Composite Restorations

The laboratory process for producing indirect composite restorations is simple, quick and efficient for the technician in comparison to ceramics and metals. Three main methods of fabrication exist:

- Direct-indirect: This involves applying a separating medium onto the tooth prior to condensing the composite into the cavity and light curing. The composite is then removed from the mouth and subjected to further curing processes, involving heat or pressure or both, before being cemented in place
- Conventional indirect: This involves the fabrication of a die and the application of composite to this in layers before enhanced curing
- CAD/CAM milling of prefabricated composite blocks manufactured to optimise filler loading and curing. These are sometimes referred to as “resin-ceramic” materials.

Resin composite can also be used as a veneering material over a metal substructure. Gingival shades of resin composite are available that allow for replacement of lost gingival tissue in localised sites on single crowns or more generally on implant supported bridges.

More recently, Mainjot et al. [85] noted that more and more indirect composite restorations are being made using CAD/CAM milling (Fig. 14.12). They reported that most CAD/CAM composite blocks are manufactured using particulate filler dispersed within a resin but castigated manufacturers for giving insufficient information to characterise their products properly. A promising development is the polymer-infiltrated ceramic network (PICN) which as mentioned earlier is a hybrid of ceramic and composite. It is like the glass-infused ceramics, but instead a resin is infused into a block of partly sintered silica glass. Experimental PICNs are now almost as strong as milled lithium disilicate, although commercially available PICNs currently offer only a fraction of this performance. Yet, from an economic perspective, indirect composite restorations are easier to mill than ceramic ones; CAD/CAM burs are expensive and can mill only 5–10 glass ceramic blocks compared to over 100 resin composite blocks [86]. Furthermore, milled composite restorations show negligible edge chipping compared with milled ceramics [49] which will be reflected in the quality of a restoration margin.

Many dentists find extensive direct composite restorations of the type shown in Fig. 14.11 technically challenging and time consuming. Achieving good tooth morphology is difficult, although this can be eased using a diagnostic wax-up and appropriate stents. On the other hand, indirect composites facilitate the creation of optimal contours for the proximal and occlusal aspects of large restorations.

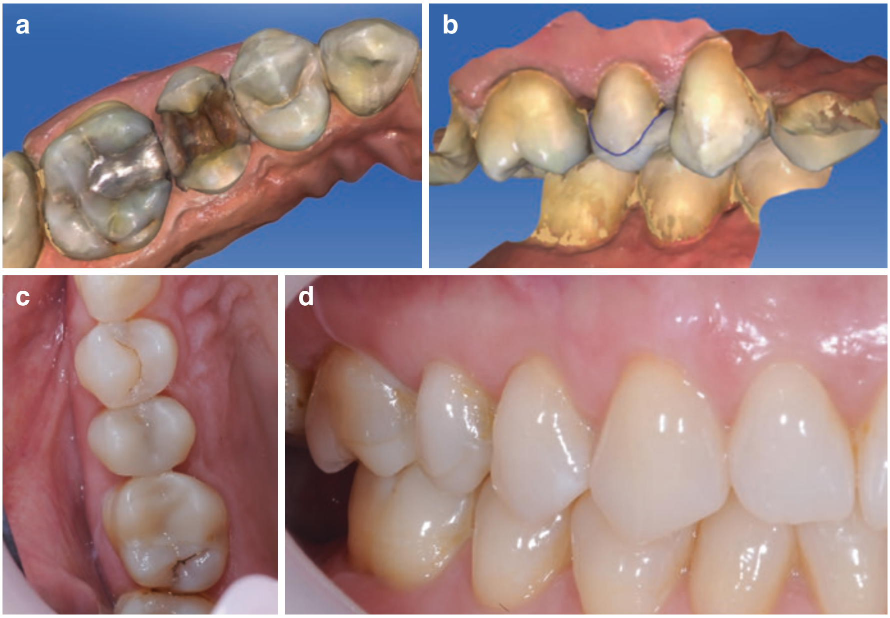


Fig. 14.12 CAD/CAM composite onlay: scanned preparation at 15 (**a**). The scanned opposing arch shown in occlusion and the onlay's outline defined (**b**). Finished case showing MOD onlay at 15 and MO onlay at 16 replacing the mesiobuccal cusp (**c**, **d**) (Courtesy of Andrew Keeling)

However, more tooth preparation may well be needed to remove undercuts to seat indirect restorations. Other perceived advantages include:

1. *A higher degree of conversion (i.e. the resin is better cured) with improved physical properties compared with simply light curing a direct restoration*. Interestingly, light-cured direct restorations can continue to cure, and water may plasticise many resin systems, so the difference in physical properties of indirect restorations compared with direct ones may become less with time in the mouth [87]. Furthermore, a high degree of conversion may make repairs less reliable as there will be less unreacted methacrylate groups available for chemical bonding. This is also an issue when luting indirect composites, so airborne particle abrasion incorporated with silane treatment (e.g. CoJet™ and Rocatec™ systems, 3M ESPE) is recommended for most materials with the exception of PICN where the glass ceramic can be etched with HF [85]
2. *Polymerisation contraction restricted only to a thin resin lute*. A long-held myth is that indirect composite restorations suffer less from microleakage because setting stresses at the interface will only be from the thin layer of luting resin. However, microleakage studies comparing direct and indirect composite restorations finished in dentine show similar results, most likely because the constrained lute has a higher "C factor" than for the composite placed directly into the same cavity. The C factor is the ratio of bonded surface area to free surface area. A high C factor may cause shrinkage stresses sufficient to disrupt bonding [88].

As a rule of thumb, dentists can reasonably choose indirect composites in situations where they wouldn't worry about a direct composite surviving (e.g. in sites not subjected to high stresses—as with many inlays and onlays). A recent systematic review and meta-analysis of clinical studies [89] concluded that there was no difference in the longevity of direct and indirect resin composite restorations in permanent posterior teeth.

There are large numbers of in vitro studies comparing indirect composite inlays/onlays to their ceramic counterparts with one review identifying 91 in vitro studies but only a handful of clinical studies. A randomised controlled trial (RCT) demonstrated similar survival rates of ceramic and composite inlays at 10 years when repairs were not considered failures [90]. A large multicentre RCT is currently ongoing on this topic [91].

With regard to crowns and bridges, very limited clinical data exist, but many consider indirect resin composite a good material choice for long-term provisional as shown in Fig. 14.13. Dentists should be aware that there are CAD/CAM resin blocks specifically designed for provisional restorations. These materials are significantly less durable than those designed for definitive restorations and are best used only for the short or medium term. Interestingly, composite crowns have been shown in vitro to absorb a considerable amount of occlusal force compared with ceramic crowns [92]. This "shock absorbing" characteristic may theoretically be beneficial for patients with implant crowns or periodontally involved teeth, but this hypothesis has not been tested clinically. A fly in the ointment is that elastic

Fig. 14.13 This case highlights the use of indirect composite restorations as a long-term provisional restoration during disease stabilisation in a patient with generalised aggressive periodontitis who already had existing crown and bridgework. The benefits of using indirect composite in this situation are the good aesthetics, relatively low costs, and ease of chairside modification, e.g. to aid cleaning or to refine tooth shapes

deformation of the crown during occlusal contact may disrupt the cement lute. Indeed, debonding has been reported a significant issue for one CAD/CAM composite system used with zirconia implant abutments [85].

An interesting development combines direct and indirect composite techniques using preformed composite veneers made from a 0.3-mm-thick layer of industrially cured "nano-hybrid" (Componeer™, Coltène/Whaledent AG). These are fashioned chairside or in the laboratory to approximate the shape of the underlying tooth—in a similar way to the preformed leucite ceramic veneers mentioned previously—and then bonded using a direct nano-hybrid composite. This concept is not new as it was used in the early 1980s with preformed acrylic laminate veneers which failed lamentably because of the composite debonding from the acrylic. By contrast, early bond strengths have been reported for the new "nano-hybrid" similar to those obtained with etched lithium disilicate [45]. Clearly, clinical studies are needed before this approach can be recommended.

Conclusion

In this chapter, we have focused on the wide range of materials available for extra-coronal restorations and their continuing development—often underpinned by CAD/CAM technology. The choice of material for individual patients should of course be assessed from a material science perspective—where possible with evidence-based clinical data (Chap. 2). Just as important is to ensure there is a healthy start before restoration (Chaps. 3–8) and that future risk is managed (Chaps. 9–13). The best time to carry out a careful assessment of the patient's needs, expectations and ability to undergo treatment is while undertaking the history and examination (Chap. 18). Once a diagnosis has been reached, the patient can be offered appropriate restorative options and the prognosis and aesthetics (Chap. 16) of each discussed.

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Luting, Cements and Bonding

15

James Field, Michele Barbour, and Robert Wassell

15.1 Learning Points

This chapter will emphasise the need to:

- Appreciate why conventionally-cemented extra-coronal restorations require preparations with retentive axial walls (minimally-tapered and sufficiently long)
- Avoid creating a thick lute between a preparation and the inner surface of a restoration
- Ensure your technician facilitates seating of the restoration by die spacing, venting the crown or programming a lute space using CAD/CAM
- Be familiar with surface treatments which can enhance resin-bonding to tooth structure and restorative materials
- Be familiar with resin-bonding agents, their uses and limitations
- Choose a luting agent which is appropriate to the situation.

As discussed in the previous chapter, a successful outcome partly depends on the material chosen to make an indirect restoration. However, the lute used to secure it to a tooth is equally important. At one time, the only option was conventional zinc phosphate cement with its simple setting chemistry and no adhesive properties.

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Nowadays, not only are there other conventional cements but also a wide range of adhesive resin materials and surface treatments, so gaining an understanding is a bit more of a challenge. Therefore, the purpose of this chapter is to consider the mechanisms and materials employed for luting.

But firstly, what do we mean by a lute? How does it hold a restoration in place, and what can we do to optimise chemical adhesion? Many of these materials are technique-sensitive and require meticulous handling. Luting procedures, hints and tips are considered later in chapter 24.

15.2 Luting and Lute Micro-mechanics

The Oxford English Dictionary broadly defines a lute as "a liquid clay or cement that is used to seal a joint". For a lute to be effective, it has to be sufficiently viscous to allow for handling but runny enough to effectively wet the surfaces of the substrates it is sealing [1]. In dentistry, these substrates are the abutment (either a prepared tooth or an implant) and the intaglio (fitting) surface of the restoration. To the naked eye, abutments and restorations look smooth, but microscopically they are irregular and rough, e.g. from bur marks, airborne-particle abrasion or chemical etching. Close adaptation of the set lute to this surface provides *micro-mechanical bonding*. In addition, some cements offer *chemical adhesion*, and these will be discussed later. Aside from a lute's ability to wet a surface, its *cohesive properties* are important—we don't want the lute to disintegrate under loading.

Behaviour at the restorative margin is also important. A lute needs to *resist dissolution* where it is exposed to the oral environment. It must also be *biologically compatible*.

15.2.1 Luting to Relatively Flat Surfaces

Look around—lutes are everywhere—most obviously the mortar between bricks. Indeed, mortar and dental cements, like zinc phosphate, work in a similar way. An onlay luted to a flat occlusal surface has a similar configuration to cemented bricks. With bricks this configuration supports the vertical load of the wall. Similarly, a flat dental onlay supports apically directed occlusal forces. It works because both mortar and dental cement are strong in compression. However, they are both weak in tension. So, a brick wall can easily be prised apart. Similarly, if a patient eats a toffee, the cement lute easily fractures, and the onlay is dislodged (see Fig. 15.1).

Most clinicians would be rightly hesitant about using a dental cement like zinc phosphate to lute a restoration to a flat tooth surface. However, resin cements are sometimes used for this purpose because they have greater cohesive strength and provide both micro-mechanical bonding and chemical adhesion, particularly if there is sufficient intact enamel. Enamel is, of course, a much better and more reliable substrate for resin bonding than dentine.

There are several issues relating to thickness and stiffness of the set resin cement which, for the technically-minded, are summarised in Box 15.1.

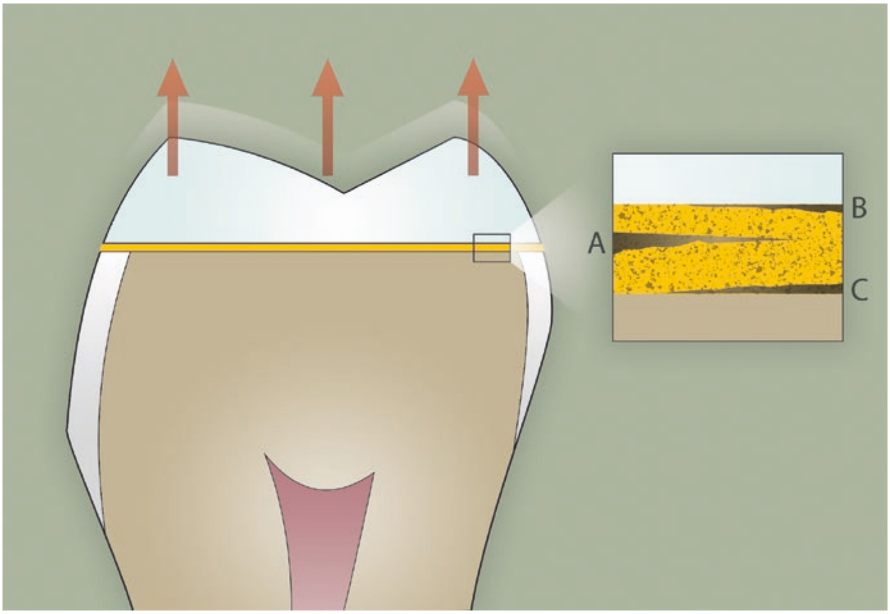

Fig. 15.1 A flat onlay cemented to an occlusal surface with a conventional cement like zinc phosphate. Axial withdrawal forces cause tensile stresses which easily disrupt the lute: *A* cohesively, *B* at the interface with the restoration, or *C* with the tooth

Box 15.1: Concepts of Optimum Resin Cement Film Thickness and Stiffness

Minimum cement film thickness is measured in a standardised way simply by pressing a sample of the unset material between two glass slabs under a specified load. Most cements comply with the ISO specification of 25 μm, but film thickness rapidly increases when used 2–3 min after starting mixing [2].

The optimum thickness for one resin cement is quoted as 90 μm [3, 4]. However, it is worth emphasising that this value reflects the *bond between the lute and two alloy substrates*—not the bond to dentine. The optimum thickness for bonding to tooth is likely to differ between cements and the configuration of the tooth preparation. Optimum cement thickness may reflect the interaction of many factors including:

- Polymerisation stresses within the lute competing with the development of adhesive bonds—particularly to dentine which must be regarded as the weak link in the chain. Polymerisation stresses in resin appear less disruptive in a slightly thicker resin layer [5], but there is still a race between establishing a dentine bond and the setting of the resin. Clinically, this may explain why bonding a restoration (e.g. a veneer) to a sclerosed dentine surface of a worn tooth is not particularly reliable, because the resin sets in advance of the dentine bond being fully formed causing the bond to rupture [6]

(continued)

Box 15.1 (continued)

- The cement's modulus of elasticity (i.e. its stiffness) should be low enough to allow some cushioning of applied loads but high enough to distribute resulting stresses through the bonded system [4, 7]. There appears to be an interaction between cement modulus and preparation design which makes it difficult to recommend a specific modulus cement. However, there is no advantage in making it any higher (18 GPa) than for dentine [8]
- Thick cement layers may contain porosities and other defects causing stress concentrations which result in cohesive/adhesive failure under load.

15.2.2 Luting to Preparations Extended Axially

We will consider tooth preparations in detail in Chap. 20, but at this stage we need to consider some important but very basic principles in relation to cementation with conventional cements (i.e. zinc phosphate, zinc polycarboxylate and glass ionomer cement) which are all strong in compression but weak in tension.

The way to avoid these cements from failing is to design your preparation to extend the restoration axially. In this way non-axial forces cause less damaging stress concentrations in the lute (Fig. 15.2). In addition, preparations must be sufficiently long and minimally tapered [9] and with a thin cement lute [10, 11]. This configuration favours shear and compression stresses within the lute rather than disruptive tensile stresses.

A thick lute will be vulnerable to cohesive damage or rupture of an interface. However, the thicknesses of cement lutes measured clinically under crowns are often much higher than ideal (often approaching or exceeding 100 μm) [12–14]. In these circumstances, we are ever more reliant on our preparation features to retain a cemented restoration.

There are several causes of thick lutes:

- Restorations made using traditional techniques rarely fit perfectly
- During cementation, it is difficult to seat restorations fully and without slewing (uneven seating) unless a laboratory seating rig [10] is used—clearly impractical for clinical dentistry
- Hydrostatic pressure developed under a crown during cementation.

Methods of controlling cement layer thickness and improving seating focus largely on reducing the hydrostatic pressure during cementation and are considered at the end of the chapter.

Of course, restorations are not only displaced by axially directed forces. During chewing or bruxism, restorations are often loaded obliquely which will tend to twist the restoration about its preparation. This results in a complex pattern of

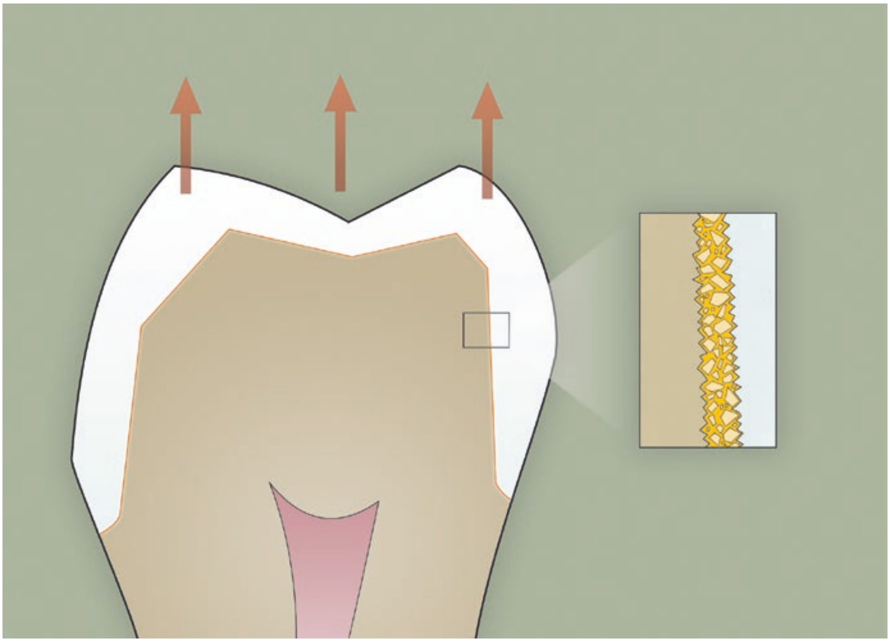

Fig. 15.2 Here the restoration is extended axially with a retentive preparation and a thin cement lute. At a microscopic level, the cement particles of the lute engage asperities of both the abutment and the restoration causing less tensile stresses. This is a much more favourable situation than Fig. 15.1 for conventional cements like zinc phosphate

> **Box 15.2: Definitions of "Retention and Resistance"**
> - The *retention form* of a preparation relates to its ability to prevent dislodgment of a luted restoration along its path of insertion.
> - The *resistance form* of a preparation prevents dislodgment of the luted restoration when subjected to oblique forces.

tensile, shear and compressive stresses within the lute and its interfaces [15]. Tensile stresses acting on the lute at the margin are particularly damaging (Fig. 15.3) and when combined with repetitive loading may result in fatigue failure, often with the lute peeling away from the weaker interface. Fortunately, these issues can largely be overcome with careful tooth preparation which optimises features of retention and resistance (terms defined in Box 15.2 and explored in greater depth in Chap. 20).

To some extent, adhesive bonding with strong resin lutes has reduced our total dependence on preparation design to secure a retentive restoration. In the next section, we consider how to optimise adhesion of these materials.

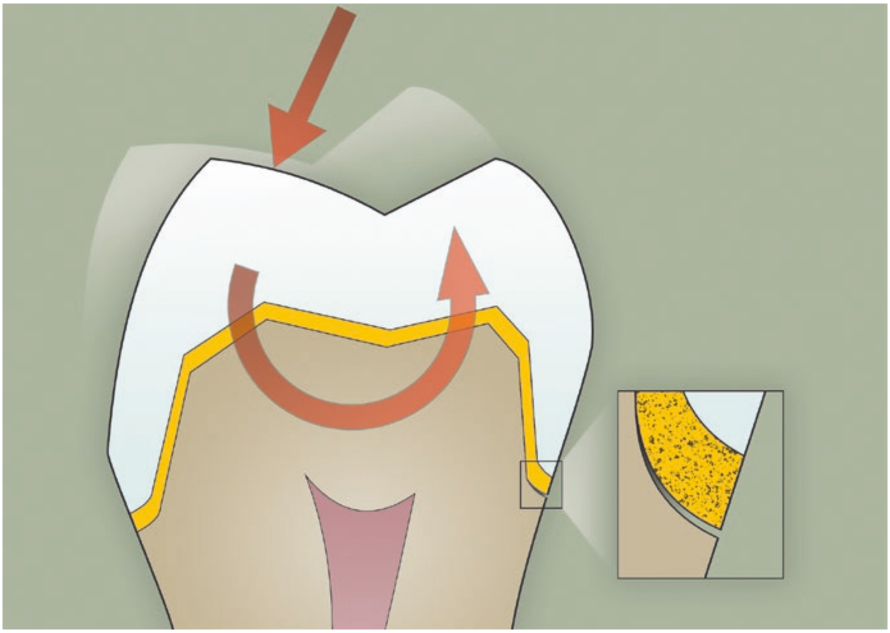

Fig. 15.3 Obliquely directed occlusal forces will tend to rotate the crown about its preparation particularly if it is short/tapered and the lute is thick. Lute failure will occur at the weakest link—often the interface with dentine. The lute then peels away from the dentine explaining why it is frequently found in the dislodged crown

15.3 Surface Treatments and Coupling Agents for Chemical Adhesion

Most recent advances in resin cements are based around chemical adhesion of the lute (to both the abutment and the restoration). However, at the tooth interface, we still rely largely on a micro-mechanical bond between the bonding resin and the etched enamel or conditioned dentine (Fig. 15.4). In addition, the bonding resin has hydrophilic and hydrophobic reactive groups allowing a chemical bond to tooth tissue and composite resin, respectively. Methods of achieving this bond are considered later in this chapter.

Nowadays, dentists can bond to a range of materials. This has been made possible by the introduction of surface treatments and chemical coupling agents which have multiple reactive sites (see Table 15.1). So, resins can now be bonded to the intaglio surface of indirect restorations made from alloys, ceramics or resin composites. Surface treatment and coupling agents may also be used in an already-restored tooth, to chemically bond the cement to an underlying but well-retained core or to repair a ceramic fracture.

The surface of a restoration or tooth can be treated by various means to ensure the potential for micro-mechanical retention and chemical adhesion is maximised [17]. Airborne-particle abrasion (aka sandblasting) with alumina grit (27 or 50 μm) [18] is the most common method. It works by roughening and cleaning the surface allowing

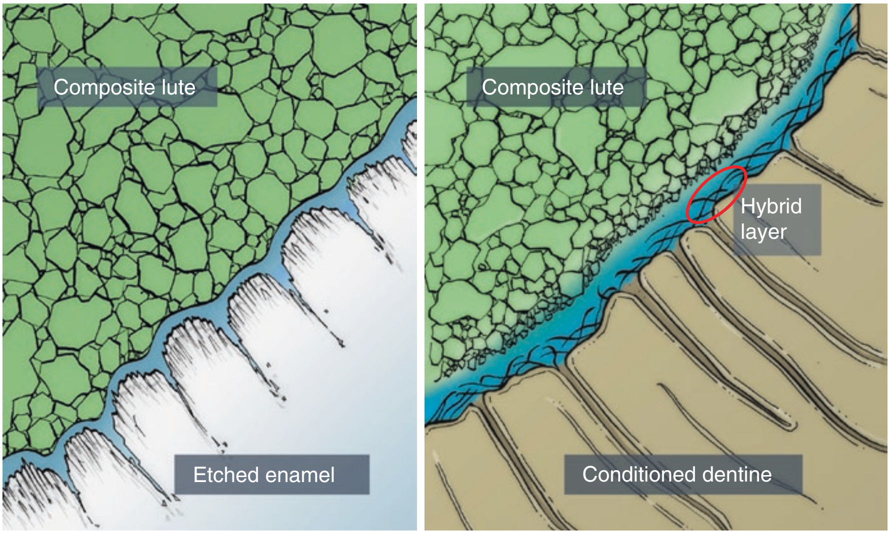

Fig. 15.4 Schematic showing the difference in the micro-mechanical bond of bonding resin (shown in blue) to etched enamel and conditioned dentine. With conditioned dentine, a hybrid layer is formed (ringed in red) consisting of demineralised collagen and infused bonding resin

easier wetting by conditioners or bonding agents. Short-term improvements in bond strength are similar to those obtained by roughening with a diamond but cause much less tooth destruction [19]. It is tempting to think that sandblasting alone is sufficient to condition tooth tissue, but to avoid poor bonding, sandblasting must be followed up with proper etching or chemical conditioning [20].

Some intra-oral sandblasting systems are designed specifically to enhance resin bonding to restorative materials [16]. CoJet™ (3M ESPE), considered by many to be the "gold standard", can provide a fused silica surface to many restorative materials, including metals, ceramic and composite. This process of silication (see Fig. 15.5) may also reduce the degree of microleakage observed at the marginal interface [22]. Although CoJet™ is not indicated by the manufacturers for use on dental tissues, it has been shown to produce an enhanced bond to dentine—at least in the short-term—when combined with a self-etching primer [23]. Whilst it would not be unreasonable to use CoJet™ to surface treat an existing restoration and adjacent tooth tissue, further work is needed before recommending it for routine pre-conditioning of tooth tissue prior to dentine bonding.

Dental laboratories have a similar material to CoJet™ called Rocatec™ (3M ESPE) which has had a good track record since its introduction in 1989 [24–26].

Before the introduction of silication, some labs enhanced the resin bond to cast-gold restorations by heat treating them to produce a surface-active layer of black copper oxide. Alternatively, they tin-plated the intaglio surface to get a chemical bond. Early research showed that the heat-treated surface gave superior bond strengths [27]. However, heat treatment never caught on as a mainstream method because the black oxide formed all over a restoration and had to be polished away after luting to avoid contaminating the intaglio surface.

Table 15.1 Examples of surface treatments and coupling agents to enhance bonding to restorative materials—derived from Lung et al. [16]

Surface treatments		
Type of treatment	Suitable restorative substrates	Comments
Sandblasting 50 µm alumina	• Cast alloys • Ceramics • Tooth	Routinely used by dental laboratories to clean and roughen the intaglio surface of cast alloys. Care must be taken with ceramics as sandblasting can easily cause damage Useful intra-orally to clean and roughen enamel and dentine surface prior to etching, conditioning and bonding
Sandblasting with tribochemical silica coating	• Cast alloys • Ceramics (*non-etchable with hydrofluoric acid e.g. zirconia and densely sintered alumina)* • Indirect composites • Direct composites	Critical for the lab or intra-oral sandblaster to have correct pressure and nozzle to obtain tribochemical effect. Silane coupling agent then brushed on to obtain siloxane linkage to composite resin and to dislodge loose abrasive particles
Etching with hydrofluoric acid (HF)	• Feldspathic ceramics • Leucite-containing ceramics • Lithium silicate and disilicate ceramics	HF is a hazardous material and best suited to laboratory rather than clinical use. To get sufficient etching, but avoid over-etching, the recommended concentration of HCF and etching times must be followed for each ceramic material. Again, silane coupling is needed after etching and before resin bonding
Coupling agents		
Agent	Suitable restorative substrates	Comments
Silanes	Ceramic (HF etched) Ceramic (silica coating) Composite (silica coating) Alloys (silica coating)	Come as single-bottle or two-bottle systems with the latter having a longer shelf life Silane chemistry is complex, and some silanes, e.g. 3-methacryloxypropyltrimethoxysilane (MPS), appear more effective than others
Phosphate Esters (e.g. MDP, PENTA, thione and thiol primers)	Metal alloys Zirconia	MDP phosphate monomer (10-methacryloyloxydecyl dihydrogen phosphate) and PENTA (dipentaerythritol penta-acrylate phosphate) not only bond to sandblasted metal; They also bonds chemically both dentine and enamel. They may also offer some prospect of bonding to zirconia
Adhesive and self-adhesive resins	General purpose	Adhesive resins use one or more of the above bonding agents prior to bonding. Self-adhesive resins are designed to eliminate multiple conditioning and priming stages, but bond strengths are not so strong

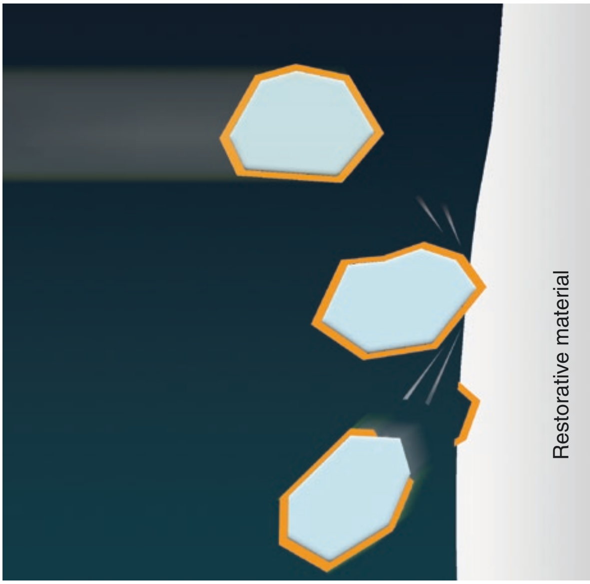

Fig. 15.5 Enhancing bonding to restorative materials using airborne-particle abrasion and silication. CoJet™ (3M ESPE) consists of 30 μm alumina grit coated with silicic acid [21]. When blasted onto the surface of restorative materials, the impact energy produces roughening and breakdown of the silicic acid causing silica to be released and impregnated into the surface. This is termed a “tribochemical process”. A silane coupling agent is then applied for bonding composite

Surface treatments and coupling agents are generally very effective, but there are two caveats. Firstly, there is no point trying to bond intra-orally to existing restorations which are defective or poorly retained. When faced with existing restorations (as if often the case when preparing for veneers) unless you are confident of their provenance, it is better to replace them. This can be done before tooth preparation. Alternatively, it can be done at the time of cementation. Secondly, it is worth being aware that bonding to zirconia has proven problematic; many formulations, protocols and products have failed in vitro to give a durable bond unaffected by aging and thermocycling. However, some adhesive monomers and silanes in combination with tribochemical silication (as described above) show promise but really need to be supported by clinical data before they can be confidently recommended [28]. Until then it is best to ensure the underlying preparation or implant abutment is mechanically unretentive.

15.4 Luting Cements

Before we consider the various types of dental luting agent, it is worth emphasising that dental materials often appear in different guises—it may be that the same type of material can be employed as a luting agent, restorative material, liner or base. To provide suitable handling characteristics for each application, subtle changes are made to their formulation. This section focuses primarily on material properties and uses as luting agents. Dental cements can be broadly categorised as "soft" or "hard", and these will be discussed in turn, below.

15.4.1 Soft Cements

Soft cements are generally used for luting provisional restorations. Occasionally, they are also used for trial-cementing definitive restorations where the aesthetics, occlusion or the condition of the pulp is in doubt. Trial cementation with a soft cement permits easier restoration removal and clean-up than with hard cements.

15.4.1.1 Zinc Oxide Eugenol Cements

The classical soft cement is zinc oxide and eugenol mixed on a glass slab. Nowadays, proprietary versions are available (e.g. TempBond™, Kerr) which can be further softened with a "modifier" paste to make removal of the restoration easier (e.g. with retentive preparations or definitive implant-retained prostheses).

Zinc oxide cements are also available which have been reinforced with ethoxybenzoic acid (EBA), aluminium oxide and polymethylmethacrylate particles. To be effective these are mixed to a putty consistency which makes them more suitable for temporising cavities rather than luting.

Eugenol is a known resin plasticiser and has the potential to soften composite cores and reduce resin bond strength to dentine exposed to zinc oxide eugenol cement—even for a relatively short time [29]. Whilst some resin cements may be less susceptible to this effect than others [29, 30], it is better to avoid using a eugenol-containing temporary cement prior to bonding to a composite core or bonding with a resin adhesive, particularly as non-eugenol alternatives are available.

15.4.1.2 Soft Resin Cements

Some situations require a soft translucent cement, for example, for luting temporary veneers. These materials (e.g. TempBond Clear™, Kerr) are not based on zinc oxide eugenol but on the hydrophilic resin, hydroxyethylmethacrylate (HEMA) and, the antimicrobial agent, triclosan. They are not suitable where the preparation has been pre-bonded with a dentine-bonding agent immediately after tooth preparation as they are then too well-bonded for clean-up purposes.

15.4.2 Hard Cements

Hard cements are often categorised into conventional or resin-based cements. Conventional cements (such as zinc phosphate, zinc polycarboxylate and glass ionomer) rely on an acid-base reaction resulting in the formation of an insoluble salt (the cement) in the presence of water. By contrast, resin cements set via a polymerisation reaction—requiring a chemical and/or light initiation. A third, hybrid group consists of resin-modified glass ionomer cements—these will also be discussed below.

15.4.2.1 Zinc-Based Cements

The main zinc-based cements are zinc phosphate and zinc polycarboxylate. Zinc phosphate (ZP) utilises phosphoric acid buffered with zinc and aluminium ions, whilst zinc polycarboxylate (ZPC) contains a polyacrylic acid. Both use zinc oxide powder and are mixed by hand as powder-liquid systems. The proportions of powder and liquid are not normally measured, and therefore care must be taken to produce a "mix", which provides a cement of low initial viscosity to form a thin film but with sufficient powder incorporated to give adequate strength once set [31]. The powder should be incorporated in increments to prevent the cement setting too quickly as a result of the exothermic reaction. A slab cooled in the refrigerator can further extend working time. The consistency of zinc phosphate may be checked by lifting the cement on the spatula and holding it over the slab. It should string out slightly between the spatula and slab before running back onto the slab. If it requires to be pushed off the spatula, it is too thick, and conversely, if it runs off too quickly, it is not thick enough. ZP has the longest track record and continues to be popular for luting purposes due mainly to its higher compressive strength, relatively long working time and ability to form a low film thickness between crown and tooth. The polyacrylic acid of ZPC has a much higher molecular weight, and so this material tends to be more viscous and is more difficult to form into an even film thickness. This isn't a huge concern since the cement undergoes "shear thinning" whereby the force required to seat the crown reduces the cement viscosity [32]. However, ZPC is weaker in compression than ZP and is more likely to undergo deformation under repetitive occlusal loading.

The retaining action of ZP cement is one of micro-mechanical interlocking between surface irregularities of the crown and tooth. It does not, however, chemically bond to tooth substance or restorative materials. By contrast, ZPC both provides micro-mechanical interlocking *and* chemical adhesion to enamel and dentine, with the bond to enamel being the strongest. ZPC will also bond tenaciously to stainless steel, and so it is important to ensure that mixing spatulas and carrier instruments are well-cleaned prior to material set.

These cements are, to some extent, soluble. ZP has a low solubility in water and marginal loss of the cement lute isn't commonly reported. However, ZP is susceptible to acid-mediated dissolution [33], and this is a consideration in patients suffering from acid reflux, vomiting or regurgitation. Historically, ZP cements have been identified as having a potential irritant effect on the pulp [34]. This has been attributed to the low pH of the cement at the time of cementation, but preparation trauma, temporisation and bacterial contamination may also have been responsible.

Although ZP is acidic on mixing (pH 2–3.5 depending on brand), this acidity recedes over the first 24 h and stabilises at a near neutral pH of 6.5. Despite the acidity, Brannstrom and Nyborg [35, 36] found no irritating effect on the pulp per se, and, in practice, this potential irritant effect does not seem to be significant.

Of course, a dentine-bonding agent could be used to protect the pulp, and, anecdotally, this has helped with teeth that have been sensitive after preparation. ZPC is less acidic on mixing (approx. pH 4.8), with little reported irritation to the pulp [37] possibly because there is little penetration of the large polyacrylic acid molecules into the dentine tubules, but these claimed benign properties have not been scientifically tested.

Zinc-based cements	
Advantages	Disadvantages
• Long track record • Good lute thickness • Reasonable working time • ZPC bonds to enamel and dentine • Adequate resistance to water dissolution • No adverse effect on pulp although initially acidic	• Susceptible to dissolution in acids
Recommendations	
• Preparations with good retention form (ZP) • Working time can be extended for cementation of multiple restorations by incremental mixing and cooled slab (ZP) • For provisional restorations identified as needing a stronger cement (ZPC)	

15.4.2.2 Glass Ionomer Cements

Conventional glass ionomer cements (GIC) were first introduced into dentistry as a filling material in 1972 [38]. Like polycarboxylates, glass ionomers may be supplied as a powder and aqueous acid (polyalkenoic) or powder and water. The aluminosilicate glass powder of GIC luting cements has smaller particles than GIC filling materials to reduce film thickness, which may be like zinc phosphate cements or lower. For luting purposes, mixing is either by hand or by automix capsule/dispenser.

GIC compares favourably with ZP as regards compressive strength. GIC has a significant advantage over ZP in that it forms a significant chemical bond to tooth tissue by reaction with the calcium salts in the tooth structure. It also releases fluoride ions, although whether this offers a genuine clinical benefit continues to be a matter of some debate. The higher solubility in water of GIC in comparison with ZP and ZPC has been identified as a problem when the cement is used for luting purposes. Early moisture contamination of the cement lute adversely affects this solubility. As such, margins should be protected with a varnish immediately following cementation, although this may be difficult when the crown margin is subgingival. Solubility is not a great problem clinically once the cement is set.

Another disadvantage of GIC is that its pH during setting is even lower than that of ZP and some concern has been expressed regarding post-cementation hypersensitivity [39]. However, a randomised, double blind trial of GIC versus ZP showed no significant difference in sensitivity [40], but it should be noted that in this study cementation procedures were carefully controlled, including the use of encapsulated mixing. Dentine desiccation may on occasion be responsible for sensitivity; some authorities are convinced that dentinal fluid is drawn into the setting GIC cement, which may cause pulpal problems if the preparation is overdried with an air syringe.

Glass ionomer cements	
Advantages	Disadvantages
• Good lute thickness • Reasonable working time • Strong chemical bond to enamel and dentine • Fluoride release	• Sensitive to early moisture contamination • Susceptible to dissolution in acids • May cause pulpal sensitivity if prep overdried
Recommendations	
• Used empirically for conventional crowns where patient has had a previously high caries rate • May be used as an alternative to zinc-based cements	

15.4.2.3 Resin-Modified Glass Ionomer Cements and Compomers

Resin-modified glass ionomer cements (RMGICs) are a hybrid of traditional glass ionomer cement with small additions of light-curing resin [41] and were originally introduced with the aim of overcoming the moisture sensitivity and the low strength of conventional glass ionomers. Generally, RMGICs have the advantages of combining the strength and insolubility of resin with the fluoride release of GIC.

Compomers are also a hybrid of resin and glass ionomer but are more closely related to composites with the glass ionomer setting reaction occurring slowly as moisture is absorbed into the set resin matrix. Following some early difficulties with compomers, they have largely fallen out of use. RMGICs, on the other hand, are becoming more popular for luting purposes because of their relatively high bond strength to dentine and their ability to form a very thin film layer. RMGICs leach fluoride, and a recent study confirmed a benefit at the restorative margin [42]. RMGICs have also been advocated for bonding extra-coronal restorations in patients with amelogenesis imperfecta or vitamin D-dependent hypomineralisation [43].

There have been anecdotal reports of high-strength porcelain crowns fracturing following cementation with RMGICs, possibly because of expansion of the cement from water sorption: RMGICs contain the resin HEMA which is hydrophilic. Although several studies confirm the phenomenon of hygroscopic expansion [44, 45], there is little clinical evidence that RMGICs result in fracture of full-coronal restorations made with a range of ceramic systems [46, 47].

Resin-modified glass ionomer cements and compomers	
Advantages	Disadvantages
• Good compressive strength • Reasonable working time • Resistant to water dissolution • Fluoride release	• May expand and crack overlying porcelain because of water absorption
Recommendations	
• As for GIC, may be of benefit in patients at risk of acid erosion	

15.4.2.4 Resin Cements: Total Etch, Self-Etch and Self-Adhesive

Resin cements are composites composed of a resin matrix, e.g. bis-GMA or urethane dimethacrylate, and a filler of fine inorganic particles. Resin luting cements differ from restorative composites primarily in their lower filler content and lower viscosity. Following on from their successful use in the cementation of resin-bonded bridges and veneers, their popularity has been increasing in recent years for crown cementation because of their use in conjunction with dentine-bonding agents (DBA).

As is always the case for newer materials, there is limited clinical data, and the continued introduction of new and modified versions means that any clinical studies rapidly become out of date as materials become obsolete. Nevertheless, one clinical study comparing fixed partial denture (bridge) retention with either self-adhesive cements or zinc phosphate indicates a similar performance at 38 months [48]. Hopefully, similar studies will eventually become available relating to single-unit crowns. An important aspect of any such study would be to determine the performance of resin cements and DBAs where tooth preparations offer insufficient retention for conventional cementation (e.g. with zinc phosphate).

Below we present frequently asked questions about resin DBAs and resin cements that dentists often find confusing.

How Do DBAs Work?

Typically, resin cements adhere to the underlying tooth structure by micromechanical retention (look again at Fig. 15.4). Within enamel, the resin infiltrates the differentially-etched enamel prisms to provide a very strong, reliable bond. For dentine bonding the gold standard is often considered to be a 3-step ‘etch, prime and bond’ technique [49, 50]:

1. Conditioning—etching the enamel and dentine with phosphoric acid (32–37.5%) followed by rinsing with water
2. Priming—suffusing the conditioned tooth with resin adhesive contained in a solvent (e.g. alcohol, acetone or water) and then evaporating the solvent
3. Bonding—application of an unfilled or lightly filled resin.

It must be remembered that the gold standard is often determined in well-controlled laboratory studies - and whether the ‘ideal’ moisture levels of dentine can be replicated clinically with these technique-sentitive protocoles is debatable. As such, newer dentine-bonding systems aim to simplify the process, from three stages to two or just one stage (only one bottle for the combined etch, primer and bond). With the two-stage approach, there are a wide variety of materials. Many of these rely on a “self-etching primer” where the conditioner (an acid weaker than phosphoric acid) is combined with the primer, but not rinsed. Clinical studies suggest that simpler, less technique-sensitive procedures, can result in a more consistent clinical result. Two-stage and one-stage materials vary in their capability for dentine bonding as shown by in vitro tests and clinical trials of nonretentive class V restorations [51]. However, some of the self-etching primers show reasonable dentine bonds, approaching that of the gold-standard three-stage technique [49, 51, 52].

Why Must Some DBAs Not Be Rinsed After the Etching/Priming Stage?

With two-stage self-etching primers and one-stage systems, the dentine is not rinsed after the etching/priming stage because an etchant weaker than phosphoric acid is used. Instead of being washed away, the dissolved mineral ions are incorporated into the “hybrid layer” (see Fig. 15.4) by employing a specially formulated mixture of acids and solvents. The dentine bond would be weakened by washing off the self-etching formulation.

Why Is Enamel Pre-etching with Phosphoric Acid Needed with Some Self-Etch Systems?

This seems almost an anathema as selective enamel etching adds an additional stage to a simplified bonding procedure. However, many self-etch systems (both two-stage and one-stage), whilst bonding well to dentine, bond less well to enamel. The weak acids in these systems may etch enamel less effectively than phosphoric acid. When selective etching is carried out, the application should be limited to enamel to avoid weakening the dentine bond [49]. Most importantly, the phosphoric acid must be rinsed effectively for at least 15 s. Notwithstanding the above, some recent products claim not to need selective enamel etching.

Why Does Dentine Need to Be Moist for Effective Bonding?

Good moisture control is imperative whilst bonding to enamel and dentine. When bonding to dentine, etching the surface will remove the mineral component, leaving a meshwork of exposed collagen. The meshwork is liable to collapse, however, if dentine is overdried. Conversely, resin infiltration will be compromised if dentine is too wet. So, manufacturers recommend slightly drying to leave a moist surface using a gentle airstream or blotting with gauze/cotton wool. Always check if the jets of your three-in-one syringe are not contaminated with oil from the compressor.

Must Enamel Be Fully Dried Before Bonding?

Often both enamel and dentine must be bonded too. Traditionally, etched enamel had to be dried to a frosty white appearance to allow perfusion with unfilled resin. Nowadays, for most systems the enamel doesn’t need to be desiccated in this way; the primers in DBAs, including self-etching primers and primer bonds, are effective on both moist dentine and enamel. The solvents in the primer displace water on the tooth surface and are then evaporated by a gentle airstream before light curing. This advice is contained in most manufacturers’ instructions. Bearing in mind the practical difficulty of achieving bone-dry enamel adjacent to damp dentine, it is best to choose a DBA where the instructions don’t make this stipulation.

How Does All This Affect Moisture Control?

Students sometimes make the mistake of forgetting about moisture control when using DBAs and are surprised when shortly afterwards restorations fail or teeth become hypersensitive. So, to ensure an effective resin bond to a moist tooth surface, there are two important caveats:

1. Before priming the tooth must be moist with *clean water*—not contaminated with saliva which ruins bonding
2. After priming the tooth surface must be kept dry and free from saliva before applying the bond or resin lute.

Is Dentine Disinfection Necessary?

Some dentists favour an additional "dentine disinfection stage" prior to applying a self-etching primer. This involves two separate applications of glutaraldehyde and HEMA [53]. The glutaraldehyde may have some beneficial effects on cross-linking of dentine collagen [54]. Initially, dentine bond strengths are high but like any dentine bond tend to reduce with time. Claims are made that post-operative sensitivity is reduced in the busy surgery setting, but not more than when the total-etch technique is carried out meticulously [55]. However, as each application of glutaraldehyde and HEMA takes 1 min, the total time for bonding is likely to be more than for the gold-standard three-step total-etch technique. Before adding this extra step during luting, we advise waiting until further evidence, preferably endorsed by manufactures, is available.

What Are "Self-Adhesive Cements"?

Some of the most recent luting systems do away entirely with the separate dentine-bonding stage and are simply self-adhesive cements. These cements have acid residues incorporated into the resin component which offer a degree of etching of the dental hard tissues, particularly the dentine [56]. Although these materials do undoubtedly have their proponents, it is generally recognised that as products move away from employing separate steps (conditioning, priming and bonding), the bond strengths are inevitably compromised (see Fig. 15.6) [57, 58]. However, a better bond to enamel can be obtained with self-adhesive cements by selectively pre-etching the enamel with phosphoric acid [56]. Again, great care must be taken to confine the etch to enamel. If the dentine is also pre-etched, it can detrimentally affect the bond strength of self-adhesive cements [59].

What Other Types of Resin Cement Are Available?

As well as the self-adhesive cements, there are resin cements that must be used with a separate DBA. These are available as auto-cured, light-cured and dual-cured materials. Luting cements are typically dual-cured because of the inability, or at best difficulty, of applying sufficient light through ceramic and metal restorations.

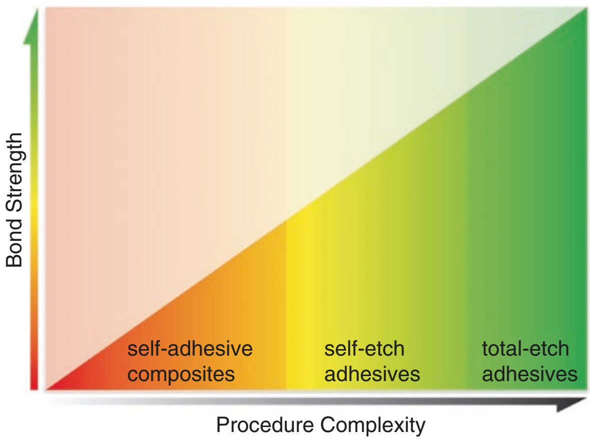

Fig. 15.6 The relationship between procedure complexity and bond strength. Currently, the best bond strengths are obtained with multistage adhesives. However, the multiple stages make bonding more technique sensitive than for simpler systems

Examples include the various generations of Panavia™ (Kuraray) and Variolink II™ and Multilink Automix™ (both Ivoclar Vivadent). Variolink II™ can be used either as a dual-cured material, or it can be light-cured by just using the base paste. Light-cured luting materials are usually more colour stable than dual-cured materials. Consequently, they are favoured for luting veneers but can only be used where a thin layer of ceramic allows sufficient passage of the curing light.

How Do the Properties of Resin Cements Compare with Conventional Cements?

The mechanical and physical properties of resin cements compare very favourably with conventional cements. Tensile strength is about ten times that of zinc phosphate, which in combination with a high bond strength explains why preparation geometry is of less importance to retention than with conventional cements.

Adhesive resin cements are less soluble than conventional cements, particularly in acid environments. They also produce a better marginal seal than zinc phosphate cement [45]. Both the seal and solubility will depend on proper resin curing; otherwise the lute will be vulnerable to chemical dissolution by the oral biofilm [60].

A spin-off from having a well-bonded composite lute is that it can strengthen an overlying ceramic restoration much more than a weaker conventional cement. This feature has been demonstrated in vivo with ceramic inlays which were almost five times more likely to fracture when cemented with conventional glass ionomer than with a resin cement [61].

All these factors make resin cements useful for bonding restorations on tooth preparations insufficiently retentive to succeed with conventional cements. Nevertheless, for a reliable outcome, bonding must be meticulous, and a ring of sound enamel is needed to bond inside the restoration margin. Some dentists call this “the ring of confidence”! The resin lute must, of course, also bond to the inside of the restoration.

Are There Any Problems Associated with Resin Cements?

Resin bonding is not effective to all ceramics (see Chap. 14). For example, some high-strength ceramic cores cannot be etched effectively with the usual hydrofluoric acid protocols either because of the lack of heterogeneity in soluble phases in the material (e.g. In-Ceram™, VITA Zahnfabrik) [62] or because of a relatively unreactive surface (e.g. with zirconia cores or monolithic restorations) [28].

Perhaps the biggest problems are posed by subgingival preparation margins, for two reasons: firstly, ineffective isolation and moisture control and, secondly, incomplete removal of hardened excess resin from inaccessible margins. Indeed, proximal extrusions of resin cement are often radiolucent and may remain undetected [63]. These issues often preclude resin cements and favour conventional cements.

Other problems with the use of resin cements for luting full crowns include excessive film thickness with some materials [64, 65]. In addition, marginal leakage because of setting shrinkage and severe pulpal reactions when applied to cut vital dentine occasionally occur. Assuming the resin is properly cured, these problems may be related more to bacterial infiltration than to chemical toxicity [60]. Pulpal response is reduced by the effective use of dentine-bonding agents ensuring dentine tubules are sealed and microleakage reduced [66].

An interesting chemical problem is that resin cements which are auto-cured or dual-cured can have significantly compromised bond strength to the surface of some DBAs because of residual acidic monomers which interfere with the cements' chemical curing. These residual acidic monomers occur on the air-inhibited surface of some two-step DBA systems (primer and bonding resin in the same bottle) and all-in-one systems. To overcome this difficulty, auto-cured and dual-cured resin cements should only be used with DBAs which are three-step total etch or with have self-etching primers [60].

15.4.2.5 Resin Pre-bonding of Dentine

As mentioned in Chap. 9, immediate dentine sealing (IDS) is becoming increasingly popular. Here tooth preparations are sealed immediately after completion with resin-based DBAs. Aside from reducing dentine sensitivity, there is in vitro evidence that this approach can improve the bond strength, reduce micro-gaps and decrease microleakage of the final resin-cemented restoration [67]. Whilst the technique has its proponents, others raise concerns that the sealing process may flatten out carefully prepared retentive features and also create a smoother finish [68], both of which may impact on the effectiveness of the cement lute. Further, some consider that etching and ineffective resin bonding of the dentine surface may make it more permeable compared to leaving the natural smear layer that forms during preparation with a diamond bur and partly occludes the cut dentine tubules [69]. Clearly the IDS procedure is technique sensitive, and outcome is likely to vary depending on the dentine-bonding system employed and how the final restoration is cemented. It is worth noting that there may also be potential drawbacks during provisionalisation, given that sealed dentine surfaces have the potential to bond to resin-based provisional materials and cements [67], and eugenol-based temporary cements must be avoided as they may degrade the sealed dentine surface as well as the final resin lute [29].

Resin cements	
Advantages	Disadvantages
• Bonding to dentine and enamel possible • Good compressive and tensile strengths • Resistant to water dissolution • Relatively resistant to acid dissolution • Can enhance strength of ceramic restoration if bond obtained	• Best dentine bonds are the most technique sensitive to achieve • Film thickness varies substantially between materials • Excess material extruded at margin may be difficult to remove proximally and subgingivally
Recommendations	
• Material of choice for ceramic veneers, ceramic onlays and resin-bonded ceramic crowns • May be used to improve retention where preparation geometry is suboptimal • Dual-cure cements should be avoided for veneers as they may discolour with time	

15.5 Controlling Lute Thickness

The interposition of a cement lute inevitably affects crown seating. Consequently, the art of cementation is to choose a cement with an inherently low film thickness and use techniques which allow it to escape whilst the crown is being seated. Cement flow can be hindered by preparation features, which cause a build-up of hydrostatic pressure. Preparations that are long, display sharp line angles, are near parallel and have a large surface area are most at risk of causing problems. This can be overcome by careful finishing of the preparation, die spacing and controlled cement application—or by venting the crown. These techniques should apply for all crowns, not just apparently retentive ones. Die spacing is the most common method of achieving space for the cement lute [70]. Traditionally, it involves painting layers of die relief agent over the whole of the die but keeping clear of the finish line by 0.5–1 mm. Typically a space of 30–40 μm is provided [71]. Nowadays, the die space may be programmed using CAD/CAM software. The increased cement space results in more rapid and complete seating with decreased deformation of the restoration [72–74].

Die spacing results in a slightly loose fit of a crown on its preparation, but the crown should still seat without any rock prior to cementation. Following cementation its effect on retention is unclear with some studies reporting an increase in retention [75], whilst others report a decrease or no effect [76]. One study concluded that decreasing the width of the cement layer increases the resistance to dynamic lateral loading, but the results may well have been influenced by including an unrealistically thick cement layer of 0.5 mm [17]. Variability between studies may occur because of differences in cement film thickness as well as differences in experimental set-up. A very thin cement lute may have higher stress concentrations than a slightly thicker one [77]. However, as mentioned in Box 15.1, a too thick cement lute is also undesirable as it is liable to fracture.

Another factor which influences the vertical seating of crowns and hence marginal adaptation is the amount of cement loaded into the crown prior to cementation. The cement may be loaded into the restoration in various ways. These have been categorised as (a) gross fill, (b) paint/brush on and (c) marginal application. A study on the effect of volume of zinc phosphate cement reported that smaller amounts of cement placed within a crown resulted in smaller marginal discrepancy and better occlusal accuracy [78]. Indeed, a crown treated in such a way seated almost 70% better than an identical crown completely filled with cement. However, care must be taken in applying cement in this way to apply an even layer but not to exceed the working time or the cement may be too viscous at the time of seating.

Venting is an effective [31] but less popular method of reducing cement film thickness. With external venting the technician makes a perforation in the occlusal surface of the crown, which the dentist seals with a separate restoration after cementation. With internal venting to help cement escape, one or more escape channels are created either in the axial wall of the preparation or the intaglio surface of the crown. With CAD/CAM restorations, there is a potential to programme a sophisticated pattern of internal venting channels allowing both closeness of fit to enhance resistance and retention and good cement escape. Manufacturers may wish to explore this concept further.

Crowns luted onto implant abutments (see Chap. 16) may vent some of the cement internally into a hollow abutment, taking care not to block future access to the abutment screw.

It is worth bearing in mind that there are now a multitude of resin lutes available on the market, and each will show slightly different handling characteristics. Indeed, the force required for maximum seating of cast-vented crowns has been shown to be cement-specific [79]. Generally resin lutes tend to be more viscous than conventional cements. With viscous cements ultrasonic vibration has been advocated for faster crown seating under lighter loads than for manual seating [80].

15.5.1 Marginal Configuration and Lute Thickness

Whilst material choice most often dictates the marginal configuration, there may be situations where the choice of margin can affect the seating of a crown. Early work by Gavelis showed that shoulder preparations allowed for a better seating of the restoration than the shoulder with a bevel, knife edge and chamfer finishing lines. Gavelis suggested that this was due to the geometry of the shoulder providing a wider marginal opening during seating allowing excess lute to escape more easily [81]. His study was carried out using well-fitting dies without die spacing or venting. Clinically, crown seating may well be influenced by marginal configuration—particularly if no die spacer has been used.

15.6 Further Research

The holy grail of a user-friendly adhesive cement for bonding restorations reliably to dentine has yet to be developed. Such a cement would be without polymerisation and water absorption problems. It would easily provide a strong and stable bond to all restorative materials including zirconia. In the meantime, surface conditioning and coupling agents show considerable promise to enhance bonding with resin cements. Clinical protocols need to be developed and tested to determine the best methods of dealing with difficult bonding situations (e.g. sclerosed dentine in patients with tooth surface loss where highly mineralised tertiary dentine is laid down). Laboratory protocols are also needed to optimise die spacing and internal venting for specific cements, particularly for CAD/CAM restorations which can now be machined to exacting tolerances.

Conclusion

Choosing a cement for a purpose not only requires an understanding of the cement's material properties but also an appreciation of how the cement lute interacts with the tooth and restoration. Use conventional cements for restorations with retentive preparations, use them also in patients without issues of acid erosion, and where preparations extend subgingivally making clear-up of extruded cement tricky. Use adhesive bonding for less retentive preparations and in patients with a history of acid erosion. Remember a more reliable resin bond will be formed to ceramic restorations which can be etched effectively with HF. Some bonding agents and cement types offer a stronger bond to enamel and dentine than others, but all adhesive bonding must be carried out meticulously. Surface treatments and coupling agents are recommended for use on the intaglio surface of restorations and to enhance bonding to existing restorations. Airborne-particle abrasion (sandblasting) can also be used on the tooth being restored. Die spacing is recommended for all restorations but particularly for crowns to control seating and lute thickness; alternatively, crowns may be vented.

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Implant Abutments for Crowns

16

Richard Holliday, Francis Nohl, and Robert Wassell

16.1 Learning Points

This chapter will emphasise the need to:

- Be aware of the wide variety of abutment designs and materials which can be used for implant crowns
- Provide implant-related treatment in line with training and competency
- Choose an appropriate design and material for an implant abutment based on aesthetic, functional, and parafunctional demands and ensure there is sufficient space to accommodate the abutment and the crown without occlusal interference
- Prefer screw-retained one-piece restorations to enhance retrievability, and avoid problems with residual cement
- Be aware of the options to re-angulate screw-retained one-piece restorations
- Use a torque wrench or torque-controlled handpiece to tighten abutment screws reliably according to manufacturers' recommendations.

Dental implants are becoming an increasingly mainstream treatment option, and, as mentioned in Chap. 2, at least 1% of dentate adults have one or more dental implant restorations [1].

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Dental implant restorations are complex, being made up of several components. The three main components are:

- *The dental implant* (aka the fixture) which is responsible for osseointegration with the alveolar bone
- *The abutment* which connects the dental implant to the prosthodontic part of the restoration. Some systems use a separate abutment component, while others incorporate the abutment either with the prosthetic tooth replacement or with the implant
- *The prosthetic tooth replacement* which could be a single crown, bridge, partial denture, or full arch prosthesis (fixed or removable).

In this chapter, we will focus on individual implant-retained crowns. Many dentists refer patients for implant placement by an oral surgeon, periodontist, or another dentist trained in implant placement. While some patients also have the prosthetic tooth replacement provided as part of the referral, others return to the referring dentist for these procedures. So, whether a dentist is simply advising patients or providing the prosthetic service, they need to be aware of the options available, particularly the wide range of abutment designs. For advice on the scope of implant practice in general practice, see Box 16.1.

There are several key factors to consider in the delivery of a functional, aesthetic, and long-lasting dental implant abutment:

- Abutment materials
- Implant-abutment connection mechanisms
- Abutment screws
- Biological considerations
- Options for abutment design.

Box 16.1: Advice on Scope of Implant Practice

Appropriate supplemental training (following General Dental Council guidance) is required for the provision of implant dentistry, but the general dental practitioner (GDP) has an essential role to play in the maintenance of implant restorations. In addition to providing supportive periodontal care, GDPs may also be called upon to replace the screw access restoration on screw-retained crowns or provide bonded composite repairs for minor ceramic fractures—two of the commonest prosthodontic complications (see Chap. 2). Where cement-retained restorations have debonded, it would be appropriate to recement, unless there are complications (e.g. the abutment's finishing line is inaccessible or the abutment is loose). Alternatively, a temporary restoration may be provided. Provision of definitive restorations should be limited to those with supplemental training.

Only definitive abutments will be considered here. Temporary abutments and the detailed stages involved in the provision of an implant restoration are beyond the scope of this chapter.

16.2 Abutment Materials

Several materials are utilised for the construction of definitive abutments: gold, titanium, zirconia, and recently high-performance polymers have entered the market. Although a restoration usually hides the abutment, it still has aesthetic implications. Its subgingival portion may affect the colour of the overlying gingival tissue. For example, in sites with a thin gingival biotype, titanium abutments can "shine through" causing greying (Fig. 16.1). Furthermore, if any recession occurs, the crown margin and abutment can become exposed. An exposed zirconia abutment is less obvious than a titanium, but either could require the costly remake of the crown with abutment modification (Fig. 16.2). However, a systematic review recently concluded that from an aesthetic outcome perspective, there is no difference between the abutment materials, at least in the short term. However, a consistent report from the studies evaluated was that facial positioning of the implant resulted in more recession [2].

Biological interactions with different types of implant abutment materials, including plaque adhesion and potential for epithelial attachment, are considered later.

With regard to mechanical properties, early in vitro studies found titanium superior to zirconia both for fracture resistance and fatigue reliability [3, 4]. The zirconia abutments fractured predominately at their apical portion, which was presumably the thinnest region. However, a more recent meta-analysis of seven in vitro studies showed no significant difference between titanium and zirconium abutments, but both were adversely affected by fatigue testing more than a million cycles. With both types of materials, abutment design was important—internal abutments were stronger and more fatigue resistant than external abutments [5].

Fig. 16.1 Greying of tissues. Titanium abutments in a thin biotype

Fig. 16.2 Recession on a cement-retained crown (22), exposing a zirconia abutment 1 year after the crown had been fitted. This has little aesthetic consequence due to the colour of the zirconia and a low lip line. If the abutment had been made of titanium, the patient may well have requested a replacement restoration

Despite continuing reservations over the mechanical properties of zirconia abutments, a systematic review of the clinical literature concluded they were reliable in the anterior region, both biologically and mechanically [6]. Nevertheless, the review was limited to only three studies and did not identify patients with bruxism which may pose a risk to abutment survival.

In summary, the abutment material of choice should be made on a case-by-case basis considering the aesthetic, functional, and parafunctional demands and limitations of the abutment design.

16.3 Implant-Abutment Connection Mechanisms

Unless you choose a one-piece implant where the abutment is an integral part of the implant (see later), there will inevitably be a connection between abutment and implant and an interface between them. So, dentists should be familiar with the different connection mechanisms and any associated issues.

The simplest classification of abutment connections is to divide them into external or internal designs. External designs, as you may expect, have a projection on the external surface of the implant head that engages with the abutment. Internal designs have the abutment projecting into the internal surface of the implant (Fig. 16.3). The connection system can be further classified into passive/friction-fit joint, butt/bevel joint, and its geometry (hexagon, octagon, conical, etc.) [7].

External designs, used on the first implant systems (e.g. Brånemark), had a simple flat connection (butt junction) around the periphery with an external hexagonal projection to engage the abutment. This external hexagon acted as an anti-rotation device for the abutment and was also used to engage with a “fixture mount” during the implant placement. Although this system has been used successfully for many

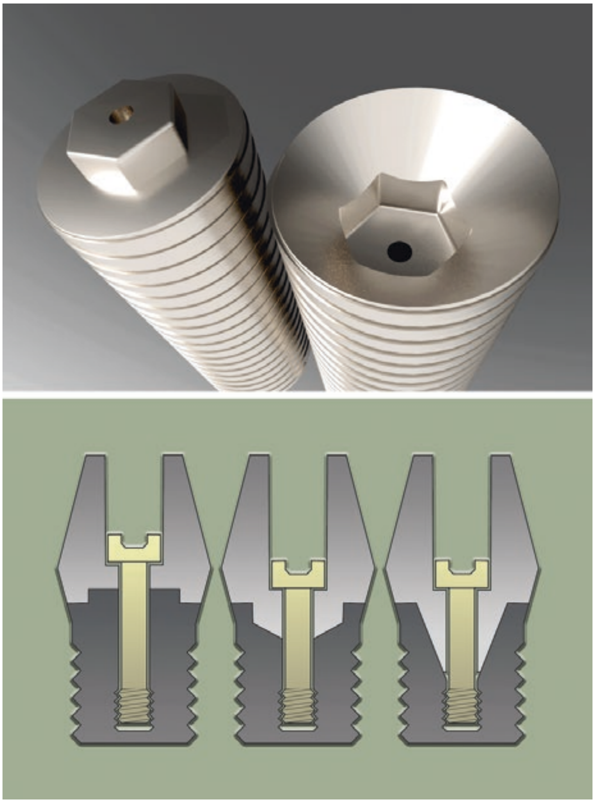

Fig. 16.3 Examples of abutment connection mechanisms: fixtures with external and internal (hexagonal) connection designs (top). Cross sections through screw-retained abutments for cemented crowns (bottom) showing external connection (left), internal connection (centre) and tapered internal connection (right)

years, it has been proposed that under certain conditions micro-movement can occur at the abutment-fixture junction leading to screw loosening [8, 9].

Internal designs, first developed during the 1980s, aimed to improve on the shortcomings of the external design [10]. The internal abutment connection is usually tapered. It also includes an anti-rotation feature within the implant, which can vary from a 12-point double internal hexagon to a three-lobed internal tripod. Compared with external abutment connections, the internal design is considered to have several benefits. The vertical prosthetic height requirements are reduced, although an abutment screw still needs to be accommodated—an important consideration in ensuring the final crown does not interfere with the occlusion [11]. Occlusal forces are distributed more favourably with stresses dispersed deeper within the implant and across a larger area of contact between abutment and implant [12]. This corroborates the fatigue tests mentioned previously which reported internal abutments stronger and more fatigue resistant than external abutments [5]. In addition, the improved stress distribution and a greater potential for a microbial seal may contribute to the reduced marginal bone resorption seen in some recent clinical studies of internal versus external abutment connection [13, 14]. However, other comparative studies have not shown a difference [15]. These studies are difficult to interpret clearly because of confounding factors (e.g. smoking, implant position, occlusion). Much more work is needed to determine which implant abutment design works best clinically.

A variation on the internal design is the “locking” or “Morse” taper which provides an interference (or “friction”) fit between the machined components. An example is the 1.5° taper used by Bicon™ dental implants. No abutment screw or anti-rotation feature is required. Instead, the implant-abutment connection is secured using the interlocking of the surface asperities between the near-parallel sides. Placement requires a custom seating jig and a sequence of taps with 250 g or heavier mallet.

The concept of “platform switching” was developed unintentionally when “wide” implants were introduced. Dentists who didn’t have the correctly sized componentry used standard-sized abutments on the “wide” bone-level implant heads. This created a horizontal step on the “bone-level” implant surface which effectively repositioned the implant-abutment interface further away from the bone. It was observed that this configuration resulted in less crestal bone loss than expected [16]. Subsequent systematic reviews and meta-analysis have indicated promising results, although well-conducted, long-term randomised controlled trials are required [17, 18].

Similarly, some manufacturers have introduced “tissue-level” (aka “transmucosal”) implant heads which move the implant-abutment interface away from the crestal bone. In comparison with conventional “bone-level” implant heads, it is unclear to what extent, if any, moving the interface more coronally conserves crestal bone level [19]. An unintended consequence of having the implant head close to the gingival crest is that it may complicate establishing an optimum emergence profile for a crown, particularly in the aesthetic zone.

16.4 Abutment Screws

An abutment screw serves to secure an abutment to the implant. Sadly, abutment screw loosening is reported to be one of the most common complications of the dental implant restoration [9, 20].

As may be anticipated, internal abutment connections have less screw loosening than external connections. A systematic review reported a higher incidence of screw loosening in implant systems with external connections for both metal-based and zirconia-based abutments [9]. For example, metal-based abutments demonstrated 3-year cumulative screw loosening incidences of 1.5% and 7.5% for internal and external connections, respectively.

Abutment screws are more likely to loosen when there is a tall stack of crown and implant abutment [21]. However, the ratio of crown (plus abutment) height to implant height appears not to significantly impact on marginal bone loss [22]. Inevitably, both of these factors will be determined by the implant position and are often out of the control of the restoring dentist.

Pragmatically, the most important factor in screw loosening is likely to be simply incorrect application of the correct torque to achieve sufficient preload with the screw. Preload is the clamping force between the abutment and implant resulting from the restricted elastic recovery of the screw. It occurs because the abutment screw slightly elongates when tightened placing the screw shank and screw threads in tension. Dentists placing abutment screws should do so with a device that reliably applies the correct torque (e.g. a torque wrench or torque controlled handpiece). Importantly, the recommended torque requirements vary between implant systems according to the design, size, and materials used. It is worth noting several manufacturers recommend that abutment screws are only fully tightened once. This implies that if an abutment screw loosens, it should ideally be replaced. How often this ideal is met is unknown.

16.5 Biological Interactions

Dental implants differ from natural teeth in their attachment apparatus. Coronal to the osseointegrated zone dental implants have a soft tissue connection. This consists of a scar-like supra-bony connective tissue zone and more coronally a long junctional epithelium [23]. By contrast natural teeth have a much more robust epithelial and connective tissue attachment.

Implant abutments and their abutments therefore occupy an important transgingival region where plaque accumulation can lead to peri-implant pathology. Although it has been suggested that zirconia abutments may represent a material surface less attractive for early plaque retention compared to titanium, clinical studies have shown little difference [6, 24].

The soft tissue interface to the dental implant restoration is affected by many factors such as implant position, peri-implant biotype, and physical design of the implant system. We have already mentioned how the concept of "platform switching" which moves the implant/abutment junction further away from the bone, is showing promising results. Manufacturers continue to strive to optimise implant and abutment design, but only time, and good clinical studies, will sort the wheat from the chaff.

The abutment material chosen (titanium, zirconia, or gold) could also potentially influence the quality of the epithelial attachment. Animal studies have shown poorer outcomes with gold abutments, with a lack of "connective tissue integration" and apical migration [25, 26]. However, systematic reviews of animal and human histological studies demonstrated no statistically significant difference with regard to peri-implant bone levels and soft tissue levels between the materials [27].

16.6 Abutment Designs for Crowns

Dentists can be forgiven for being bewildered by the range of dental implant systems available worldwide and with each system having its own intricacies. Fortunately, the basic principles are largely the same for many of these systems.

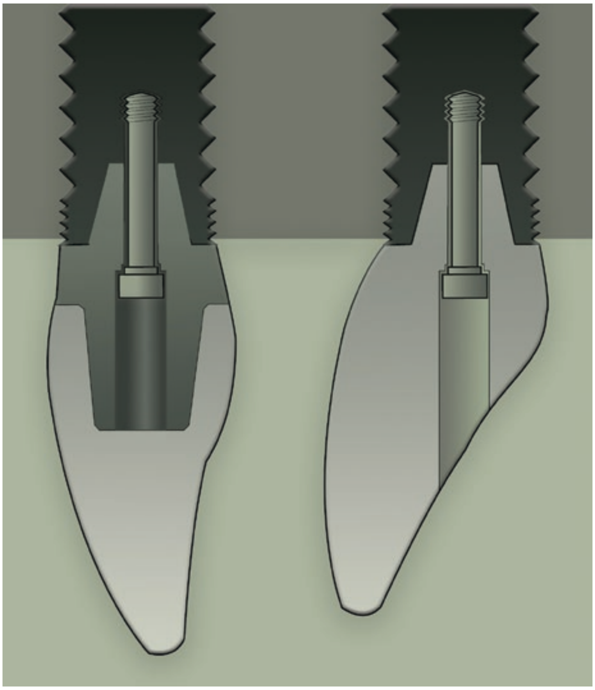

Fig. 16.4 Abutment designs: cement-retained crown on separate screw retained abutment (left). Screw-retained crown with incorporated abutment allowing the crown to be attached directly to the implant (right)

There are typically two main options (Fig. 16.4) for how the final restoration connects to the dental implant:

- Screw-retained one-piece restoration
- Cement-retained two-piece restoration.

Both options use an abutment screw to secure the abutment to the implant. The exceptions to this are the Bicon™ system, mentioned previously, which uses an interference fit to secure the abutment to the implant and the one-piece implant abutment (see below) where the implant and abutment are made as a single unit. In both systems crowns are cement-retained.

16.6.1 Screw-Retained One-Piece Restoration

The screw-retained implant restoration essentially incorporates the abutment and crown(s) in one piece. For the reasons we explore below, it is often seen as the optimum restorative design and is the aspiration during the preoperative planning stages. One of the biggest advantages of screw-retained restorations is their retrievability, allowing an implant to be examined more easily, and the restoration to be repaired in the laboratory. The absence of cement is also a significant advantage.

Excess cement may be an aetiological factor in the development of peri-implant pathology—like calculus is with periodontal disease. Additionally, with the subgingival and supragingival portions being made of the same tooth-coloured material, any recession is less critical than for cement-retained restorations where the abutment material may become exposed and unsightly.

A systematic review comparing the clinical outcomes of screw- and cement-retained restorations showed no difference with regard to implant survival for single crowns, but as the size of the restoration increased, the incidence of implant failure increased for cement-retained restorations, most likely due to the presence of excess luting cement [28]. Survival rates of the reconstructions were not statistically different between screw- and cement-retained restorations of any size. Screw-retained restorations did show more technical complications (e.g. screw loosening, chipping of the veneering ceramic), but more significantly, cement-retained restorations showed higher incidence of biological complications such as bone loss of over 2 mm.

To provide a screw-retained restoration, the trajectory of the dental implant needs to be very precise. This is because the emergence of the screw access hole must be in a position that is aesthetically acceptable and mechanically sound for the restoration. So, the screw access hole should emerge in the palatal cingulum region for anterior teeth or through the occlusal surface for posterior restorations. If the hole is too close to the incisal edge, the thin layer of unsupported ceramic is prone to fracture. This reinforces the importance of "tooth-down" restorative planning from the outset to optimise implant position.

When the screw access hole would be in an unfavourable position, there are three options which may help correct the situation without the need for a cement-retained crown:

- A "lateral set screw" (aka "cross pinning") [29]
- Screw head technology allowing screw drivers to engage sufficiently when not directly in line with the screw trajectory. An example is the Nobel Biocare Angulated Screw Channel system that allows up to 25° of correction (Fig. 16.5)
- Implants having an angulated platform and angulated abutment screw channel, e.g. Co-Axis™ Implants (Southern Implants™). With this arrangement, the implant must be screwed in so that the offset implant head is aligned in the desired orientation.

For obvious aesthetic reasons, screw-retained crowns in the anterior region are usually constructed using a zirconia substructure with overlying feldspathic or pressed fluorapatite ceramic (e.g. e.max Ceram™, Ivoclar Vivadent—see Chap. 14). Some systems incorporate a titanium insert as a base to the zirconium abutment. This may introduce a structural weakness, but the manufacturer emphasises it ensures optimum fit between the implant and abutment as well as being efficient for laboratory processes.

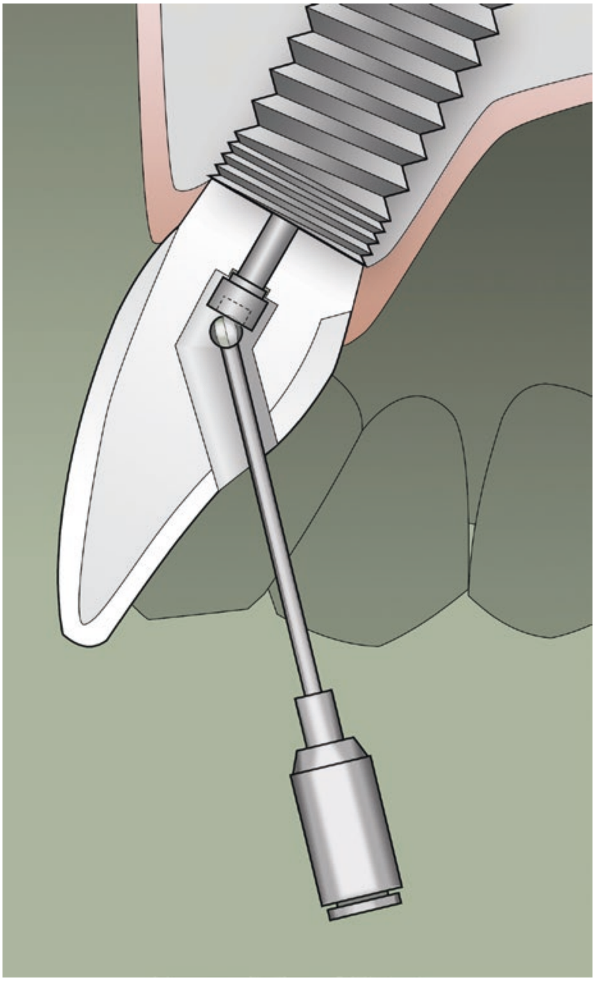

Fig. 16.5 To avoid the screw hole emerging through a crown's incisal edge, some implant systems provide a special abutment screw and driver allowing an offset of up to 25°

16.6.2 Cement-Retained Two-Piece Restorations

Cement-retained restorations consist of a separate abutment that is secured to the implant with an abutment screw prior to cementation of an overlying restoration such as a crown, bridge, or full arch restoration. The abutments for these restorations can either be "off-the-shelf" prefabricated abutments or customised abutments made by the laboratory.

16.6.2.1 Prefabricated (Stock) Abutments

"Off-the-shelf" abutments are available in zirconia and titanium and in a range of sizes, heights, and angulations. The use of prefabricated abutments can lead to a quicker and simpler treatment, with reduced numbers of clinical stages required.

However, being prefabricated, they have several limitations. These include being less likely to provide optimum soft tissue support, emergence profile, restoration contour, and crown margin position. Therefore, the clinical indications for these restorations are limited, and they are best avoided in high-risk aesthetic cases.

16.6.2.2 Customised Abutments

As their name suggests, customised abutments allow for complete customisation of the abutment to achieve optimum aesthetics, a mechanically sound structure and optimal contour—for cleansability and to avoid food packing.

Customised abutments can be fabricated on an implant level cast (i.e. a cast with a replica of the implant head) but without any prior modification of the soft tissue. The abutment is simply built to an assumed ideal soft tissue profile for the site. Alternatively, a provisional implant crown, usually constructed of resin composite, can be used to mould the tissue to the required tissue profile (see Chaps. 17 and 23) before being used to prescribe the contours of the definitive abutment. Production methods include scanning a pattern for CAD/CAM, investing and casting a pattern, or using virtual design and CAD/CAM.

16.6.2.3 Abutment Preparation

Most cement-retained abutments are designed to have crown preparations like teeth with a shoulder or deep chamfer marginal configuration. Whether a prefabricated abutment or a customised abutment is chosen, the laboratory should ideally return the abutment in its final form as zirconia and titanium can be challenging to modify intra-orally. There are specific titanium and zirconia cutting burs available, but those without experiences of modifying zirconia should note that copious sparks are often produced! It is also worth noting that some manufacturers recommend no adjustments are made to the finished zirconia. As mentioned in Chap. 14, adjustments may weaken the material which makes a strong argument to prescribe a customised abutment rather than substantially modify a stock abutment.

For zirconia abutments the depth of preparation has been shown to be detrimental to the fracture resistance of the abutment with preparation depths of 0.5 mm being preferential to 0.7 and 0.9 mm [30]. The failures in this study occurred between the zirconia abutment and titanium insert rather than in the crown. This suggests the deeper margins may have weakened the abutments simply by reducing their bulk. Clearly, this is an area where compromise may be necessary particularly if ceramic materials are chosen for the crown which requires a 1 mm margin. Where strength is critical (e.g. in a bruxist), a monolithic zirconia crown with a 0.5 mm margin combined with a zirconia or titanium abutment would be a reasonable choice.

16.6.3 One-Piece Implant Abutments

In this design, the abutment and implant are provided together as one-piece. The abutment can come prepared with crown margins and optimum contours. The main advantage of this technique is the potential simplicity, efficiency, and speed at which a restoration can be provided to the patient. Additionally, the potential for micro-leakage or micro-movement or both between the implant and abutment is eliminated, potentially minimising bone loss. As there is no abutment screw, there is no problem of screw loosing or fracture. The one-piece design will allow for maximum strength of the implant/abutment complex which may prove particularly useful in narrow sites where incorporating all the componentry of two-piece implant systems reaches it limits. Therefore, narrow diameter one-piece abutments are frequently chosen for maxillary lateral incisor and mandibular incisor sites. Currently two-piece implant systems have minimum diameters of about 3 mm [31] whereas one-piece systems have diameters less than 3 mm. This is a rough guide as a consensus has yet to be reached on what diameters are represented by the terms “extra-narrow”, “narrow”, “standard”, and “wide” [32].

Case selection however is critical as there are several limitations to one-piece implant abutments. The implant must be “immediately loaded” (see Chap. 12) with no option to use a submerged placement technique; hence, primary stability must be good. The use of guided bone regeneration procedures at the time of implant placement may also be compromised. The relationship between the available bone and proposed tooth position needs to be optimal as the implant and integral abutment are fixed in their relationship (usually straight). This means there is little option to accommodate re-angulation from implant to restoration trajectory, as can be done with two-piece designs. The need to adjust the abutment immediately after placement raises concerns about heat generation, surgical emphysema, and debris getting into the tissues. Furthermore, there are very limited options for customising the soft tissue contour to ensure optimum emergence profile and aesthetics.

A systematic review with meta-analysis of one-piece implants concluded that good long-term implant survival rates could be achieved but that prosthetic survival rates were significantly worse than for two-piece designs [33]. However, small diameter two-piece designs are also vulnerable to prosthetic complications (decementation and abutment fracture) as reported by a recent multicentre study of a 3 mm diameter implant system [32]. At 5 years 10.3% of implants had prosthetic complications which compares unfavourably with 3.7% for all types of implant-retained crowns [34]. With improvements in abutment, refinement using CAD/CAM (rather than a bur intra-orally) may come improvements in clinical outcome for this type of restoration. Irrespective of abutment design, clinicians will still need to manage the occlusion carefully on the final restoration.

16.7 Abutments for Larger Edentulous Spans

Longer span restorations (e.g. implant-retained linked crowns or bridgework) directly attached to multiple implants can rarely be restored with one-piece screw-retained restorations. This is due to the inevitable difficulty in accurately engaging multiple implants with differing trajectories. One solution is to attach individual abutments to the implants which provide a common path of insertion for a cemented bridge. Alternatively, specially designed “off-the-shelf abutments” are used that allow for screw-retention of a linked prosthesis. These include both an abutment screw, allowing the abutment to be attached to the implant, and a prosthetic screw hole, allowing the prosthetic component to be attached to the abutment. This type of abutment is usually made from titanium and is available in a range of heights and angulations (e.g. Meso Abutment™, Straumann).

Conclusion

The provision of an implant abutment (which may be part and parcel of the final restoration) is an obligatory step in the delivery of a successful dental implant restoration. Clinicians referring patients for implant crowns should be familiar with the types of abutment available. Clinicians providing these restorations should have a detailed knowledge of implant dentistry and the range of implant abutment options available. Clinicians also need to be aware that abutment screw loosening is a common cause of failure and how to avoid it. In addition to assessing patients as suitable for implant crowns, care should be taken to consider the abutment system, design, and material. This will help ensure a restoration is delivered that is aesthetic, functional, lasting, and amendable to maintenance.

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17 Aesthetic Control

James Field, Andrew Keeling, Robert Wassell, and Francis Nohl

17.1 Learning Points

This chapter will emphasise the need to:

- Identify and define the patient's aesthetic problem
- Consider the balance between aesthetics and tooth destruction for conventional and adhesive restorations
- Be aware of the aesthetic limitations of restorations, including implant crowns
- Ensure that a patient's expectations are realistic and be alert to patients with unrealistic expectations
- Incorporate procedures leading to better aesthetics at each clinical stage
- Be confident in determining shade, be aware of digital shade analysis as an option, and communicate effectively with the laboratory.

A pleasing dental appearance is a subjective phenomenon, derived from an appreciation of the shade, shape and arrangement of the teeth and their relationship to the gingiva, lips and facial features. Understandably then, achieving aesthetic success is not always easy. To be successful, thorough assessment, careful planning and precise clinical execution are required. Every bit as important, though, is good

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communication, both with the dental laboratory and particularly with the patient. In few areas of dentistry can effective communication be as critical as it is here.

The retention of natural teeth into old age is increasingly common and, whilst usually desirable, it brings with it considerable additional problems. Making uniform well-aligned teeth in a complete denture is usually straightforward, but matching a single crown or veneer to a group of natural incisors is technically much more demanding. This problem is illustrated by data from the 1988 survey of Adult Dental Health in the United Kingdom [1] which showed that having just one or two crowns was more likely to be associated with dissatisfaction with the appearance than having none or many.

Where patients require restorations, dentists always strive to provide an aesthetic outcome. This is different to “aesthetic” dentistry (aka “cosmetic dentistry”) where dental treatments, many of them irreversible and some highly destructive of tooth tissue, are used to cosmetically enhance the appearance, often of previously unrestored teeth.

17.1.1 Aesthetic Dentistry

In the last two decades, aesthetic dentistry has become increasingly popular, its growth largely driven by a combination of:

- Media interest and exposure
- Pressures and expectations from patients
- Development of business opportunities for dentists and the dental industry.

To illustrate the level of interest in this subject, the British Dental Journal launched a series of articles on aesthetic dentistry. We encourage interested readers to refer to the introduction [2] which deemphasises extensive tooth preparation for ceramic crowns and veneers. Nowadays, leaders in the field urge a less invasive approach that incorporates adhesive dentistry and modern materials. In addition, orthodontics is recommended to correct tooth misalignments rather than straightening teeth with ceramic restorations requiring excessive tooth preparations. Nevertheless, orthodontic treatment is still potentially vulnerable to adverse outcomes, and patients consenting to treatment need to understand the risks of resorption, instability, caries, recession and failure to deliver optimal tooth positioning [3]. This is in addition to understanding the risks of associated restorative procedures [4].

Undoubtedly, some aesthetic procedures like bleaching are relatively innocuous and provide many patients with a non-invasive improvement in appearance. Others are less so, and veneer and crown preparations are not without a biological price. This may be a risk worth taking where a patient stands to gain an improvement in quality of life through the correction of “ugly teeth”, but rather less so when virgin teeth are sacrificed to obtain limited aesthetic improvements. Reacting to a rising tide of invasive aesthetic dentistry, concerns have been raised [5–7]—but there is also a dampening effect from the growth in medicolegal claims by disaffected patients fitted with crowns, veneers and implant retained restorations [4]. Perhaps the best advice is Burke and Kelleher's "Daughter Test"—would you carry out the procedure on your own (real or imagined) daughter? [8]

17.1.2 Cost-Benefit?

So, whatever the reason for restoration, a dentist should make a cost-benefit analysis, any aesthetic benefits being balanced against the biological costs of tooth tissue removal and subsequent effects on the pulp and periodontium.

The type of materials used (see Chap. 14) will influence both the appearance and the amount of tooth preparation, to accommodate a sufficient bulk of material. Restorations requiring minimal preparation, such as the ceramic veneer and dentine-bonded crown, whilst much less destructive of tooth tissue than conventionally cemented crowns, do have limitations: specifically, the problem of masking the colour of darkly stained teeth, problems of temporisation and the inability to cement definitive restorations provisionally (see Chap. 23). However, some ceramic systems now come in a variety of translucencies/opacities which in combination with tooth bleaching can provide much better results than before. There have also been recent improvements in indirect composite technology, including CAD/CAM manufacture, but so far there is limited clinical evidence of their stability and longevity.

17.1.3 Key Decisions for Anterior and Posterior Teeth

The key decisions are similar for anterior or posterior teeth but with less room for aesthetic compromise at the front of the mouth. On posterior teeth, it may be feasible to sacrifice optimum aesthetics and choose a ceramo-metal restoration. However, unless the tooth preparation is carefully designed, it may result in up to 75% of the coronal tooth substance being lost up the aspiration tip [9]. A more conservative ceramo-metal preparation can be designed by restricting the use of ceramic only to the most visible sites and by using a metal collar to avoid cutting a destructively deep shoulder. This approach will help conserve the health of the pulp, preserve the strength of the tooth and, with less space needed to accommodate a metal occlusal surface, enhance axial wall height and retention of the restoration. It may also be possible to use a resin-bonded onlay which leaves the bulk of the buccal surface intact (see Chap. 20).

A promising approach for the teeth not prominently on display (e.g. posterior teeth and lower incisors) is to use monolithic zirconia crowns which may not have all the aesthetic possibilities of other ceramic systems but require considerably less tooth reduction (see Chaps. 14 and 20). However, bonding to zirconia still needs to be perfected, and it would be helpful to have long-term trial data. An unfortunate consequence of the difficulty in making endodontic access through zirconia may be a temptation to extract a tooth rather than root-treat it.

Whatever material is chosen, a conservative approach equates not only to less pulp morbidity but more tooth remaining should the need arise to remake the restoration, which at some point is likely—particularly for younger patients. In consenting to treatment, a patient needs to understand fully the advantages and limitations of the restorative solution—and sometimes may be best advised not to proceed.

This article aims to address practical issues associated with getting a good aesthetic outcome. There is some science in the field of dental aesthetics, but this is largely confined to developments in instrumentation for helping with shade taking and indices being developed to quantify aesthetic need [10]. Inevitably, many aesthetic considerations are highly subjective and, thus, difficult to research. Much of the advice we offer and the recommendations we give are necessarily based more on experience than scientific analysis.

17.2 Identifying the Problem

The first and fundamental key to obtaining a successful aesthetic result is, at the outset of treatment, to establish the precise nature of a patient's demands. What is perceived as "natural" or pleasing to the dentist or technician may be far from pleasing for the patient (and vice versa). This may sound obvious, but without a detailed assessment, it is easy to fail to make a precise diagnosis of a patient's desires and risk treating something they were not concerned about.

If you ask a patient what shade they had in mind and they point to the white ceramic spittoon, there is little point making natural looking veneers or crowns, however technically excellent. Nevertheless, before going ahead the patient needs to understand there may be a visible mismatch between restored and natural teeth. Furthermore, if other teeth are then restored solely to eliminate a shade mismatch, can the inevitable risks and costs—both financial and biological—be justified? If a patient insists on lighter teeth, a better option is often bleaching, particularly for unrestored or minimally-restored teeth.

Table 17.1 lists the many factors which must be considered in defining a patient's aesthetic problem. In defining what constitutes an attractive smile, it is worth bearing in mind that dentists make their assessment from close to and often place a disproportionate weight to the teeth. To gain a similar perspective to patients, it is important to stand back and take more of the face into account [11].

Table 17.1 Factors contributing to dental aesthetics

Dental	Mucogingival	Facial	General
• Shade • Contour • Texture • Shape • Position • Arrangement • Interproximal contacts • Incisal embrasures • Gingival embrasures • Incisal level • Posterior occlusal level	• Margin level • Margin pattern • Shape of papillae • Colour • Thickness	• Lip levels at rest • Lip levels in function • Centre line	• Age • Occupation • Gender • Personality

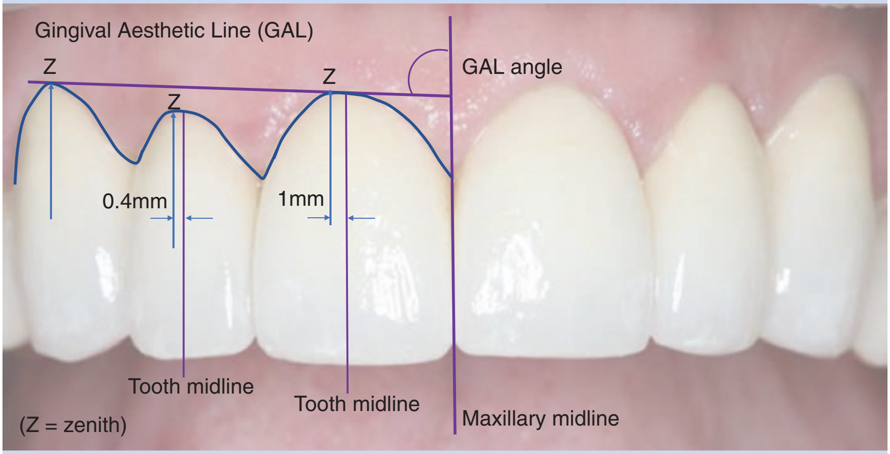
Interest often focuses around functional lip position in what is sometimes termed "the smile line". Generally speaking, the upper incisal edges should follow the curved outline of the lower lip displayed in a smile [12]. Of course, dentists may need to temper their enthusiasm for such a prescriptive smile design if a patient has a less-than-ideal lip morphology.

A small Dutch cross-sectional study of 122 randomly selected individuals aged 20–55 made two useful observations in respect of the amount of upper and lower incisor display. Firstly, younger individuals, particularly females, tend to have a higher smile line, revealing 75–100% of the upper incisors, often with a visible band of contiguous gingiva. Secondly, older patients have a longer upper lip and tend to show less upper teeth but more of their lower teeth [13]. Larger studies in different ethnic groups may offer useful baselines for comparison with individual patients, but, until then, dentists must make shared decisions with their patients based on best judgement.

Various rules of thumb have been described to help dentists create an aesthetic gingival contour around the restored teeth [14]. Few have been validated, and some may require a multidisciplinary approach to correct tooth and skeletal alignment. So, dentists acting in a patient's best interest must be careful not to use a sledgehammer to crack a nut.

One useful concept is that of the gingival aesthetic line (GAL) [15]. This is a tangent joining the most apical part of the gingival margins of an upper central incisor and an upper canine on each side of the maxillary midline (see Box 17.1). Some asymmetry of the GAL is natural [16], so dentists should not strive unreasonably to create a symmetrical smile perpendicular to the maxillary midline, particularly if this puts a patient's dentition at risk via overlong crowns and heavy tooth preparation.

Box 17.1: The Gingival Aesthetic Line (GAL)



(continued)

Box 17.1 (continued)

The GAL joins the zeniths of the free gingival margins of the central incisor and canine and for an "ideal outcome" should be slightly less than 90°. Whilst an ideal outcome may not be possible in many dentitions, the following guidelines may be useful when planning gingival surgery or developing restoration contours:

1. There should be reasonable symmetry between left and right
2. The canine zenith should be level or slightly higher than the central incisor zenith
3. The lateral incisor zenith should be at, or just below, the line
4. The zenith of the central should be 1 mm distal to the midline of the tooth
5. The zenith of the lateral should be 0.4 mm distal to the midline of the tooth
6. The Zenith of the Canine should be in the Midline of the Tooth [17].

One frequently mentioned concept is that of the "golden proportion" which has the proportion of 1.6103 to 1. This proportion often appears in nature and has been used in architecture for millennia. Following its enthusiastic promotion by Levine in 1978 [18], many dentists and technicians embraced it: firstly, to determine the progression in apparent width reduction (when viewed anteriorly) from an upper central incisor to a lateral incisor to a canine and, secondly, to decide how long and wide incisor crowns should be. However, tooth arrangements decided by the golden proportion are not to everyone's taste. Furthermore, crowns made to golden proportion dimensions often appear far too long, particularly when made for patients who have teeth of normal length [19]. Clearly, it would be unwise to use the golden proportion to restore teeth worn by bruxism—the unnaturally long crowns may act as levers resulting in destructive forces being applied to the teeth and supporting structures.

17.2.1 Matching Expectations with Reality

So, after a thorough clinical assessment, a dentist must decide whether:

- The patient's expectations can be realistically achieved
- The proposed treatment options are in the best interests of the patient's oral health
- The dentist, and the dental technician, both have the skill to carry out the treatment.

One of the greatest challenges for dentists providing crowns, veneers and onlays is the need to match expectations to what is technically and aesthetically achievable. There also needs to be a mutual understanding and continual dialogue between

Fig. 17.1 Short anterior crowns causing an aesthetic problem (**a**). Diagnostic wax-up at an increased occlusal vertical dimension (**b**, **c**)

clinician and technician; several commercial labs are now finding relatively novel ways of communicating information, for example, through social media and smartphone messaging. If you are tempted to do this, it is wise to ensure that the patient is aware and that you have consent to send the images, especially if the patient is identifiable from them.

Most patients appreciate a full and frank discussion about what is achievable, both at initial consultation and subsequently at various critical clinical stages. Early discussions can save a lot of time and money overall. Discussions can be aided by one or more of the several reversible means of helping patients understand the scope, and possible consequences, of treatment:

- Wax mock-ups (diagnostic wax-ups) on stone casts can be very useful for demonstrating treatment options and acting as blueprints for carrying out clinical and laboratory work (Fig. 17.1). Some dentists prefer these models to be created in tooth-coloured wax, but others select a non-tooth-coloured wax which may appear unattractive to patients but can be helpful in assessing shape. If wax-ups are to be used as diagnostic aids and to create matrices, they should be checked very carefully—tooth-coloured wax can hide a multitude of morphological, approximal and marginal sins. The wax-up is sometimes duplicated into stone, for example, to make vacuum-formed matrices; however, alginates recorded of partly soaked casts are usually highly inaccurate. Better to use a quality duplicating medium as when making partial dentures
- Composite resin or provisional crown materials can be used directly on teeth—without etching—to indicate the potential for shade and additive shape changes (Fig. 17.2). This is like carrying out a wax-up intra-orally, but the material is easily removed because it isn't bonded
- When viewed against the darkness of the mouth, a black, water-soluble ink marker can give an idea of the effect of subtractive shape changes such as shortening overerupted lower incisors (Fig. 17.2)
- Image manipulation software is now commonplace, and some dentists use it in discussions of treatment options. The downside of this approach is that it may be difficult to provide restorations exactly as created on screen, especially if a patient is given a colour-enhanced print of the expected outcome! Unlike the techniques described above, computer manipulation of images has no physical limits and may thus create unrealistic expectations

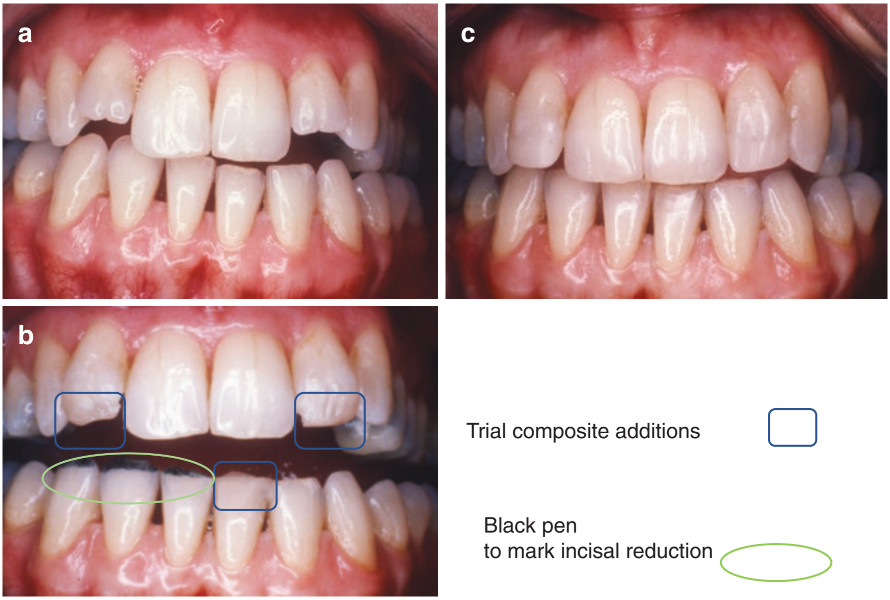


Fig. 17.2 Case requiring changes in upper lateral incisor length and levelling of lower incisal plane (**a**). Trial alterations using unbonded composite added to upper incisal edges and water-soluble ink to lower right incisors and canine (**b**). Restoration with directly applied composite resin (**c**)

- Photographs of previous cases may help patients understand some of the possibilities and limitations. Restricting these to your best results may be a mistake; if there are clearly going to be aesthetic limitations, it helps to illustrate them with realistic examples. Patients may be more likely to agree to treatment if they can picture the outcome, rather than imagine it from a verbal description
- Provisional restorations can allow the subtle relationship between the shape and form of the teeth, the soft tissues and facial features to be evaluated, decided and prescribed, before the final restoration is constructed. Provisional restorations can also ensure sufficient tooth preparation for restorative material (by establishing the desired shape and form and then measuring the thickness with callipers—see Chap. 23).

17.2.2 Unrealistic Expectations

Some patients may demand changes in appearance which are objectively difficult to appreciate and, still more, difficult to realise. In most cases this may simply be a problem of communication, but unrealistic expectations and a history of multiple previous treatments addressing appearance may be a warning of a patient with body dysmorphic disorder (BDD) or dysmorphophobia [20]. BDD is a preoccupation with a defect in appearance which is either imagined or excessive in relation to a minor defect and which causes significant distress in social, occupational and other areas of life. BDD is probably rare, but many dentists seem be aware of these patients. Undoubtedly, BDD is extraordinarily difficult to manage, and patient demands to change their appearance are unlikely to be satisfied, particularly if psychological aspects are not addressed. A second opinion is a perfectly acceptable course of action if in doubt. In the UK referrals can be made to a restorative or prosthodontic specialist working within the NHS or privately.

17.3 Final Planning and Clinical Procedures

Having decided a case can go ahead, the types of restoration must be finalised, along with their margin features. Then follow the clinical stages, ultimately leading to cementation.

17.3.1 Choice of Restoration

The emphasis in this book is to use restorations requiring minimal preparations, particularly when restoring otherwise unrestored teeth—or to conserve tooth tissue which would otherwise be sacrificed during crown preparation (see Fig. 17.3).

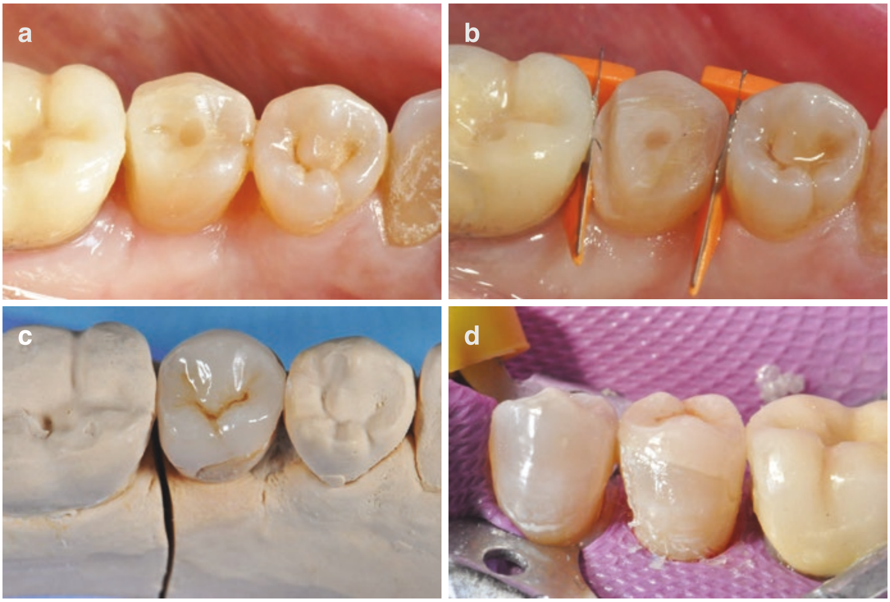


Fig. 17.3 Choose an aesthetic restoration, which conserves existing tooth structure and provides sufficient durability. Here, the root filled 35 with cusps undermined by a large DO composite (**a**). The onlay preparation (**b**), the pressed lithium disilicate onlay (**c**) and the onlay after luting under rubber dam. Courtesy of Marco Ferrari

Nevertheless, bruxism may cause any sort of ceramic veneer to fracture, and so ceramo-metal crowns still play an important role for some patients (see Chaps. 12 and 13). As mentioned previously, monolithic zirconia restorations hold promise but have limited clinical data.

Of course, patients may present with restored teeth, some extensively so. In these situations, the type of restoration may well be dictated by those that are already present and which may also need to be replaced.

Where a combination of veneers and crowns is planned, technicians often prefer the relatively translucent veneers to be fitted first and then the crown shade matched to them. This improves the predictability of the outcome. Combining adjacent ceramic and composite restorations aesthetically can also be difficult, particularly on anterior teeth. Undoubtedly, composites can provide an excellent match with adjacent teeth if they are built up in layers using shades and translucencies that mimic the underlying construction of enamel and dentine and simulate the shape of the amelo-dentinal junction [21]. This is still technically demanding and often requires a much thinner enamel layer than is expected. A slight deterioration in appearance with time [22] can usually be resolved with polishing.

A newly-placed, lone-standing composite is often distinguishable amongst a group of ceramic restorations, but this is clinically less of an issue when restorations are symmetrically distributed; e.g. ceramic veneers on the central incisors and composite veneers on the laterals. If using combinations of composite and ceramic, it's worth discussing with patients beforehand the possible need for maintenance of the composites and the replacement of either type of restoration.

17.3.2 Supra-, Equi- or Subgingival: Where should a Margin Go?

The location of restoration margins (see Chaps. 10 and 20) should be discussed and agreed with a patient before the preparation appointment. What follows is a summary.

Supragingival margins are preferable from a biological perspective and can often be prescribed without concern in invisible areas (e.g. those that lie lingually or proximally or are normally covered by the lips and cheeks). Not only will this facilitate finishing and maintenance but should also favour periodontal health. The appearance of a supragingival margin can be optimised by ensuring the finish line is in harmony with the level of the gingival margin, and the restoration has a minimal emergence profile—in other words it is not made too bulky near the margin. This often means ensuring that the margin is sufficiently deep to accommodate enough material bulk. The exception to this rule is a metal collar finished to a knife edge—although this can yield unaesthetic results if the lip line is unfavourable.

Equigingival margins are preferred with resin-bonded crowns and veneers in the aesthetic zone, because a subgingival margin makes removing extruded excess resin cement difficult and can unnecessarily complicate moisture control.

Where exposed crown margins are likely to create an aesthetic problem, margin placement into the gingival sulcus may be acceptable by up to 1 mm. Take care not to invade the biological width and cause subsequent problems with unsightly gingival inflammation, gingival recession or both. Risks are heightened with prominent roots and thin gingival tissues, or in the presence of periodontitis. Of course, the periodontal tissues should be stable before recording impressions for definitive restorations (see Chap. 21).

17.3.3 Shoulder or Chamfer Preparation Margin?

As described in Chap. 20, the preparation margin should be suitable for the chosen material. With ceramic restorations, a chamfer is preferred as it helps with the optical transition between ceramic and tooth. It also helps with reducing stress concentration. Chamfer depth is dependent on the type of ceramic and if it is resin-bonded. For example, chamfers of 0.4–0.6 mm are prepared for ceramic veneers but may be slightly less for ultrathin veneers. Ceramic crowns which are cemented conventionally (e.g. with glass ionomer cement) generally require a deep chamfer of around 1 mm but may be less deep for monolithic zirconia.

With ceramo-metal crowns, the choice for the buccal margin is whether to have a metal collar (with a fine chamfer or knife edge) or a ceramic margin (with a deeper shoulder or chamfer). The ceramic margin is sometimes called a “butt fit”. Structurally, a metal collar is preferred as it requires less tooth reduction, but realistically it can only be used on teeth whose margins are hidden by soft tissues, often just the lower teeth and the upper molars—but an assessment of the patient’s smile line will make things clearer. Skilled technicians can create a life-like marginal appearance for ceramo-metal crowns[23], but generally there is less scope to create as translucent a restoration margin as can be made with many all-ceramic crowns.

17.3.4 The Ceramo-Metal Junction

If a ceramo-metal crown is chosen, there are structural and biological advantages to not covering the whole metal substructure with ceramic, as this will require considerable tooth reduction. So, some forethought is needed as to which parts of the teeth are covered just in metal and which in both ceramic and metal (see Chap. 20). It should then be obvious to a technician examining the resulting die where to locate ceramo-metal junctions (Fig. 17.4). However, to avoid misunderstandings the extent of metal coverage should be explicit in the laboratory prescription. There are laboratory cost implications to provision of ceramo-metal crowns of this sort. It is likely necessary to wax a full contour restoration on the die, mark the ceramo-metal junction and then cut back space in the wax pattern for ceramic. Without a clear prescription, the laboratory may simply default to a thin metal coping over the whole preparation which is then covered by ceramic.

Fig. 17.4 Ceramo-metal crowns are still useful for bruxists. Die showing reduction to match veneering material(s): the larger buccal axial reduction is needed to accommodate metal *and* ceramic, the smaller palatal reduction is for metal alone

17.3.5 Shade Matching

Shade matching is something many of us find difficult and is consequently often done last—but it should of course be done first! It is not an exact science, involving a good deal of subjective judgement. Although an accurate reproduction of shade is an obvious goal, it cannot be divorced from consideration of shape, surface texture and special characteristics, which are described later. Teeth possess a range of natural optical features seemingly designed to make clinical shade matching difficult! Teeth:

- Are non-uniform in colour
- May have complex visible internal and surface features
- Have regions of translucency and opacity
- Exhibit a degree of fluorescence
- Change shade and shape with age.

In addition, a well-matched shade of ceramic in one light condition (e.g. daylight) may be a poor one under lighting with different spectral distributions (e.g. fluorescent lighting): a phenomenon termed metamerism. Added to all of this is the inherent variability in perception of colour by the human brain and eye [24].

Despite these obstacles, the best ceramic and composite restorations go a long way to reproducing nature by technicians using a combination of skilful artistry and optical trickery. Before recording and prescribing shade, it is useful to have a basic understanding of the science and dimensions of colour and texture so that shades can be interpreted and communicated precisely.

17.3.5.1 Dimensions of Colour

We perceive colours because of the way our brains interpret stimuli from the eyes' retinal red, green and blue cone receptors. It was the work of American painter and scientist Albert Munsell at the start of the twentieth century which formed the basis for quantifying perceived colour scientifically [25]. Indeed, a refined Munsell system is still used as an industrial standard for measuring and communicating colour, and it provides an elegant means for understanding colour in terms of three dimensions:

1. *Hue* The name of the colour: Munsell described five primary paint hues: red, yellow, green, blue and purple. By mixing paints of adjacent primary hues, intermediate hues are formed (e.g. yellow-red), making ten hues in all. Clearly, there is an infinite variety of hues depending on the proportions of primary hues used to create the intermediate hues, but for practical purposes, each hue is divided into 10 giving a colour wheel of 100 enumerated colours [26]
2. *Value* An achromatic measure of the lightness or darkness of a colour such that high value refers to a shade which is light and low value to one which is dark. Two completely different colours can have the same value. To help understand this, think about how a black and white photographic image represents colours
3. *Chroma* The strength or saturation of a colour of particular hue. Imagine increasing the chroma of a small amount of colour pigment diluted in water by adding more of the same pigment.

These three dimensions of hue, value and chroma define what is called "colour space". Of course, the Munsell system is not the only way of defining a colour space, and most electronic shade recording systems discussed later are calibrated using the CIELAB colour space. CIE stands for "Commission Internationale de I'Eclairage". This system defines a colour by its L*a*b* coordinates. L* denotes "lightness" (or colour intensity), whilst "a*" and "b*" represent coordinates, on the red-green and yellow-blue colour axes, respectively. These have perceptual meaning being based not only on spectroscopic readings under standardised lighting but also on the ability of the human eye to distinguish incremental colour differences. A full account of the underlying theory can be found elsewhere [27].

17.3.5.2 Shade Guides

Most dentists use ceramic shade guides supplied by the ceramic manufacturers. Unfortunately, these are not designed for a systematic assessment of the dimensions of colour and have been criticised for not including a broad enough range of shades for matching natural teeth, with anticipated deficiencies in the yellow-red hues, higher values and higher chromas [28].

Two commonly used guides (VITA Classical™ and Ivoclar Chromoscope™, made by VITA Zahnfabrik and Ivoclar Vivadent, respectively) are composed of groups based essentially on hue (VITA Classical™: A = reddish brown, B = reddish yellow, C = grey shades, D = reddish grey; Ivoclar Chromascop™: 1 series = cream, 2 series = orange, 3 series = light brown, 4 series = grey, 5 series = dark brown), with subclasses of varying value and chroma. For patients demanding whiter teeth, these and other ceramic manufacturers offer three or four "bleach shades" to complement existing shade selections.

Fig. 17.5 VITA Lumin™ shade tabs with stained necks removed in order of decreasing value **B1, A1, B2, D2, A2, C1, C2, D4, A3, D3, B3, A3.5, B4, C3, A4, C4**

The VITA Classical™ shade guide is aptly named as it is the rebranded VITA Lumin™ guide available to dentists for decades (Fig. 17.5). This guide can have its tabs arranged in order of ascending value rather than hue, because value is the most important dimension in colour matching for ceramic restorations [29]. Another modification which can be made to the guide is to grind away the neck (root portion) on each tab. This stops the neck darkness having an unwanted influence on shade selection.

Whichever guide is used, it is useful to understand the Munsell colour terminology (hue, chroma and value) as it forms a language for communicating additional information about colour to the laboratory.

17.3.5.3 Surface Texture

This quality describes surface contour both at a "macro" level, such as developmental lobes and ridges, as well as fine surface detail such as perikymata. The lustre of a restoration describes the level of glaze produced in the ceramic oven or by various rotary instruments and polishing techniques. Lustre can affect value perception such that high lustre raises value. It is therefore an important feature to match and one which is often neglected. At the very least, terms such as high, medium or low lustre can be used on the prescription and are more effective if they are linked to a standardised reference guide which can be used both in the surgery and in the dental laboratory. The technician can often get a good indication of other surface features from the surrounding teeth.

17.3.5.4 Special Characteristics

These are particularly useful for matching crowns and veneers to adjacent natural teeth. They include simulated fracture lines, white spots and translucency. The best-looking special characteristics are incorporated during incremental ceramic application. Surface stains can be used to produce some of these effects but are prone to wearing away with time.

17.3.5.5 Choosing and Prescribing a Shade

Dentists sometimes struggle to achieve a good shade match to existing teeth or restorations. Indeed, inter- and intra-operator reliability is sometimes poor when different dentists try to match the same shade or when the same dentist repeats a previous shade match [30]. Part of the problem may relate to the complexity of shades within a tooth, but there are other more practical reasons which may influence outcome:

- Inappropriate viewing conditions, including delaying shade matching until later in the appointment when one's eyes are tired and the patient's teeth partly desiccated
- Shade guides are often made from thick layers of high-fusing ceramic and require some interpretation
- Colour blindness [31].

Another issue is that recording a shade requires both skill and understanding. Dental students who have had colour education and training for shade matching perform significantly better than those who have not [32]. The same is likely to be true for dentists.

Shade selection will benefit from adherence to a protocol based on sound reasoning. It also helps considerably if the technician who is to make the restoration is involved in recording the shade. Box 17.2 gives a method for assessing shade and surface texture [33] which is grounded in common sense and easy to apply. Occasionally, custom-made shade tabs with varying ceramic thicknesses and a range of surface textures and special characteristics are helpful.

Box 17.2: A Scheme for Shade Determination

1. Use a neutral colour environment:
   - Avoid brightly coloured surgery walls
   - Ask patients to remove brightly coloured make-up
   - Drape the patient with a neutral (e.g. light blue) coloured cover if clothing is bright.
2. Use a shade guide familiar to the technician and appropriate to the choice of tooth coloured material.
3. *Determine shade at the start of an appointment* before the risk of eye fatigue and tooth dehydration with resultant shade change (especially after use of rubber dam).
4. Use either natural light (not direct sunlight) or a daylight-corrected artificial light source. Also, try shade under different lighting conditions (e.g. warm white).
5. Assess value by squinting. The reduced amount of light entering the eye may allow the retinal rods to better distinguish degrees of lightness and darkness. (Shade tabs set in order of value facilitate this—see Fig. 17.7).

(continued)

Box 17.2 (continued)

6. Make rapid comparisons with shade tabs (no more than 5 s for each viewing). Gazing at a soft blue colour between attempts for 15–30 s is said to reduce blue fatigue, which can result in accentuation of yellow-orange sensitivity.
7. Choose the dominant hue and chroma within the value range chosen. The canines have high chroma and may be a useful guide to assessing hue. Make separate assessments for the body, cervical, and incisal portions of the proposed restoration.
8. Compare selected tabs under different conditions: e.g. wet vs. dry, different lip positions, artificial and natural light from different angles.
9. Select a shade which is higher in value (lighter) if in doubt. Surface stains tend to make an underlying shade darker so may be able to correct too light a shade.
10. Look carefully for colour characterisation such as stained imbrication lines, white spots, neck colouration, incisal edge translucency and halo effect (a thin opaque line sometimes seen within a translucent incisal region). Use the special shade tabs representing the characterisation ceramics and stains for this task. Determine surface lustre. Simple diagrams are invaluable.

If a technician cannot attend the shade-taking appointment, a digital photograph may be of help, ensuring that the photograph also captures the appropriate shade tabs, in line with the arch (holding a shade tab labial or palatal to the arch can considerably alter its value). There are also more sophisticated digital methods of analysing tooth shade, and these are considered in the following section.

17.3.5.6 Digital Photography and Computerised Shade Analysis

As already mentioned, a digital photograph, complete with oriented shade tab, is an excellent and readily available tool for communicating with a technician. Some systems go further in providing software to blend an image of the tooth with an image of a shade tab (taken with the same camera) to help with shade selection. This, coupled with well-controlled lighting, would seem to produce a better intra-examiner agreement of shade than has been previously reported [34]. However, these methods still rely ultimately on the human eye; hence, there is a desire to automate the entire process to standardise quality.

Automatic measurement of shade can be accomplished using various techniques such as spectrophotometry, colorimetry or calibrated digital photography. Spectrophotometry has some market presence and there is a considerable range of products. Some have a small diameter tip (e.g. 3 mm) which only scans a spot on the tooth surface (e.g. Shade-X™, X-Rite; VITA Easyshade Compact™, VITA Zahnfabrik). Thus, separate scans must be made across the cervical, body and incisal regions. Other products can scan the whole tooth surface (e.g. SpectroShade Micro™, MHT Optic Research; Crystaleye™, Olympus). The Crystaleye™

combines spectrophotometry with digital photography giving both a photograph and a digital map of the recommended ceramic shades. These instruments are being continually developed and improved, but studies on repeatability are often equivocal, with several recent reviews suggesting that these tools should be an adjunct to manual shade-taking and that more research is required [35, 36].

Users of these systems should be aware of possible shortcomings. The mappings from these instruments are two-dimensional and often represent average shade tab values without necessarily considering the proposed restoration's surface characteristics or its thickness or if it will have a core (metal or ceramic). They may also "average out" colour data across broad areas of tooth surface leading to inaccurate shade information [37]. Other possible drawbacks of small-tipped instruments are the limited region of sampling on the tooth surface, the effect on shade of tip angulation and the fact that some systems are powerful enough to be affected by the colour of the background behind the tooth.

Colorimetry (derived from colour chemistry techniques for analysing the constituents of compounds) involves viewing the tooth under varying illumination or filtering, to produce three measurements corresponding to the red, green and blue cones of the human eye. These are subsequently combined to produce the colour. Dental systems allow the full image of the tooth to be captured, and thus provide a more complete aesthetic prescription. As before, there is little evidence to suggest they can replace manual shade-taking, but rather they can supplement it.

Finally, the rise in availability of digital cameras has driven development of automated digital photographic methods. Generally, these systems require calibration within each image, using one or more pantones (standardised coloured or grey tiles), and control specular reflections by using cross-polarized illumination. Developed over the past 20 years from initially cumbersome equipment (Fig. 17.6),

Fig. 17.6 The Ikam™ (Metalor Technologies SA), a pioneering digital camera-based system for shade analysis. The screen image (right) gives a two-dimensional representation of the selected ceramic shades

Fig. 17.7 The Smile Line system (Smileline SA, Switzerland) combines with a mobile phone and uses similar technology to the Ikam™ (see Fig. 17.6)—but advanced over 15 years

such systems are now finding their way onto mobile phones using physical attachments to enhance the camera. However, the efficacy of more recent systems remains unproven (Fig. 17.7).

In summary, the current best practice would seem to be the use of an automated system as an adjunct to good manual shade selection under controlled lighting. However, the research field is active, and it is likely that soon, full automation will become the preferred technique, perhaps to the relief of many practitioners.

17.3.6 Tooth Preparation

Achieving optimum aesthetics depends heavily on providing the technician with adequate space for the incremental application of ceramic (Fig. 17.8). The considerations have already been discussed above, but when it comes to the practicalities, the extent of tooth preparation is best visualised intra-orally by reference to a preparation guide. A small putty mould, made over the tooth before preparation, and then cut in cross-section is invaluable if the shape of the tooth is to be maintained (Fig. 17.9). A putty mould made from a diagnostic wax-up is required if the shape of the tooth is to be changed (Fig. 17.10). Alternatively, a vacuum-formed clear plastic matrix is made on a stone cast duplicated from the diagnostic wax-up (Fig. 17.11).

Depth cuts to guide tooth reduction may be a useful guide to ensure adequate reduction but are not very helpful when shape changes are planned. Matrices are particularly helpful on the buccal surfaces of upper anterior teeth which are curved when viewed from the mesial or distal. There is a tendency to prepare the buccal surface in a single plane, ignoring the curvature, but to achieve a good result, buccal preparation should follow the natural curvature of the tooth. We will return to these considerations in Chap. 20 where tooth preparation is discussed in detail.

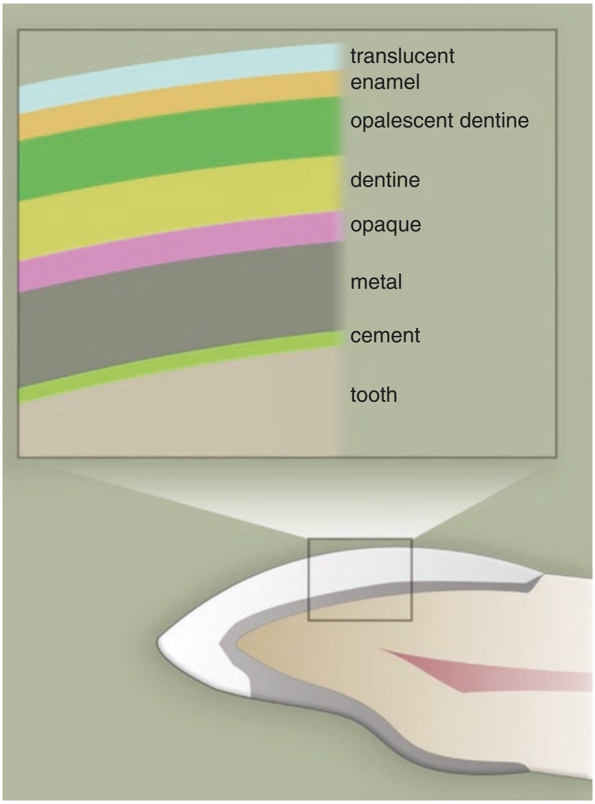


Fig. 17.8 Ceramo-metal crown—space required for five layers of ceramic, metal coping and cement. The thickness of each ceramic layer is illustrative and will vary from case to case and at different parts of the crown

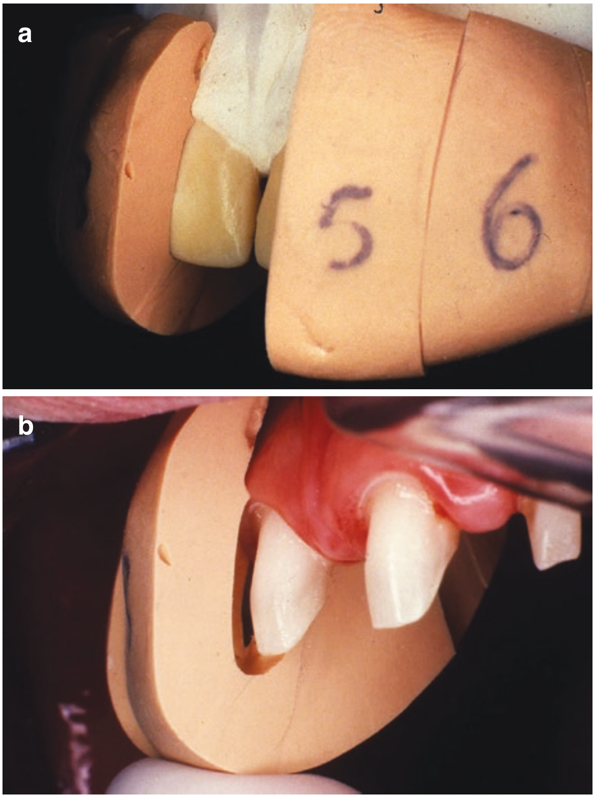


Fig. 17.9 Putty matrix sectioned and numbered on a diagnostic wax-up (**a**). Putty matrix component in situ to help visualise appropriate tooth reduction (**b**)

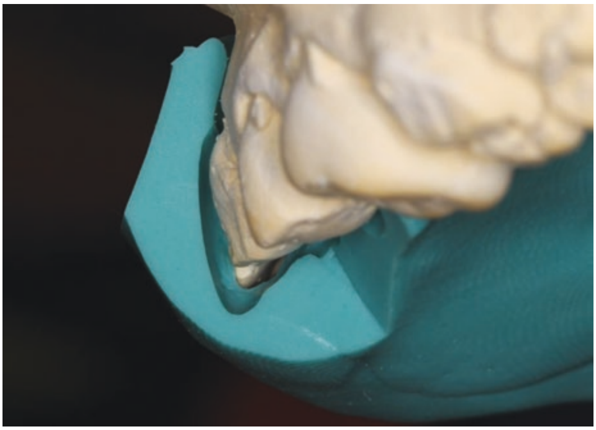


Fig. 17.10 A good example of when a matrix can be helpful to assess where, and by how much, tooth reduction needs to be carried out—especially when the starting point is tooth already reduced by tooth surface loss

Fig. 17.11 Vacuum formed matrix in situ. Some dentists prefer this to a sectioned putty matrix

17.3.7 Implant Aesthetics

Unlike crowns placed on natural teeth, implant crowns provide a unique opportunity to define the soft tissue contour. This is due to the “emergence” of the abutment from the implant head—which is normally subgingival. This emergence profile may well be predefined as part of the implant, with limited scope to adjust it (if “tissue-level” implants are placed). However, most clinicians would value the opportunity to influence soft tissue aesthetics anteriorly in the mouth, particularly the upper incisors—and it is in these cases where bone-level implants are useful. A good emergence profile can help form an interdental papilla but importantly will also account for a cleansable restoration.

Provisional implant crowns can be customised, initially by the laboratory—but then at the chairside using flowable composite—to give a better emergence profile than that formed simply by the cylindrical healing abutment. The procedure may require several appointments scheduled over a few months, but it is best to try and limit the number of times repeated removals and insertions disturb the delicate peri-implant tissues. A screw-retained provisional restoration may be less damaging in this respect than one that is cemented.

At each appointment, the contour of the abutment is adjusted to provide an outward pressure on the gingival tissues; any blanching must resolve before the end of each appointment. Clinically, this “dynamic compression technique” can give excellent results but is currently only supported by case reports. It is not always straightforward with success determined by many factors including the position of the implant in relation to adjacent teeth or other implants, patient-dependent factors and risk factors [38].

The height of the restoration’s proximal contact above the bone surrounding the implant is also important. With natural teeth, Tarnow’s classical study showed that a papilla could be expected to fill a well-contoured embrasure space between natural teeth providing the interproximal contact area began 5 mm or less above the alveolar crest [39]. However, a less optimal situation exists when implants are involved. So, between a natural tooth and an implant, this distance will be slightly less than

5 mm. However, between adjacent implants, it will be very much less often resulting in the papilla being sited 2 mm or more apically, leaving a "black triangle" below the interproximal contact [40]. Indeed, the average height of the papilla above the bone between adjacent implants is reported as 3.2 mm but ranges between 1 and 7 mm [41]. Despite the potential for the dynamic compression technique to give better results, dentists still need to be cautious when advising patients of the aesthetic limitations of having crowns on adjacent implants.

Figure 17.12 shows development of a papilla after careful adaptation of the subgingival contour of the provisional restoration. The method of contouring is discussed

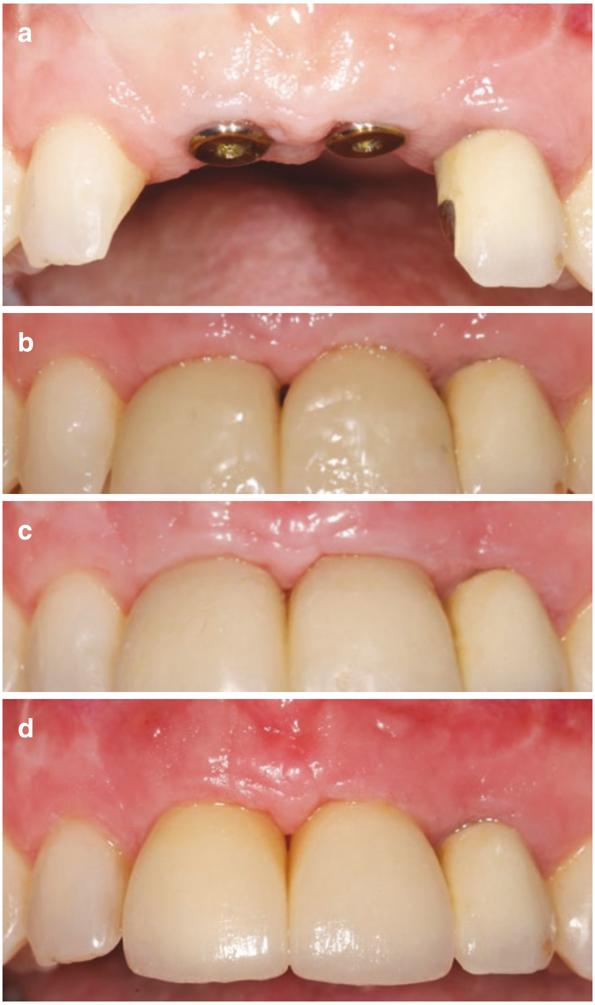


Fig. 17.12 The dynamic compression technique used to encourage papilla formation. Healing abutments (**a**) are removed and the provisional restorations inserted (**b**). The papillae developing after progressive recontouring of the provisional restorations (**c**). Definitive restorations placed—note the more limited papilla formation between the two implants (**d**)

further in Chap. 23, “Provisional Restorations”. We recommend dentists interested in this approach undergo a suitable training programme in implant provision.

17.3.8 Clinical Records

Dentists increasingly use face bows to help develop restorations on an articulator which will fit functionally and aesthetically with minimal adjustment. As discussed in Chap. 12, a face bow records the relationship between the maxillary occlusal plane and the intercondylar hinge axis—and ensures that articulated working casts are orientated to the base of articulator in the same way that the patient’s teeth are orientated with respect to the floor (if the patient’s head is upright and the anatomical features used as reference points are normally related). This helps the technician “see” the restorations orientated as they would be when observing the patient. Very occasionally an ear bow recording can give an erroneous interpretation of the relationship of the occlusal to the horizontal plane. This discrepancy occurs when skull asymmetries result in the occlusal plane being at a different orientation to the plane determined by the ears (the Frankfort Plane) and may need to be compensated for where multiple anterior crowns are prescribed. Devices to help decide an appropriate anterior occlusal plane in these more difficult cases are covered fully elsewhere [42].

17.3.9 Try-In and Cementation

Pigmented luting agents allow subtle manipulation of shade for adhesive ceramic restorations. Some systems provide water-based trial cements to facilitate choice of colour, and as a rule of thumb, it is best to try the “neutral” paste first rather than second guess which paste will give the best result. Manufactures’ instructions should be followed especially in relation to cleaning of the restoration and preparation prior to definitive cementation.

With ceramo-metal crowns, there is merit in trial placement of moistened restorations before giving them their final surface finish (Fig. 17.13). With more challenging cases, surface stains and changes in surface form can be prescribed at this stage (Fig. 17.14)—remembering that surface stains might eventually be lost. After glazing, a period of trial cementation leaves scope for a further period of assessment by both patient and dentist. If these restorations are subsequently returned to the laboratory for adjustment, the ceramic must be dehydrated by gently heating before firing to avoid the risk of fracture. Furthermore, temporarily cemented definitive crowns can be difficult to remove. Therefore, use a modifier to reduce the mechanical properties of your provisional cement as described later in this series (Chap. 24).

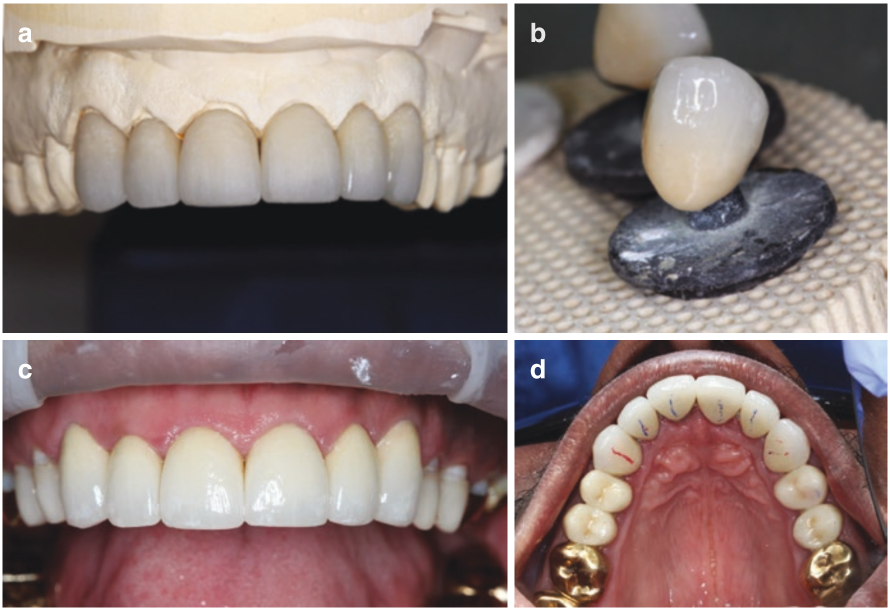


Fig. 17.13 Ceramo-metal crowns at the pre-glaze (biscuit) stage (**a**), where adjustments to aesthetics and occlusion can be made more easily. The crowns are then characterised and glazed (**b**) and then fitted (**c**) prior to verification of anterior guidance (**d**)

Fig. 17.14 Pencil marks for defining areas requiring adjustment. This case would have benefitted from a longer period after crown lengthening surgery to allow gingival maturation

17.4 Communication with the Laboratory

The dentist must accept ultimate responsibility for all aspects of completed laboratory work. On the face of it, this might suggest that a prescriptive one-way communication is required. Not surprisingly such an attitude can lead to feelings of frustration and dissatisfaction to all concerned. It doesn't have to be like this! Trained technicians are highly skilled in a unique blend of art, craftsmanship and science (as can be appreciated very rapidly by any dentist attempting to wield wax

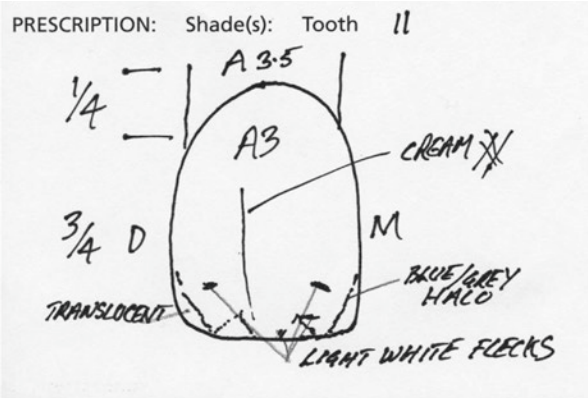


Fig. 17.15 A simple diagram highlighting notable aesthetic features is invaluable to a technician. In addition, the laboratory instructions should also mention if a face bow mounting is needed, if guidance needs to be copied (e.g. from casts recorded before tooth preparation) and, for ceramo-metal restorations, the amount of metal coverage and position of the ceramo-metal junction

or apply porcelain). Better then to foster a team approach, and central to a conflict-free relationship is the establishment of dialogue and clearly defined roles for the dentist and technician. To this end there is little to beat a personal visit to the laboratory, and subsequently it is helpful to be able to speak to technicians and to share ideas on a regular basis.

Critical to communication is a clear written prescription which should include a diagram to enable regional variations in shade and special characteristics to be understood. This does not need to be complicated (see Fig. 17.15) it just needs to convey relevant information. Where there are difficulties in recording shade, a wise dentist will involve the technician in the decision. Compliments as well as constructive criticism will help technicians evaluate their work, and anyone who takes pride in their work will appreciate the opportunity to see the result of a job well done. It is also probably fair to say that quality clinical work will be rewarded with higher quality restorations.

Conclusion

A complete understanding of a patient's aesthetic problems is the key to treatment planning. Only then can an attempt be made to match expectations with realities and to provide appropriate restorations—or recommend a non-invasive approach or no treatment at all. This process depends heavily on an appreciation of the ethical considerations and limitations of the techniques and materials available.

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Part V

Planning and Provision of Extra-coronal Restorations

History and Examination: Why is it Important?

18

Heidi Bateman and Robert Wassell

18.1 Learning Points

This chapter will emphasise the need to:

- Make a diagnosis and formulate a logical treatment plan which addresses patients' needs and their capability of receiving treatment
- Work within your capabilities and refer for specialist advice or treatment when necessary
- Be prepared to collaborate as part of a multidisciplinary team
- Control disease, stabilise the dentition, design partial dentures, and plan implant provision *before* embarking on extra-coronal restorations
- Be prepared to modify your treatment plan if on further investigation teeth need different management or if a patient is unable to comply with advice or endure treatment
- Ensure your history, examination, and special tests are sufficient to address the above requirements and secure patient consent.

This is the first chapter in the "Planning and Provision of Extra-Coronal Restorations" section part. The previous parts have concentrated on the principles, but this part focuses mainly on the practicalities of providing treatment.

An accurate, and relevant, history and examination underpin a successful outcome in restorative dentistry. This is as true for extra-coronal restorations as it is for providing other forms of treatment including the replacement of missing teeth

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with implants, bridges, or partial dentures. This book focuses on extra-coronal restorations, so while we touch on the interrelationship between crowns and partial dentures, dentists wishing to explore the intricacies of replacing teeth would be encouraged to look elsewhere, and also find appropriate training for implant placement.

The placement of extra-coronal restorations is an important part of general dental practice, and most treatments are well within a competent dentist's capabilities; however, some cases (e.g. with more complex periodontal, orthodontic, or occlusal issues) may require referral for more specialist advice or treatment. Extra-coronal restorations may also be part of multidisciplinary management, and increasingly dentists may be involved as part of the team providing treatment. Active collaboration and good communication between all parties is essential for a good outcome.

It's easy to get bogged down while recording a patient's history and examination and lose sight of their purpose—to reach a diagnosis and formulate a treatment plan. So, let's first consider the process of making a diagnosis and treatment planning.

18.2 The Process of Diagnosis and Treatment Planning

While it may seem strange to discuss diagnosis and treatment planning at the beginning of the Chapter it does help clarify what is needed from your history, examination, and special tests (e.g. radiographs, pulp tests and mounted casts).

18.2.1 Diagnosis

In everyday dentistry, the diagnosis stage is sometimes omitted—for example, a dentist sees a cavity and responds by placing a restoration. However, a predictable outcome with extra-coronal restorations, and particularly with multiple restorations, needs a more considered approach. So, taking time to make a diagnosis is a good investment [1]. The diagnosis must not only record the cause and extent of any dental disease but also define the nature of the patient's dissatisfaction, e.g. with the appearance of their teeth or, more rarely, a loss of functional ability (see Box 18.1). In addition, the patient's medical and dental histories must be considered so that their oral condition can be viewed holistically.

The diagnosis will therefore provide an essential stepping stone to propose various treatment options. These will be based on a dentist's knowledge and experience and should also consider a patient's ability to attend and endure multiple operative appointments. Following discussion with the patient, a favoured treatment plan can be selected (see Box 18.2), using where possible restorations requiring minimal preparation as described in Chaps. 2 and 20.

Box 18.1: Establish a Diagnosis and Formulate Treatment Alternatives

- Document clinical findings and the results of any special tests.
- Make a diagnosis by listing the diseases affecting the teeth, periodontium, oral mucosa, and masticatory system (e.g. temporomandibular disorder or occlusal dysfunction).
- Make a diagnosis of the patient's aesthetic issues and any perceived need for an improvement in masticatory function.
- Consider treatment options to address the patient's concerns and at the same time how underlying disease may be stabilised.

Box 18.2: Decide on a Definitive Treatment Plan

A further appointment will usually be required to:

- Discuss with the patient the treatment alternatives and evaluate their prognoses. Use the patient's mounted casts and diagnostic wax-ups. In addition, photographs of previous cases can be helpful
- Decide on the design and material(s) to be used in the construction of the extra-coronal restorations
- Agree and document treatment objectives of the favoured approach
- Formulate an appointment sequence to complete treatment efficiently. Consider laboratory stages and the need for a specialist referral (e.g. for implant placement or TMD management)
- It would be considered good practice to obtain written consent to the treatment plan and relevant costs (This is a requirement in the UK National Health Service).

18.2.2 Treatment Planning

Any restorative treatment plan, including one with extra-coronal restorations, is best divided into three phases: (1) disease control, (2) stabilisation, and (3) reconstruction. Examples of the types of clinical activity during disease control and stabilisation are shown in Box 18.3. Pain control is high priority for patients and may sometimes require emergency endodontic treatment or extraction, particularly if a tooth is considered unrestorable. An early review helps to determine if patients are engaging sufficiently with preventative advice (e.g. oral hygiene and dietary changes). In addition, caries management and non-surgical periodontal treatment can be reviewed.

Often the disease control and stabilisation phases merge together, particularly with already heavily restored mouths where defective or questionable restorations

Box 18.3: Preparatory Management

Before undertaking the restorative phase (e.g. with extra-coronal restorations), one or more aspects in the *disease control* phase or *stabilisation* phase or both may need to be completed.

Disease control:

- Relief of pain (e.g. emergency endodontic treatment) and extraction of hopeless teeth
- Prevention, caries control, non-surgical periodontal therapy, TMD management
- Preliminary occlusal adjustment (in cases of trauma from the occlusion).

Stabilisation: Review the patient's response to initial treatment. If appropriate proceed with:

- Investigation of individual teeth and the placement of cores
- Definitive endodontic treatment
- Any necessary orthodontic treatment
- Any necessary surgical periodontal treatment
- Definitive occlusal adjustment or equilibration if required
- Placement of dental implants if part of the treatment plan (a detailed assessment would be carried out earlier by the dentist providing the implants).

must be removed to allow teeth to be investigated properly. Based on these more detailed findings, treatment plans may sometimes need to be reformulated. Furthermore, it may sometimes be in everyone's interest to decide on a less demanding treatment plan, particularly if patients show poor compliance with advice and attendance. For these reasons, it is best to regard the initial treatment plan as provisional. Nevertheless, dentists can often establish a definitive treatment quite quickly—it all depends on the complexity of the case and patient compliance.

Right from the start, try and visualise a case with the reconstructive phase complete. The restorations should have the characteristics listed in Box 18.4. A knowledge of the available materials (Chap. 14) and bonding (Chap. 15) will be invaluable. Visualisation is helped by studying the diagnostic information including the mounted casts and diagnostic wax-up.

Think also beyond completion of treatment. What arrangements will be needed for follow-up? A successful outcome often requires continued disease control and supportive care. This is particularly the case where extra-coronal restorations are integrated with the provision of partial dentures.

Box 18.4: The Completed Treatment Should

- Satisfy the patient's expectations and requirements.
- Conserve tooth tissue by using minimum intervention when possible.
- Provide an optimal outcome with long-lasting benefits.
- Allow for easy homecare and maintenance to prevent further active disease.
- Facilitate any further treatment, which may be required.
- Involve minimum psychological trauma.

18.2.2.1 Integrating Extra-Coronal Restorations and Partial Dentures

Patients generally prefer fixed prostheses to removable ones. However, economic considerations often dictate the latter, and a new partial denture may need to be integrated with the provision of extra-coronal restorations. Alternatively, a new crown may need to be adapted to an existing, satisfactory denture (see Chap. 25).

A trap many of us fall into is failing to design a new partial denture until after cementing the extra-coronal restorations. Embarrassingly, there may be insufficient space to accommodate occlusal rest seats, and preparing them as an afterthought can be disastrous with restorations perforating or ceramic chipping. In addition, the opportunity is lost to incorporate guide planes and strategically positioned undercuts for improved retention and stability (see Fig. 18.1).

To avoid these problems, design the new partial denture while treatment planning. Survey the initial study casts and decide the optimum position of rests, guide planes, and clasps as well as the type of major and minor connectors. The responsibility of delivering an effective prosthesis is with the dentist, in collaboration with the dental technician. The partial denture design and any design features to incorporate in your extra-coronal restoration/s will need to be negotiated and effectively communicated to your technician via the prescription. These features are best incorporated into a restoration's metal surface, so all-metal or ceramo-metal crowns are often chosen, but remember partial coverage and adhesively retained restorations can also be used. An important decision is whether any additional tooth preparation is required to incorporate the features within the extra-coronal restorations. Once the restorations are cemented, impressions for the new partial denture can be recorded.

Another less commonly used method is to make all the extra-coronal restorations (usually crowns with milled guide planes), try them in, and then record a pick-up impression. This approach allows the technician to make a master cast for the partial denture which incorporates the restorations—hence, the crowns and partial denture can be delivered at the same time. It is generally reserved for cases where denture clasps must be avoided. The near parallel guide planes milled into the crowns ostensibly provide a friction fit [2], but another retentive mechanism may also be

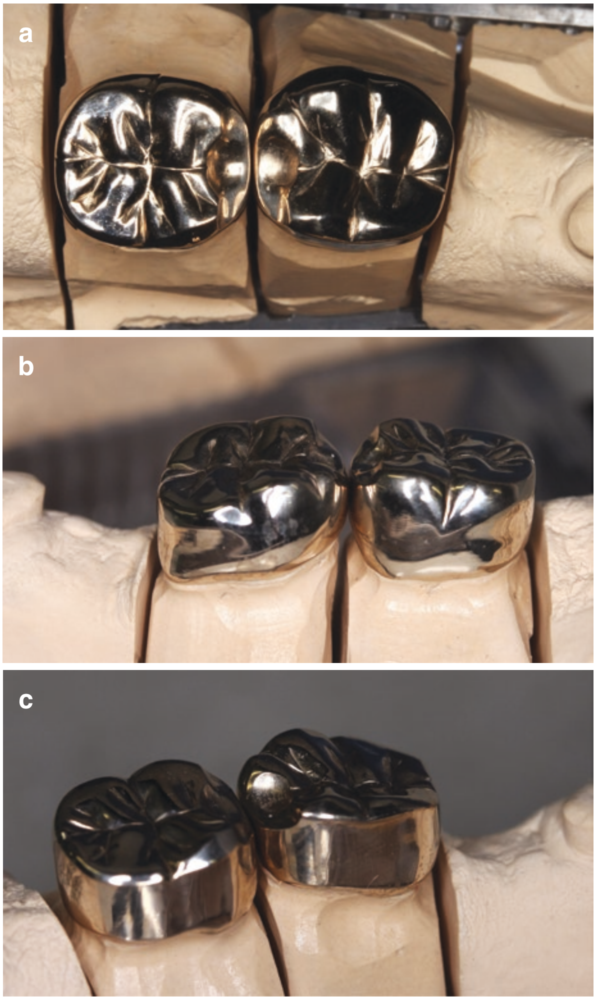

Fig. 18.1 Partial denture design should be considered before cutting preps and placing crowns. Here occlusal rest seats have been incorporated into both crowns (**a**). Viewed buccally, space has been created interproximally for clasps and the crowns contoured to give optimum undercut (**b**). Viewed lingually, guide planes are milled to the denture's path of insertion (**c**). Courtesy of Dr. James Field

operating. Following cementation, crowns often have a slew of a few microns [3] (i.e. they are slightly tipped on the preparation) which may combine with the resilience of the periodontal ligament to provide a well-retained prosthesis. It is claimed that the milled surfaces on the external surfaces of crowns are less destructive of tooth tissue than intra-coronal precision attachments. The latter have been associated with a high restoration failure rate [4]. Most at risk are post crowned partial denture abutments [5] and "linked crowns" (i.e. two or more crowns connected) used as abutments for free end partial dentures [4].

18.2.2.2 Other Aspects of Treatment Sequencing

As well as planning how partial dentures may be integrated into the treatment plan, there are other important practical aspects which also merit consideration. For example, with multistage treatments it is worth planning the sequence of clinical and laboratory stages to achieve the desired restorative outcome. This helps estimate the number of appointments and ensures sufficient time is scheduled. The appointment sequence should also accommodate sufficient time between appointments to allow work to be returned from the laboratory. Such planning is time well spent and dentists become more efficient at it with practice.

Provisional restorations are key to providing a successful restorative outcome, particularly where multiple extra-coronal restorations are needed (see Chap. 23). It therefore makes sense to plan the type of provisional restoration and whether they should be made directly or by the laboratory. Bear in mind that an adequate short-term provisional restoration for a single tooth may be wholly inadequate when used in the longer term for multiple teeth.

Diagnosis and treatment planning will be easier if you keep the above considerations in mind while recording your history and examination. At all stages communication with your patient is crucial as is comprehensive record keeping. Both will contribute to a successful treatment outcome and minimise risks associated with patient complaints and litigation. We are now able to consider history, examination, and special tests (e.g. radiographs, pulp tests, mounted casts, and diagnostic appliances). Increasingly, clinical photography contributes to a patient's clinical record and this is also mentioned.

18.3 Taking a History

A good history should always include an open discussion with patients to understand what they believe to be the problem. A detailed pain history is also needed where applicable. If a patient has an aesthetic problem (see Chap. 17), does it just involve one tooth or multiple teeth? Is it just in one arch or both arches? Get them to describe what it is they don't like about their appearance. Find out what their expectations are regarding treatment. Are these reasonable? Are they achievable? Try not to be dogmatic at this point as a considered answer usually needs to wait until the history and examination are complete.

You also want to understand the story of the patient's previous dental experience, including attendance, previous dental treatment experience, and any anxiety they may have regarding aspects of dental care.

Some of the most difficult patients to deal with are those who present with failing crowns, bridges, or implants. An early discussion with the patient is essential to determine the cause or causes of restoration failure. Patients should understand that restoration replacement would be conditional on successful preventive management of the cause(s) of failure [1]. In addition, decisions on the restorability of individual teeth may need to wait until the existing restorations are removed (see Chaps. 11 and 19). This is essential with caries under crowns where the extent of decay is otherwise difficult to determine. Patients who are left oblivious to these requirements can be guaranteed rapid failure of their new restorations.

18.3.1 Medical History

A comprehensive medical history not only ensures you can safely manage your patient, it also allows you to determine medical conditions which may increase the risk of dental disease, particularly caries, periodontal disease, and tooth surface loss (see Chaps. 3, 4, and 6), for example, medications or medical conditions which may lead to xerostomia or limit ability of a patient to manage oral self-care. By identifying these factors, you can apply appropriate measures for risk management.

Additional considerations may include a patient's ability to receive treatment (e.g. their capacity to sit or lie back in the dental chair, or where mouth opening limits access for treatment). Rarely, patients may be allergic to dental materials used in the provision of treatment or in restorations. If you or your patient suspects such an allergy, arrange an appropriate referral (Chap. 7).

Where implant placement or other surgical procedures are being considered, look out for the following conditions and treatments [1]:

- Osteoporosis
- Bisphosphonate therapy
- Uncontrolled diabetes
- Radiotherapy.

These are not always contraindications, but dentists must liaise with the patient's physician before embarking on treatment. Similarly, patients who smoke need to be informed that they are at greater risk of periodontal disease and peri-implantitis (Chap. 4).

18.4 Clinical Examination

This will include a full dental chart, periodontal assessment including oral hygiene assessment, an occlusal assessment, and a screen for temporomandibular disorders (TMDs). The TMD screen need not be complex:

- Does your patient report pain or clicking from their jaw?
- Is there pain, tenderness, or significant joint sounds on examination?
- Has the patient had previous treatment for TMD?

A more detailed assessment will be needed if there are any significant findings. For example, a detailed periodontal charting will be needed where a basic periodontal examination (or the radiographs—see below) shows signs of periodontal disease. Signs and symptoms of tooth surface loss (TSL) need to be followed up by recording their extent and severity and by detailed questioning to determine the underlying cause (Chap. 13). Similarly, a systematic occlusal examination (Chap. 12) is indicated if there are signs and symptoms of trauma from the occlusion. A full TMD examination is required where the TMD screen throws up a positive response (Chap. 8).

18.4.1 Occlusal Examination

Not every patient needs a detailed occlusal examination, but to ensure a successful and predictable restorative outcome at the very least, consider the questions in Box 18.5.

If you find any of these issues, we advise a systematic occlusal examination as discussed in Chap. 12. To avoid missing important findings, always try and sequence the examination in the same way:

- Individual arches—check for signs of occlusal overload (e.g. heavy facets, cracks, and fractures)
- Intercuspal position (IP)—view and mark up occlusal contacts
- Retruded contact position (RCP) and the slide from RCP to IP
- Excursive movements—view and mark up excursive contacts and judge whether these contacts provide guidance or interference to jaw movement.

Box 18.5: Have in Mind During the Occlusal Examination

- Are there are any problems associated with the occlusion (see Chap. 12)?
- Is the patient a bruxist?
- Are there excursive or deflective contacts on any tooth to be restored? If so, do they guide or interfere with mandibular movement? You will almost certainly remove these contacts during tooth preparation, so:
  - Do you want to reproduce the guiding contacts in the definitive restoration, or should guidance be arranged on other teeth (e.g. to avoid unwanted lateral occlusal forces on post crowns or implant crowns)?
  - Is there a risk of changing a patient's jaw position by removing a deflective contact or interference?
- Is there sufficient space available for a restoration? If not, how might it be created?
- Can the occlusion be restored conformatively, or does it need to be reorganised (e.g. for TSL patients who require restorations at an increased vertical dimension)?

18.4.2 Smile Line

The patient's smile line will influence your choice of margin position, margin type, and restoration material for extra-coronal restorations. When the patient smiles fully, can you see the gingival margins of the anterior teeth? Indeed, how far posteriorly along the buccal corridor can you see? As discussed in Chap. 20, whether you finish margins supra- or subgingivally is determined by a complex balance of several factors:

- A patient's ability to maintain plaque control which will be more difficult with subgingival margins
- Marginal position of existing restorations (it is usually best to finish a preparation on sound tooth structure)
- Pulpal and periodontal health (an epigingival or supragingival margin is preferred)
- Adhesively bonded restorations (an epigingival or supragingival margin is preferred)
- Aesthetics (a subgingival margin may be preferred, but risks being exposed by recession).

A tension clearly exists between an aesthetic argument for subgingival margins and a dental health argument for avoiding them. Patients should be involved in the final decision and understand the possible consequences of subgingival placement.

18.5 Special Tests

The clinical examination usually needs to be supplemented by one or more special tests. These regularly include radiographs, pulp sensibility testing, mounted study casts, and dietary analysis. Occasionally, diagnostic appliances may also be needed.

Where active caries or erosion are present, there is merit in carrying out a dietary analysis and establishing disease control before moving on with mounted casts, occlusal analysis, and diagnostic waxing.

18.5.1 Radiographs

Where you plan an extra-coronal restoration for a single tooth, it is wise to record a long-cone periapical film to assess caries, bone levels, and pulpal and periapical status. As well as contributing to the planning process, it also provides a baseline record of the status of the tooth prior to treatment. If radiographs have been recorded within recent months, use clinical judgement to decide if these are sufficiently diagnostic or if new ones are needed.

With multiple teeth, a sometimes difficult decision is whether to record multiple periapical radiographs or a dental panoramic tomogram (DPT). Bear in mind that more teeth are seen clearly with periapical radiographs than with a DPT—except for the second and third upper molars. However, while some DPT machines are as good as periapical radiography at detecting periapical radiolucencies [6], other more modern DPT machines are significantly better [7]. So, a good choice is a high-definition DPT, particularly if the state of the dentition (e.g. generalised periodontal disease or widespread restorations) would otherwise require a full-mouth periapical series that can carry a higher radiation exposure. Of course, if some teeth are indistinct on a DPT, they can if necessary be targeted with further periapical radiographs.

To limit exposure in accordance with national ionising radiation (medical examination) guidelines, a sectional DPT is sometimes a good option, for example, where multiple teeth on only one side of the mouth or in one quadrant need to be radiographed.

It is worth noting the increasing availability of cone beam computerised tomography (CBCT) which provides three-dimensional images. The effective radiographic dose of CBCT machines is much higher than periapical radiographs and varies hugely between different models [8]. The American Dental Association have issued a cautious advisory statement recommending CBCT only be used if it is expected to benefit patient care, enhance patient safety, or improve clinical outcomes significantly [9].

Current CBCT technology is generally regarded as helpful for planning implant treatment using digital planning programmes [10]. On the other hand, CBCT is not indicated for routine assessment of teeth scheduled for extra-coronal restorations. However, it can sometimes be helpful where a tooth is giving symptoms suggestive of apical periodontitis or a root fracture, but a periapical radiograph shows no signs of these diagnoses. Undoubtedly, CBCT does offer an enhanced view of the periapical region [11] and better diagnosis of suspected root fractures in teeth without root fillings [12], but not in root filled teeth because of associated artefacts [12, 13]. Therefore, if a crack is suspected in a root treated tooth of strategic importance, the existing restoration must be removed to confirm the diagnosis visually.

18.5.2 Pulp Sensibility Testing

As discussed in Chap. 5, pulp sensibility testing will allow you to test and record the tooth's sensory response to a stimulus, be that a thermal or electric stimulus.

Remember that pulp sensibility tests can give false positive and false negative readings so ensure you make a comparison with other teeth in the mouth to enable meaningful interpretation of your results. Record your findings.

Your clinical findings along with radiographs and sensibility tests will help determine the suitability of an existing restoration for use as a core. If in doubt, the integrity of the remaining tooth tissue is best investigated by removing a restoration. You can then judge if there is sufficient remaining tooth tissue to support and retain a viable core or an adhesively retained extra-coronal restoration (Chaps. 11 and 19).

18.5.3 Study Casts

Study casts are an invaluable aid to treatment planning. They help you visualise what is wrong with a patient's existing dentition. They help you plan and communicate changes using trial adjustments and wax-ups. They can also be used in long-term follow-up and evaluation particularly of TSL.

Remember, you want to keep one set of unaltered casts as a baseline record. So, a second set of impressions and casts will usually be needed for the wax-up. Having both sets of casts will help considerably in discussing treatment proposals with your patient.

Study casts may simply be a pair of handheld stone casts. Alternatively, the casts may be mounted on some sort of articulator to gain a better idea of tooth relationships in IP and an approximation of how opposing teeth move across each other during lateral and protrusive excursions. However, if for any reason, you are considering reorganising a patient's occlusion (Chap. 12) or making a closer analysis of occlusally related problems, then the casts should be mounted on a semi-adjustable articulator in centric relation using a face bow transfer and interocclusal record. Perhaps one of the most common reasons for considering reorganising the occlusion is where treatment of tooth surface loss requires an increase in occlusal vertical dimension (Chap. 13).

Is a face bow necessary for casts mounted in IP? Not always is the simple answer, but there can be distinct advantages in doing so, particularly when planning aesthetic changes to the anterior teeth (Chap. 17). Casts mounted in IP may not require an occlusal record if the teeth interdigitate sufficiently to hold the casts stable while mounting. If IP is indistinct, a wax or silicone mousse occlusal record will be needed. Remember to trim the silicone record to leave only cusp tip indentations for it to fit onto the casts. Also give the technician a note of which pairs of teeth hold shim stock so that the accuracy of the mounting can be verified [14].

Alginates are regarded by some as an inferior impression material, but with attention to detail, they provide excellent study casts. Remember, if you have errors at this stage, they will be compounded as you progress through the treatment, so take time to get good alginates. The same applies to alginate impressions recorded for other restorative stages, e.g. impressions for opposing casts and special trays (where indicated), or as part of constructing a provisional restoration.

18.5.3.1 Alginate Impression Technique

Hopefully, dentists will forgive the teaching of grandmothers to suck eggs, but students need this information, and there is no harm in reviewing one's own technique. Start by selecting a tray size which ensures that posterior teeth don't hang out of the back of the tray and risk impression distortion. Some dentists prefer to use metal rim-lock trays which come in multiple sizes. Others prefer perforated disposable trays which often have a more limited size range but can be extended posteriorly with greenstick [14]. Resist the temptation to extend a tray with wax. On removal from the mouth, the wax will be deformed, distorting the overlying impression. If using a perforated tray, apply adhesive but ensure you give this sufficient time for the solvent to evaporate before taking your impression. Five minutes is usually sufficient but you can speed things up by using an air jet from the three-in-one syringe. Place a paper towel behind the tray to avoid adhesive splatter.

Accurately dispense the water and alginate powder. The powder is lighter than the liquid. Therefore, add the liquid to the powder to improve wetting. By spatulating the alginate firmly against the mixing bowl wall, ensure your alginate mix is smooth with minimal incorporation of air. If there are problems with retching, sit the patient up and use distraction techniques, e.g. before placing the tray, ask the patient to lift both legs about 10 cm from the chair, and direct them to concentrate on their toes. Then, maintaining this position give instructions to breathe slowly through the nose. Next dry the teeth and record the impression.

Drying the teeth with an air jet or gauze reduces the risk of air bubbles being trapped in the impression's occlusal surfaces. You also need to smear a finger loaded with alginate across the occlusal surfaces on each side of the arch and behind the upper incisors. If air blows are trapped, they transfer to the casts as stone "blebs" on the surface, causing significant occlusal inaccuracies. Then seat the tray, having a mouth mirror available to scoop extruded material forward over the tray heels to stop it from running backwards. This manoeuvre also prevents extruded material impacting against the opposing arch and peeling the set impression from the tray upon removal from the mouth.

Once removed use a straight scalpel blade to trim extruded impression material from the distal extension of the tray to reveal the tray edge. Then check if the impression has not pulled away from the inside of the tray. If extruded material is not trimmed away, it may cause distortion of the impression while it sits waiting to be poured up. Before disinfecting your impression, check the following:

- All teeth supported in the tray
- Tray not showing through in occlusal areas and leaving voids where the stone can seep beneath the impression
- No air blows on the occlusal surfaces
- No areas pulled away from the tray.

After disinfection wash the impression under a cold tap and store in a self-seal polythene bag with some damp gauze. Get alginate impressions poured on the same day to reduce distortions due to imbibition (swelling) or syneresis (shrinkage due to drying out).

Once poured, assess your study casts for:

- Full arch accurately captured—check if the technician has not trimmed off the last standing molars
- No air blows in the stone—particularly occlusally
- No "blebs" on the occlusal surfaces—small blebs may be trimmed with a sharp instrument
- No interferences from the heels of the casts—the retromolar regions often need to be trimmed to allow the teeth to meet in IP.

Some dentists enjoy diagnostic waxing but others prescribe a wax-up from their lab. As mentioned in Chap. 17, a wax-up which looks good from a distance may incorporate a multitude of errors including overbulked margins and embrasures, inappropriate buccal contours and crown length, and inaccurate occlusal contacts. A good relationship with your lab is key to quality work. Ensure clear information and feedback, both complimentary and critical, flow in both directions. As mentioned previously, remember to design the partial denture if one is needed to integrate with your extra-coronal restorations in short or medium term.

18.5.4 Dietary Analyses

Patients with active caries (Chap. 3) or tooth surface loss (Chap. 6) where dietary erosion is a suspected cause are best investigated with a diet diary where patients record what they eat and drink contemporaneously across several days. However, dentists are often reluctant to carry out this analysis, possibly because of time constraints [15, 16]. At the very least, a detailed discussion is needed to identify cariogenic or erosive foods and drinks. Suitable alternatives can then be suggested and patients asked about progress with modifying their diet during the early part of treatment and certainly before embarking on the restorative phase. Not to make any attempt to do this is tantamount to building failure into tooth borne restorations.

18.5.5 Diagnostic Appliances

Occasionally these are needed to:

- Determine aesthetic requirements (e.g. using provisional crown material as described in Chap. 23)
- Condition the masticatory system prior to recording a centric relation record (e.g. a Lucia jig to release muscle splinting or stabilisation splint to manage temporomandibular disorder) [14]
- Create a stent with a radiographic marker (e.g. radiopaque mock-up of the final restoration) for planning implant placement in conjunction with CBCT [17, 18]. The stent may be adapted from a patient's existing denture [19].

18.6 Photographs

Clinical photographs can be helpful for both you and your patient. Nevertheless, it is essential to consider them part of a patient's clinical record with written consent recorded before photographs are taken [20]. The consent form should make clear the level of consent being requested, e.g. for clinical records only, for research or for publication (either in-house or widespread publication, e.g. web-based or journal). Improvements in digital cameras have made dental photography easier, but training and practice are required to develop sufficient skill [21]. Ensure you have a digital camera which can record high-definition close-ups and portrait shots, use good lighting conditions, retract soft tissues, and use intra-oral mirrors as appropriate.

If you take your camera on holiday, don't be tempted to take your surgery flash card! If it is stolen, the consequences of having identifiable patient images fall into the wrong hands could be extremely serious. Likewise, electronic images must be stored securely, and the original unedited image should be kept as a baseline record.

As mentioned in Chap. 17, photographic editing programmes can manipulate images which may be helpful in planning and in explaining options and potential outcomes to your patient. Your patient needs to understand this is only an indication of an outcome and the limitations of this approach.

With appropriate patient permissions, before-and-after images can help with practice promotion. In addition, photographic series of treatment are often an essential part of patient portfolios compiled as part of further training.

18.7 Finalise the Diagnosis and Treatment Plan

Once you have gathered your clinical records, considered your diagnoses, and formulated the treatment options, there is the need to return to the initial discussions you have had with the patient so you can agree on a preferred treatment plan. In all but the simplest cases, this is best done at a follow-up appointment at which you can explain:

- Alternative treatment options as well as the aims of the preferred option
- An outline of the treatment to be undertaken in each of the three phases of disease control, stabilisation, and reconstruction
- The need to make changes to the treatment plan depending on the patient's response to preventative measures and the outcome of investigations of individual teeth which may require endodontic treatment or extraction
- The necessity for any referral for specialist opinion/treatment
- The commitment in terms of time, number of visits, fees, and fee payment arrangements.

Patients also need to know what happens after treatment is complete and what to do if problems occur:

- The need for a maintenance plan
- The possibility that restorations may eventually need to be replaced and additional treatment may be required

- Any guarantee being offered. In the UK National Health Service, dentists are expected to provide a 1-year guarantee for extra-coronal restorations. In addition, further payments can't be demanded for supplementary work required within 2 months of completion of a course of treatment—but there are exclusions [22, 23]
- The arrangements to deal with any interim issues (e.g. lost temporary crown, endodontic flare-up).

All of this will help gain informed and valid consent. Many dentists confirm these details to the patient in writing to help avoid misunderstandings and reduce the possibility of litigation.

Finally, be aware that if you are presenting a patient for a professional examination, the examiners may have specific requirements for the information collected and how it is presented. It is best to check this out beforehand rather than try and conjure up information at a later stage.

Conclusion

Carrying out a history and examination without a clear idea of where they are leading is like going on a mystery tour. The provision of extra-coronal restorations is often part of a more extensive treatment plan. While the above account is by no means exhaustive, we hope it provides a useful guide to making a diagnosis, formulating treatment options, and planning the preferred option.

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Core Build-Ups and Post Placement

19

Claire Field, Simon Stone, John Whitworth,
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19.1 Cores in Vital Teeth

19.1.1 Learning Points

This part of the chapter will emphasise the need to:

- Distinguish between a core build-up acting simply as a space-filler or forming a substructure for the extra-coronal restoration
- Replace existing restorations, so what remains of a tooth can be properly assessed
- Be aware of tooth restorability indices, but use your own clinical judgement to decide which teeth can be reliably restored
- Decide if the extra-coronal restoration might be better bonded directly to the tooth without a core build-up

This chapter is in two parts: The first considers core build-ups in vital teeth as a foundation for extra-coronal restorations. The second part considers the practicalities of engaging with an increasing variety of options for restoring root-treated teeth focusing on core build-ups, the use of posts, and cast posts and cores.

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- Choose an appropriate core build-up material, prepare features in teeth to aid retention and employ appropriate adhesive bonding
- Ensure the extra-coronal restoration is extended sufficiently onto sound tooth beyond the core build-up to give a “ferrule effect”.

The Glossary of Prosthodontic terms defines a core as “the centre or base of a structure” [1] and undoubtedly, a restored tooth is a structure.

So, in vital teeth restored with indirect restorations, natural tooth structure will form at least part of the core. The other part of the core often comprises a directly placed restorative material (e.g. amalgam, composite, glass ionomer and its derivatives) to replace missing tooth structure. The purpose of this *core build-up* is twofold, firstly, to act as a *space-filler*, particularly where undercuts must be blocked out in the tooth preparation (e.g. with class III and V cavities). Secondly, where more tooth tissue is missing, the direct restorative material can be used to make a build-up shaped rather like a prepared intact tooth. In this way the core build-up provides an additional *substructure* for the restoration [2]. The strength of a chain, however, lies in its weakest link. With core build-ups, it’s not just the strength of the material which is important but also the bond (mechanical or adhesive or both) between build-up and tooth. This will be uncomfortably familiar to any dentist who has had a patient return with a build-up lodged within a dislodged crown. We will return to choosing suitable core build-up materials and how best to retain them, but first we must consider:

- The need to replace existing restorations
- Tooth restorability indices
- Restorative core build-up versus no restorative core build-up.

19.1.2 The Need to Replace Existing Restorations

There is always a temptation to leave existing restorations as core build-ups (see Fig. 19.1). However, unless you know the provenance of an existing restoration (e.g. you placed it recently), there are strong arguments to remove it:

- To check if there is any active decay beneath it
- To ensure it has no proximal marginal defects
- To determine if there would be sufficient tooth tissue to retain it following tooth preparation for an extra-coronal restoration
- To examine the dentine for any previous pulpal exposure
- To examine the dentine for cracks and determine their extent (Fig. 19.2).

Radiographs can of course give an indication of pulpal involvement and marginal defects, but being only a two-dimensional representation, they are not foolproof. Superimpositions, cervical burnout and root concavities can all mask underlying issues.

The decision on what type of extra-coronal restoration is needed (see Fig. 19.3) is best delayed until existing restorations are removed. Depending on what remains of

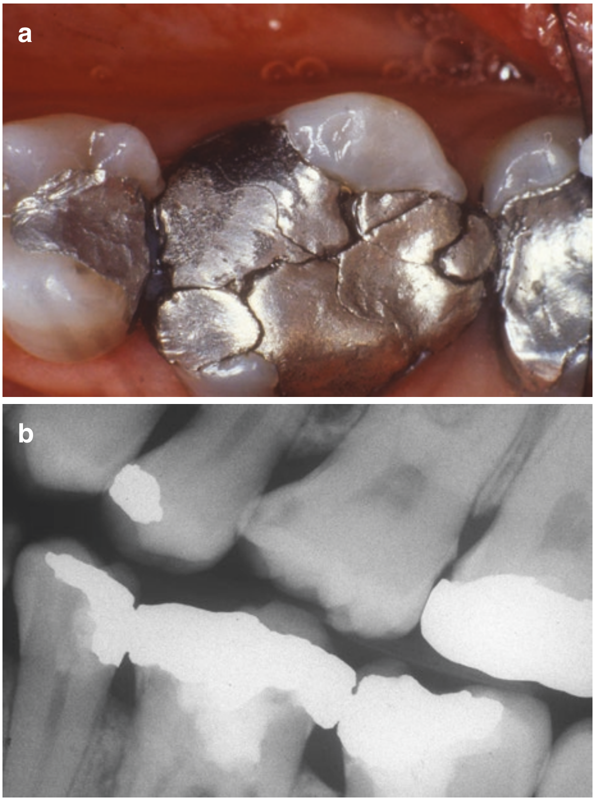

Fig. 19.1 The need to remove existing restorations. No thinking dentist would use this amalgam (**a**) to provide a core for an extra-coronal restoration, but apparently sound fillings often hide unwanted surprises. There is clear radiographic evidence of pulpal involvement (**b**); but in other cases, this is not always so obvious. Courtesy of Eoin Smart

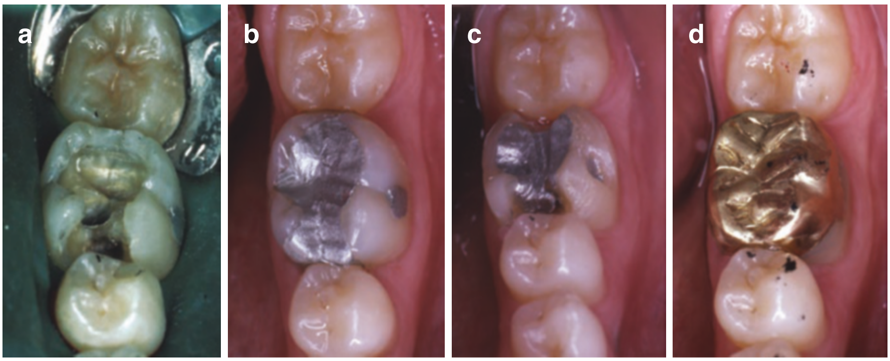

Fig. 19.2 Removing an existing restoration to assess the extent of a symptomatic crack in the distal marginal ridge of tooth 36. The crack extends just into dentine, but the cusps are heavily undermined (**a**). An adhesively bonded amalgam is placed as an interim restoration to allow symptoms to subside—a composite or glass ionomer may also have been used (**b**). This restoration becomes the core build-up for a conservative MOD onlay preparation (**c**). The gold onlay providing protective cuspal coverage in place (**d**)

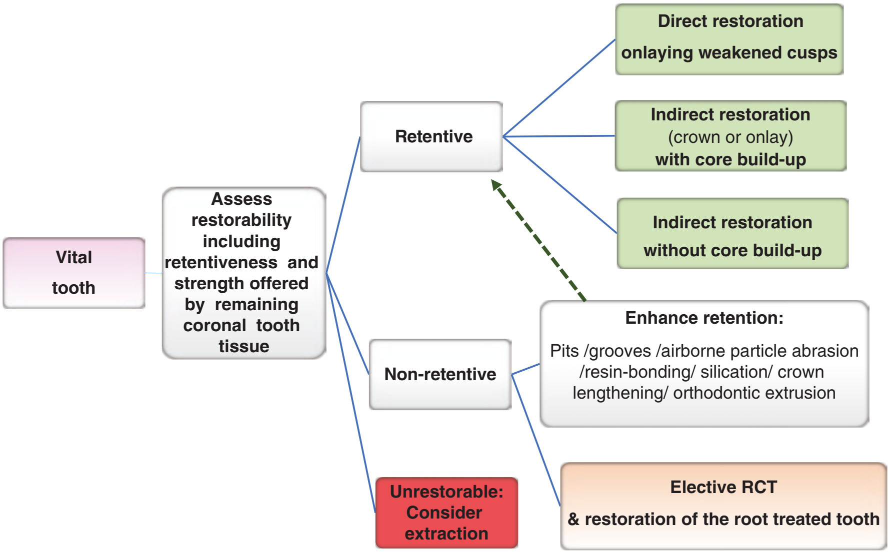

Fig. 19.3 Options for restoring a vital tooth. Assessment of restorability is key to a successful outcome. Note that some initially unretentive teeth may have retention enhanced by various means, but the ferrule effect (see text) is important too

the tooth you may decide to place a direct restoration instead of an indirect restoration. Alternatively, you may decide to place a partial coverage restoration instead of a full-coverage crown in the knowledge that this will be less destructive of remaining tooth tissue [3]. The remaining tooth structure is important either to retain a core build-up and the extra-coronal restoration (the traditional approach) or the extra-coronal restoration without a core build-up (sometimes used with adhesively retained restorations). Various strategies (discussed below) can be used to enhance retention.

Where possible, the extra-coronal restoration should be extended onto sound axial tooth surface. This is the "ferrule effect" originally described by Nayyar [4] for amalgam core build-ups placed in root-treated molars scheduled for full-coverage crowns. For a ferrule to be effective surgical crown, lengthening is sometimes needed so that at least 2 mm of axial tooth is exposed. Occasionally, elective root canal treatment may be considered for a post and core to enhance retention, but as discussed in Chap. 11 and later in this chapter, this decision needs to be made carefully. No patient wants a rapidly failing restoration.

Defects on the tooth extending deeply subgingivally require careful consideration. These are often associated with old restorations, caries or fractures. The options are:

- To place a well-adapted core build-up and prepare the margin for the extra-coronal restoration in the build-up. This makes the restoration margin more accessible, but an inaccessible core margin may hide a multitude of defects
- To chase the margin for the extra-coronal restoration onto sound tooth tissue—this can be challenging and may invade the biological width particularly for margins more than 2–3 mm subgingival [5]

- To consider surgical crown lengthening (see Chap. 10)
- To arrange extraction and possible prosthetic replacement.

There is no need to restore *everything*. Don't be afraid to decide that things are unrestorable with general approaches. However, be prepared if the patient is determined to go ahead, to formally crown lengthen, or at least place a very well-fitting (often lab-made) provisional for at least 6 weeks to assess gingival health. Once inflammatory swelling resolves, the margin may be less subgingival. Admittedly, you're more likely to embark on this for strategic anterior teeth.

19.1.3 Tooth Restorability Indices

What remains of a tooth after removing existing restorations will to a large extent determine its restorability. Dentists regularly assess broken down teeth and decide empirically whether to restore or extract, but deciding whether a vital tooth can receive a predictable and long-term restoration is a challenging task. In response to this challenge, there are two indices that are purported to help with decision-making both with vital and nonvital teeth. The TRI (tooth restorability index) considers the adequacy of the remaining tooth to support and retain a core build-up. An assessment is made at six locations around each tooth [6] (Table 19.1). At each location, the remaining wall is scored from 1 to 3, giving a potential maximum total of 18 for each tooth. The scoring criteria (see Box 19.1) are subjective and based on the operator's clinical opinion. Nevertheless, the index shows moderate-good reliability when used between assessors [7]. McDonald and Setchell recommended a minimum score of 12 for a single crown to be predictably and successfully placed using a core build-up. Scores of <9 may require a post and core or surgical crown lengthening or both. Scores between 9 and 12 may be acceptable if 2–3 tooth locations have adequate remaining dentine. However, these scores have not been validated clinically and seem mainly intended for molars. So, operators should still use their clinical judgement when assessing restorability.

Most recently, the Dental Practicality Index [8] claims to provide a framework for assessing teeth, but also for planning treatment within the local and general context of the dentition, and the patient's medical history. This is a formidable venture, but this index has yet to be tested for reliability and validity. Further, while it refers to residual

Table 19.1 Tooth restorability index (TRI) abbreviated criteria derived from McDonald and Setchell [6]

Score	Descriptor	Subjective assessment of remaining dentine (width, height and distribution) in each tooth sextant
1	Inadequate	Insufficient dentine to make any meaningful contribution to retention and resistance. Wall less than 1.5 mm thick (compared with bur diameter of 1.6 mm)
2	Questionable	More dentine present than for 1 but operator not confident whether it will or will not make a predictable difference to retention and resistance
3	Adequate	Sufficient dentine in the sextant to contribute fully to retention and resistance of the core

tooth tissue and a ferrule, the user is again required to make a subjective judgement about whether an adequate volume of tooth tissue is present for a restoration.

To a large extent, deciding on restorability will not only be influenced by the presenting condition but also by a dentist's skill and experience. Also important are the patient's wishes, medical history, and their ability to endure dental treatment (for more on treatment planning see Chap. 18).

19.1.4 Core Build-Up Versus No Core Build-Up

The traditional approach of building up the core for an extra-coronal restoration has several advantages:

- The core build-up can be used as an interim restoration allowing:
  - Other teeth to be treated (see Fig. 19.4)
  - The occlusion and periodontium to be stabilised
  - The endodontic status to be monitored, particularly where there have been pulpal symptoms
- Retrievability is facilitated—extra-coronal restorations, particularly crowns, are best sectioned to aid removal. Having an underlying core build-up limits the extra-coronal restoration's thickness, so there is less material to cut through
- Less casting porosity than when alloys are cast in thick section
- More economical when using expensive cast noble alloys (e.g. for a crown).

Where there is insufficient tooth tissue, the retention of a core build-up may be unreliable. However, if a ferrule can be created in combination with a ring of sound enamel, it may be possible to design an extra-coronal restoration (e.g. an onlay or crown) which is luted directly to the tooth without a core build-up. Figure 19.5 is an example of a short preparation for a gold crown where a core build-up was not used. Instead, the preparation was made sufficiently retentive by using the box forms from

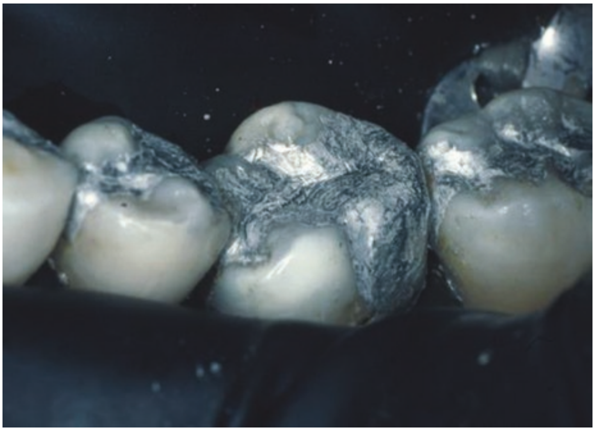

Fig. 19.4 A large amalgam restoration placed in a patient who required multiple restorations as part of disease control and stabilisation. At a later stage, an extra-coronal restoration may be placed

a previous restoration. This approach reduces the number of material interfaces and does away with the potentially weak interface between the core build-up and dentine. It can sometimes work well, particularly with monolithic metal or ceramic restorations (see Chap. 14). A ceramic should be chosen where the intaglio (fit) surface can be etched for resin bonding (e.g. lithium disilicate). However, omitting a core build-up should be used selectively for two reasons:

- Additional tooth structure may need to be sacrificed to allow the prescribed extra-coronal restoration to seat, particularly if undercuts are not blocked out with a core build-up
- Retrievability can be difficult. A failed, bonded restoration may require intricate dissection from a complex preparation form.

It would be helpful to have trial data for adhesively retained crowns and onlays where no core build-up has been used. This would help clarify how much ferrule is needed in this situation.

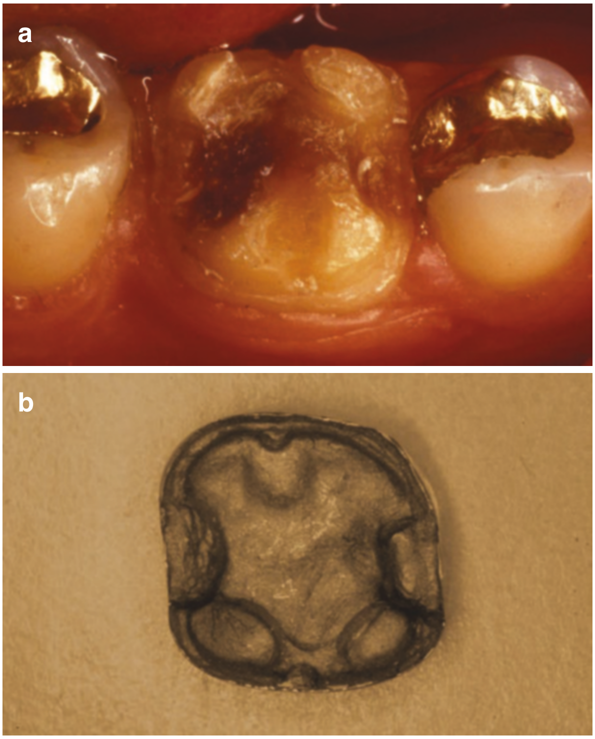

Fig. 19.5 A core build-up is not always needed. Here a lower first molar with a short clinical crown has had its previous MOD restoration removed (**a**). The preparation has been made sufficiently retentive by utilising the proximal boxes and placing grooves on the buccal and lingual axial walls. These features are reproduced in the restoration's intaglio surface (**b**)

19.1.5 Material Choices

The material requirements of a core build-up will differ depending on whether it is to be used as a simple space-filler or if it is to provide a substructure for the extra-coronal restoration. Empirically, if sufficient tooth remains to provide a strong and retentive preparation, then the restorative core build-up will act simply as a space-filler. Should you be in any doubt, it is better to choose a strong, well-bonded, build-up material than risk mechanical failure of weak filler material. However, it is best not to place too much reliance on tooth-coloured filling materials as a replacement for tooth tissue. Over-reliance on the core build-up where what remains of the tooth is weak can cause catastrophic failure of either the restoration, the tooth or both. So, we present two further rules of thumb to help with planning cores and extra-coronal restorations:

- Where less than 1 mm of height in ferrule exists, assume no ferrule effect
- Where dentine after tooth preparation is less than 1 mm wide, it should be regarded as not there at all.

Nevertheless, a core build-up is often indicated, and the following sections are intended to help with choosing an appropriate material.

19.1.5.1 Amalgam

Many old school dentists traditionally consider amalgam as the best build-up material under conventionally cemented crowns. It has good bulk strength and is sealed by its own corrosion products. Importantly, it is not especially technique sensitive—providing that during placement it is well condensed and not grossly contaminated by blood or saliva. Although it is possible to find rapidly setting amalgam alloys, crown preparation is better delayed for at least 24 h.

Amalgam's main disadvantage lies in its mercury content. In line with the Minamata Treaty and World Health Authority recommendations, its use is being *phased down* at a rate decided by individual nations [9]. However, calls for it to be *phased out* have been resisted because it is still unequalled as a restorative material, particularly in patients with a high caries rate [10]. Nonetheless, dentists are encouraged to use mercury-free materials if they are similarly effective [9].

Amalgam is weak in thin section and for this reason has no role to play in the provision of cores in anterior teeth. In posterior teeth, an amalgam core may flake away if left in insufficient bulk following tooth preparation. Its retention is mainly mechanical, but increasingly adhesive cements and resin adhesives are being used to provide chemical bonding as will be discussed later.

19.1.5.2 Composite

Composites for making cores have tensile strengths at least as good as amalgam [11], but are much more technique sensitive. Many of these materials can be used to make core build-ups both for vital teeth and root canal-treated teeth with endodontic posts. Some have novel formulations, for example Build-It FR™ Fiber Reinforced

Core Material (Pentron Clinical) which incorporates chopped glass fibre and is dispensed via a syringe mixing tip as a dual-cured material. Our experience of its handling properties has been good. In vitro studies support its use [12, 13], but there are no clinical studies.

Effective bonds between composite and tooth are now expected, but only where moisture contamination and polymerisation shrinkage can be properly controlled. Experience shows blood and saliva contamination render bonding useless. Patients may experience pain, and caries can follow in a matter of weeks. If rubber dam cannot be used, no compromises should be made with salivary ejectors and cotton wool rolls. To avoid problems from polymerisation contraction, place light-cured composites incrementally. Chemically cured composite can be placed as a single increment as shrinkage stresses are partially dissipated through the much longer setting time. To this end we allow Build-It FR™ Fiber Reinforced Core Material (Pentron Clinical™) to set chemically before light-curing. Where effective isolation cannot be achieved, as in many subgingival situations, the use of composite cores is contraindicated.

Composite core build-ups can be problematic when identifying whether a preparation finish line lies on the build-up or on sound tooth tissue. This is much less a problem with amalgam.

19.1.5.3 Glass Ionomer Cement (GIC)

Some dentists favour GIC for core build-ups, in view of the apparent ease of placement, adhesion, fluoride release and matched coefficient of thermal expansion. It is a water-based material, so while still needing moisture control, it is not as technique sensitive as composites. Nevertheless, many workers regard GICs as too weak and brittle to support major core build-ups [11, 14–16]. The diametral tensile strength of GICs is about one tenth of that of composites [17]. Hence the recommendation that a tooth should have at least two structurally intact walls if a GIC core is to be considered [18]. In our view, it is best to regard GIC as an excellent space-filler. As a structural build-up material, it is vulnerable to fracture, particularly if not used in sufficient bulk (e.g. in a premolar). Choose a viscous GIC with good early strength properties [17] (e.g. Fuji IX™, GC Corp). If possible, delay preparing the tooth until the next appointment to allow the material to fully mature, so it is less likely to crack. To protect a GIC core, the crown margin should, wherever possible, completely embrace 1–2 mm of sound tooth structure beyond the margin with GIC.

19.1.5.4 Resin Modified Glass Ionomers (RMGICs) and Compomers

RMGICs were developed to provide properties intermediate between regular GICs and light-cured composites. There is a spectrum of such materials. At one end are those that start to set in the same way as a GIC following mixing but are rapidly hardened by light-curing the incorporated resin, e.g. Fuji II LC™ (GC). At the other end of the spectrum are the "compomers", which have an initial setting reaction like composites (e.g. Dyract XTRA™, Dentsply). Here, the GIC reaction does not occur until later when moisture from the mouth is absorbed into the set resin matrix where it activates incorporated polyacids.

Dentists have received these materials with some enthusiasm not least because the adhesive systems are easier to use than for composite resin, and unlike GICs their rapid set does not delay tooth preparation. As well as good handling properties, there is also the advantage of fluoride release. 3M Vitremer™ is a dual-cured RMGIC with good strength properties [19], specifically advocated as a core material where at least half the core remains as tooth [20]. In a short-term clinical trial, it behaved satisfactorily under gold crowns, without the need for pin placement [21]. However, during the 3 months before crown preparation, a third of the core build-ups developed significant surface defects, which, although eliminated by crown preparation, suggest the material is unsuitable for long-term interim restorations, e.g. when establishing occlusal stability. The authors were also at pains to emphasise the need for ferruling the crown preparation onto sound dentine in the same way as for regular GICs. At 5 years 24 of the original 51 crowns were reviewed, but only 1 had failed [22].

The resins used in these materials are hydrophilic and swell slightly following water absorption. This expansion has the potential to fracture ceramic restorations overlying core build-ups and cements made from RMGICs or compomers [23]. Indeed, one manufacturer has contraindicated its compomer for core build-ups [24].

We use these materials as space-fillers to block out undercuts for small defects. One RMGIC, 3M Vitremer™, may have a role in the adhesive bonding of amalgam (see "Baldwin Technique", box 19.1).

19.1.6 Methods for Retaining a Core Build-Up

Before the relatively recent advances in adhesive dentistry, pinned amalgam restorations were taught as the default for cores in posterior vital teeth. However, pin placement is not without problems. Of 429 pin placements by staff and students at Leeds Dental School 19% showed complications—most frequently a loose pin or inadequate penetration of a pin into its channel. However, 10% of complications were serious involving either perforation of the pulp or periodontium or tooth fracture [25]. A mounting body of evidence and opinion now counsels against using pins [26].

Fortunately, there are other mechanical methods of retaining a core build-up including the use of existing cavity preparation features, and, if necessary, preparing additional slots and boxes. In addition, chemical bonding using adhesive cement and resins is now used routinely. Airborne-particle abrasion is also used where necessary.

19.1.6.1 Cavity Modifications

Anyone who has had a core build-up detach within a crown will know that it is unwise to place complete faith in either adhesives or pins. To gain mechanical retention for a core build-up, try and capitalise on existing cavity features such as boxes or an isthmus. Where there is only a small amount of tooth tissue remaining, consider crown lengthening to ensure the crown margin is ferruled onto sound tooth structure.

An improved mechanical interlock between core build-up and tooth can often be obtained by cutting new boxes or grooves or by reducing weakened cusps and onlaying with build-up material. Consider reducing cusps in height where they are likely to be <1 mm thick after tooth preparation or the wall thickness to height ratio is less than 1:1 [27]. The onlay of build-up material must be sufficiently thick so it isn't weakened catastrophically during occlusal reduction of the preparation. Another useful tip is to resolve sloping tooth walls into vertical and horizontal components. This approach will improve the retention and resistance for core build-ups and crowns.

Grooves can be cut into dentine to help retain large amalgams and increase the bonding area for composite core build-ups (Fig. 19.6). Such grooves are cut into the

Fig. 19.6 Features (e.g. grooves) cut to retain a core build-up must avoid the "heart of the tooth" (H)

base of missing cusps or into the gingival floor of boxes. A small round steel bur (e.g. ½ or 1 depending on tooth size) can be used. The depth of the groove needs to be sufficient to resist withdrawal of the head of the bur when it is used to gauge the presence of undercut. This usually means cutting to between two thirds and the complete depth of a round-headed bur. Grooves need to be positioned to within 0.5 mm of the amelo-dentinal junction. Newsome has written an excellent account of the practical procedure [28]. The use of grooves (sometimes termed "slots") has proved satisfactory both in vitro [29, 30] and in vivo [31–33]. Nevertheless, care is needed not to weaken a tooth or perforate it.

When cutting these auxiliary retention features, one clearly wants to conserve tooth structure, but it is worth sacrificing non-critical amounts to make resistance and retention form reliable. Problems with pulpal involvement may occur if such features are cut into the "heart" of the tooth (Fig. 19.6)—a term used by Shillingburg to describe the central volume of dentine beneath which lies the pulp [27]. The heart may be avoided by not cutting any features more than 1.5 mm inside the amelo-dentinal junction (ADJ) in a transverse plane.

19.1.6.2 Cement Bonding (Baldwin Technique)

The late 1890s saw not only the introduction of grooves [34] and dentine pins [35] to mechanically retain amalgam, it also saw the introduction of the Baldwin technique. This technique simply involved packing amalgam onto a layer of wet zinc phosphate cement. The technique never really caught on; possibly because traditional teaching advises that a cement base must be set to prevent its displacement by the condensed amalgam. Also, if zinc phosphate were extruded to the cavity margins, it would be vulnerable to dissolution. Nevertheless, wet cement has been recommended to assist with the retention of core build-ups by some highly reputable dentists [36] and nowadays GICs offer the advantage of chemical adhesion.

The evidence for using GICs as an amalgam core adhesive is only laboratory based. This is to be regretted as GICs form a good bond to dentine and an even better one to amalgam [37, 38]. In bonding amalgam to dentine, RMGICs and GICs give at least as good results as resin adhesives both for bonding [39] and improving fracture resistance of restored teeth [40]. Empirically, we use a GIC which is normally used for luting as it is sufficiently fluid to allow application of a thin layer with a Microbrush X™ (Microbrush) and provides sufficient working time. GICs designed for use as base materials are not suitable as some have been shown to be soluble when exposed to the mouth [41]. RMGICs, such as Vitremer™ (3M—ESPE), may be suitable providing they have the capacity to self-cure.

GICs offer a single-stage solution to amalgam bonding. Box 19.1 gives a clinical guide to using GIC or a RMGIC as a bonding agent for amalgam. Composites must still be resin bonded.

Box 19.1: The Baldwin Technique Modified for Use with GIC/RMGIC/Chemically Cured Resin and Amalgam

- Optimise mechanical retention with grooves, boxes, etc.
- Use a GIC luting agent (e.g. AquaCem™, Dentsply), a dual-cure RMGIC (e.g. 3M Vitremer™) or an adhesive resin (e.g. Panavia F, Kuraray Dental).
- To prevent the set cement from sticking to the matrix band, apply a thin layer of petroleum jelly to its inner aspect. This must be done before fitting the matrix band, or the cavity will be contaminated.
- Ensure good isolation but do not overdry the cavity as this may result in postoperative sensitivity.
- Use the conditioner appropriate to the bonding agent and rinse if necessary. Apply a thin layer of cement over the entire cavity surface with a Microbrush X™.
- Condense the amalgam into the deepest areas first (e.g. boxes and grooves) encouraging the wet cement to be extruded up to the occlusal surface.
- When the cavity has been packed full, remove the last increment of cement-contaminated amalgam and repack with a fresh increment.

Ensure excess cement is removed interproximally before carving and finishing the amalgam. If using an adhesive resin, a viscous gel is applied at the margins of the cavity to prevent oxygen inhibition (e.g. Oxyguard, Kuraray Dental)

19.1.6.3 Resin Bonding and Airborne-Particle Abrasion

As discussed in Chap. 15, a composite is bonded to dentine and enamel through micromechanical and chemical retention. Resin bonding is highly technique sensitive and manufacturer's instructions must be adhered to.

Where there are concerns that a dentine or enamel surface may be resistant to bonding (e.g. sclerosed dentine), an approach which clinically appears to be effective is to clean and roughen the tooth using airborne-particle abrasion (sandblasting). For example, prior to etching with phosphoric acid, use 27 or 50 μm alumina. Alternatively, use silicoated alumina (CoJet™, 3M—ESPE) to give improved bonding for self-etching adhesives [42, 43]. However, not all airborne abrasives are effective, e.g. calcium carbonate [43]. Of course, proper isolation of the tooth, preferably with rubber dam, and protection of the airway are essential precautions.

If necessary to enhance retention of an indirect restoration, the core build-up can be sandblasted with silicoated alumina (CoJet™, 3M—ESPE) at the fit appointment. This silicates the core's surface, augmenting micromechanical retention. Then, using a silane coupling agent, a chemical bond is provided for a resin lute. For further details see Chaps. 15 and 24.

In the next part of this chapter, we consider the restoration of root-treated teeth.

19.2 Restoration of Root-Treated Teeth

19.2.1 Learning Points

This section of the chapter will emphasise the need to:

- Remove existing restorations to evaluate remaining tooth structure and determine restorability (as for vital teeth)
- Ensure root treatment does not compromise the remaining tooth structure
- Choose a root canal sealer compatible with resin adhesives (if these are to be used)
- Consider all options for managing a root-treated tooth so the best one for the patient can be chosen
- Decide if a core build-up can be used or if a more invasive post is necessary
- Make the canal sufficiently long for the type of post chosen, consider root curvature, and retain 4–5 mm of gutta-percha apically
- Avoid creating wide parallel post channels which risk apical root fracture, but ensure the post or posts fit the channel's coronal aspect
- Clean residual gutta-percha and root canal sealer from preparation walls (e.g. with airborne-particle abrasion which can also be used on the post to enhance retention)
- Choose a suitable cement and apply it both onto the post and into the post channel
- Resist crowning root-treated anterior teeth—unless there are good reasons to do so
- Provide occlusal coverage for root-treated molars (and weakened premolars)—unless there are good reasons not to
- Be aware that endo-crowns, while promising, have yet to be fully proven clinically.

In this section, we focus on the practical aspects of placing restorations in root-treated teeth. Most of the theory has been covered already in Chap. 11, but we will develop further some of the themes relating to everyday decision-making and practical technique. The principles relating to restorability and the amount of remaining tooth of vital teeth are equally relevant to root-treated teeth.

19.2.2 Conserving and Protecting Tooth Tissue

Before root treatment nonvital teeth are often structurally compromised by caries, large restorations or trauma, making them vulnerable to fracture. So, try and conserve as much tooth tissue as possible when making access cavities and shaping root canals. Teeth are particularly vulnerable if root treatment is attempted through a pre-existing crown (Fig. 19.7). Subsequent preparations for posts, cores and extracoronal restorations should also be conservative while considering the mechanical properties of the chosen restorative materials.

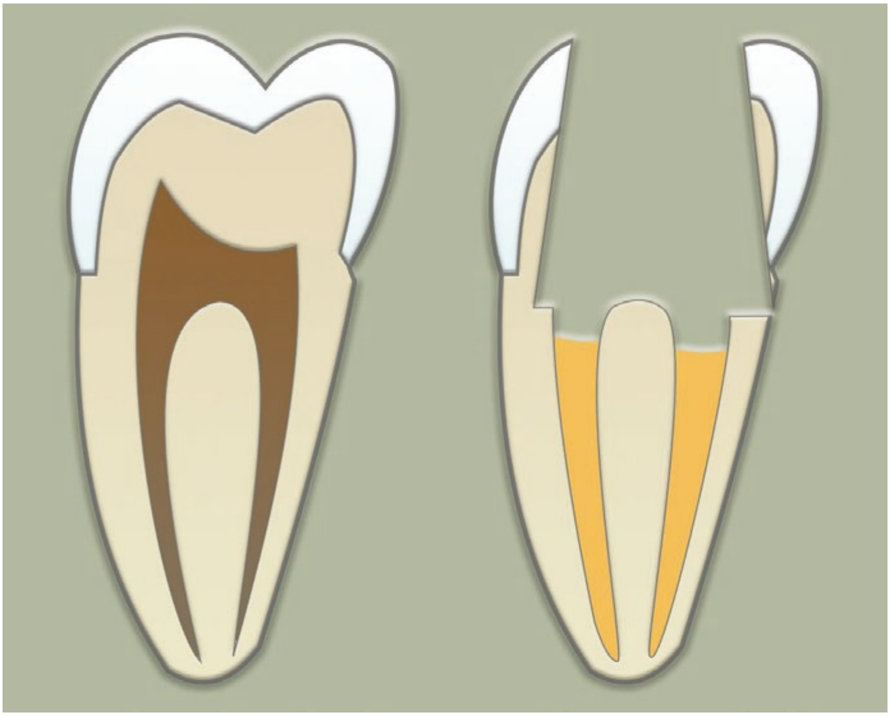

Fig. 19.7 A pre-existing crown may disorientate an access cavity. Here an excellent root filling has been placed, but the injudicious access has probably rendered the tooth unrestorable

During root treatment, a tooth may be vulnerable to catastrophic fracture from adverse occlusal loading on its weakened structure. Simple preventative measures are usually sufficient, such as reducing interfering cusps and supporting what remains of the clinical crown with an adhesive cement restoration (e.g. glass ionomer). A cemented orthodontic band or copper band (where available) may also be necessary to help hold the tooth together during this phase [44].

19.2.3 Restorative Options for Root-Treated Teeth

With an increasing number of options to restore root-filled teeth, it may sometimes be difficult to decide which route to follow. Rather than leave it simply to ingenuity and intuition, a flow chart (see Fig. 19.8) may help when deciding between:

1. Direct restoration
2. Core build-up plus indirect restoration
3. Post-retained indirect restoration (usually a crown)
4. Overdenture abutment (with or without a coping).

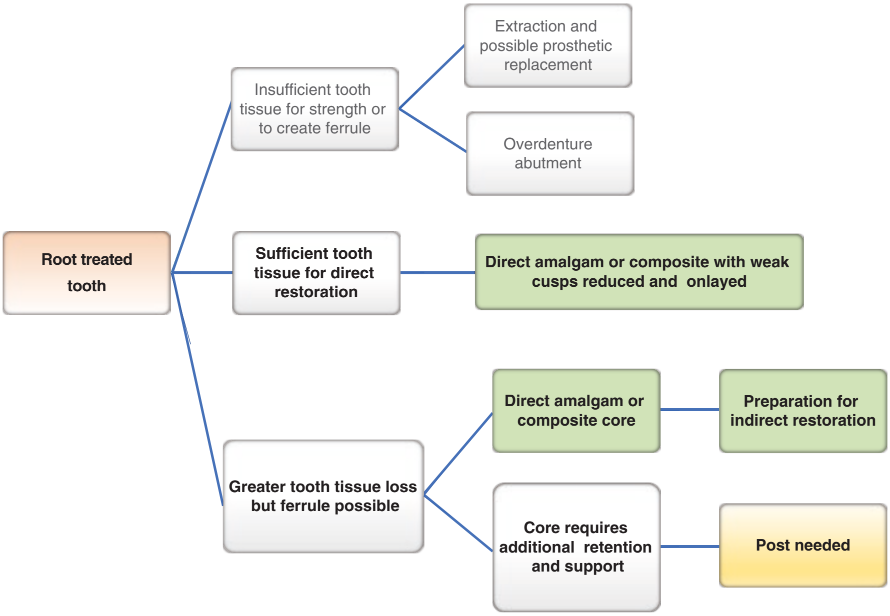

Fig. 19.8 Algorithm outlining key restorative decisions for a root-treated tooth (assuming no significant periodontal or endodontic issues). With sufficient remaining tooth tissue, a direct restoration can be placed and vulnerable cusps onlayed. Alternatively, a core can be built-up and the tooth prepared for an indirect restoration. Where a post is needed to supplement retention and support, the various options are shown in Fig. 19.10

In patients for whom a partial or complete denture is planned, a root-treated tooth may still offer useful service as an overdenture abutment despite being insufficiently robust to be built up with a crown.

Of course, there is also the additional option of extracting a nonvital tooth and prosthodontic management of the edentulous space. Extraction is a sensible approach where what remains of a nonvital tooth is weak with little prospect of creating a ferrule (e.g. by crown lengthening—see Chap. 10—or by a combination of orthodontic extrusion and crown lengthening). Clearly, an early decision to extract is preferable to heroic attempts at root treatment—only to find a restored tooth doomed to early failure. Extraction is also a sensible treatment plan for nonvital teeth of little or no strategic importance. Indeed, the resulting space may not need restoration unless there is an aesthetic issue, or the patient prefers not to have any gaps.

In the following sections we focus on the restorative options which provide a foundation to build a tooth to full contour.

19.2.4 Direct Restoration

Often root-filled anterior teeth may be restored simply with a direct restoration. This is because root-treated anterior teeth which are relatively intact are reported no more likely to fracture than vital anterior teeth [45]. So, here the main role of the direct restoration is to provide an essential coronal seal [46]. There is no need to crown a root-filled anterior tooth prophylactically [47] unless it is already extensively restored or is at risk from an existing crack propagating.

Occasionally, a root-filled posterior tooth may also be restored safely with a direct intra-coronal restoration, for example, a tooth with minimal structural damage, intact cusps and marginal ridges and not subject to lateral occlusal stresses. But remember, several studies have reported that if root-filled molars (and to a lesser extent premolars) are not restored with full occlusal coverage, they are at greater risk of failure and extraction [47–49]. The strength of root-treated posterior teeth is significantly compromised by loss of marginal ridges and loss of the occlusal isthmus [50, 51] Added to that is the access cavity which is sometimes extensive. As regards the occlusion, loading of posterior teeth will be much higher than anterior teeth [52]. Furthermore, root-treated teeth in general have less proprioceptive protection from high occlusal loads than vital teeth [53].

A direct restoration can provide full occlusal coverage to good effect, unless there are underlying issues which increase the risk of failure in comparison to placing a full-coverage crown (e.g. premolars with little remaining tooth tissue) [54, 55]. Nevertheless, dentists may find it technically challenging to sculpt composite or amalgam to create accurate occlusal and axial contours. The task requires a high level of skill to build up cuspal onlays which need to be at least 2 mm thick. To avoid these difficulties, dentists usually prescribe indirect extra-coronal restorations—often in combination with a structural core build-up made from a direct restorative material or using a post and core as discussed below.

19.2.5 Core Build-Ups for Root-Treated Teeth

Core build-ups to help support and retain indirect restorations are usually made of amalgam or composite. Occasionally, where there is sufficient remaining coronal tooth, a robust glass ionomer may be used.

Core build-ups are sometimes used as interim restorations for root-treated teeth (Fig. 19.9). This approach assures the coronal seal and gives time to assess the outcome of endodontic treatment before progressing with tooth preparation for an indirect restoration. It also provides occlusal protection and stability while other priority treatment is carried out.

Posts are certainly not always necessary to support a core build-up, and at least one study shows similar clinical outcome with or without a post [56]. Often, sufficient retention for an amalgam or composite core is achieved by removing the coronal 2–3 mm of the root filling and utilising the retentive features of the pulp chamber and access cavity. This is the classical Nayyar core originally used with unbonded amalgam [4], but these days resin bonded for improved retention and coronal seal.

Tooth preparation for a core build-up in a root-filled tooth must be carefully planned to avoid the build-up falling out later during preparation for the indirect restoration. In this respect, the deep preparation margins needed for ceramic or ceramo-metal restorations can be particularly destructive of remaining tooth tissue. Consider also if there is sufficient bulk of restorative material in the pulp chamber to resist core fracture—molars often have a more favourable configuration than premolars. Consequently, where a premolar has little remaining coronal tissue, a Nayyar style core without additional post retention is unlikely to be particularly reliable.

To achieve a satisfactory resin bond, all residual gutta-percha (GP) and root canal sealer should be removed from the preparation walls. Use a slow round steel bur and sharp excavators for gross removal, but avoid cutting away dentine. Various options have been suggested to remove the remaining residues. Some operators use solvents such as xylol, orange oil and eucalyptol, to remove sealer residue, but these solvents have been shown to reduce resin bond strength [57]. Other organic solvents such as ethyl alcohol and acetone with accompanied ultrasonic cleaning are partly effective at removing smeared root canal sealers [58], but their effect on resin bonding is unclear. Our preferred method is simply to etch the access cavity with 37% phosphoric acid and use water-cooled ultrasonics to remove the debris prior to bonding and restoration placement.

Fig. 19.9 Examples of composite (tooth 36) and amalgam (tooth 27) core build-ups for nonvital teeth. Note that both utilise the access cavities and pulp chambers to obtain additional retention. These provide an interim restoration and coronal seal before onlay or crown preparation

As already mentioned airborne-particle abrasion can effectively clean and roughen a dentine surface. A 3–4 s blast moving continuously over the surface will reduce the risk of cutting away dentine. Nevertheless, it would be wise not to use it where root walls are thin or close to a repaired perforation. Again, rubber dam is recommended to protect the patient's airway.

19.2.6 Post Preparation and Placement

19.2.6.1 General Principles

A post becomes necessary when there is insufficient coronal tooth tissue to retain a core build-up or the bulk of a restorative core is insufficient to resist fracture [54, 59]. Figure 19.10 shows the different post options available. Where there are only moderate amounts of missing tooth tissue, the choice of post system may not be as important as the placement technique which needs to be meticulous. Importantly, no gap should be left between the gutta-percha and the end of the post. These gaps are associated with an increased prevalence of periapical disease [60].

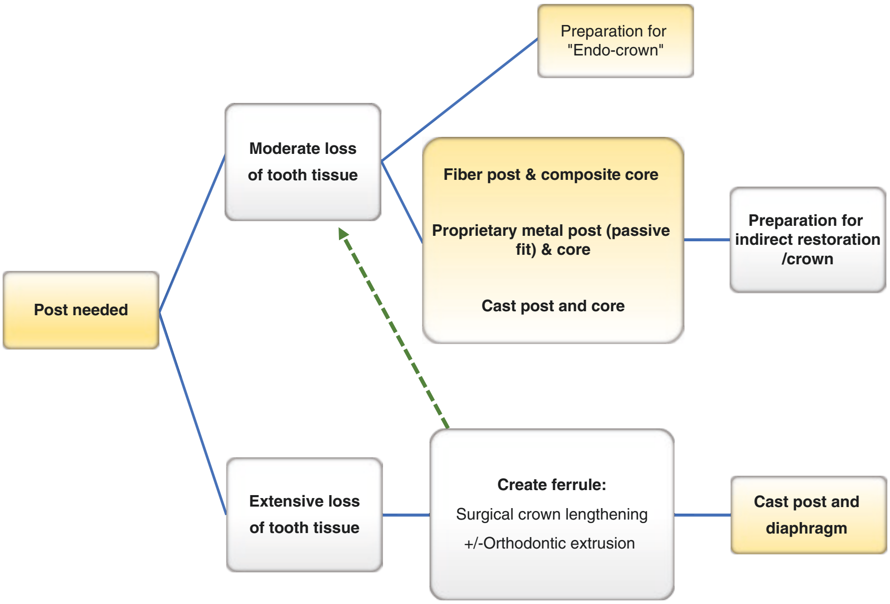

Fig. 19.10 A decision is made to provide a post-retained restoration: Several options are available where there is moderate loss of tooth tissue. The "endo-crown" saves a clinical stage, but its long-term clinical performance is not yet clear. With extensive loss of tooth tissue, consider exposing sound tooth tissue to create a ferrule before proceeding. With a favourable root form, this may allow restorative options as for "moderate loss" (dotted arrow). The cast post and diaphragm is the traditional approach to manage extensive loss of tooth tissue but still requires some ferrule to be reliable

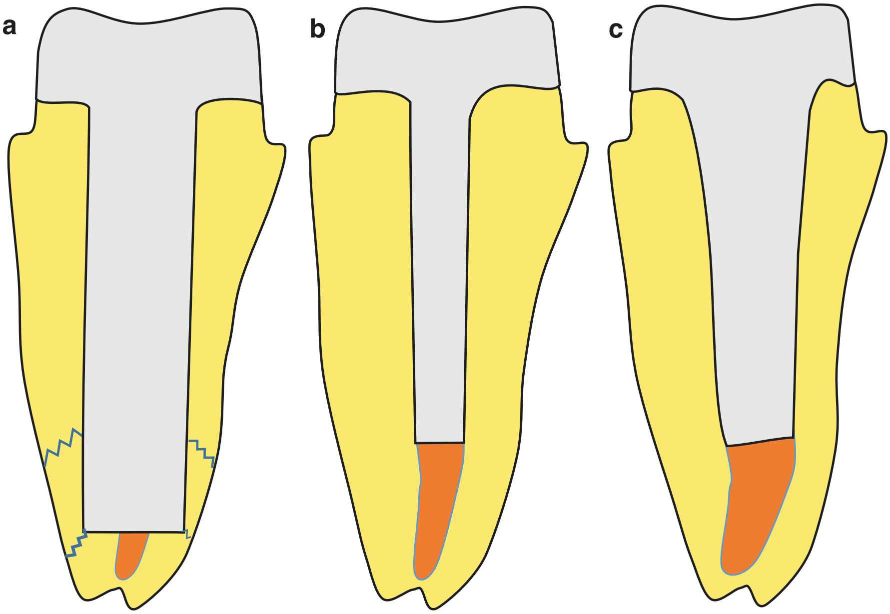

Fig. 19.11 Iatrogenic root fracture: (**a**) The root has been heavily prepared for a long parallel-sided post in the mistaken belief that it will reinforce the root. Instead, the apical portion is thinned and weakened. (**b**) A more conservative parallel cast metal post and core with a modest increase in canal width. Sufficient dentine and apical seal of gutta-percha remain with a reduced risk of root fracture. (**c**) A wide root canal prepared and fitted with a tapered post. There is sufficient length for retention without over-enlargement of the canal apically and risks of root fracture. This could feasibly be restored with either a cast metal post or a tapered fibre post with accessory posts as needed

As a rule, a good fit is needed between the post and the coronal and apical parts of the prepared post channel. This is to reduce reliance on the lute to resist lateral loading. As better luting materials are developed, the requirement to have a good coronal and apical fit may become less critical. Such luting materials will need to be stronger with less polymerisation contraction, less water sorption and more reliable bonding than those currently available.

A commonly held misconception is that posts provide reinforcement. Historically, wide metal posts were utilised to provide "reinforcement", but they merely served to create areas of stress concentration at the terminus of the post channel leading to root fracture (Fig. 19.11). Any post preparation which removes significant further dentine is likely to weaken or perforate a root (Fig. 19.12).

So, where the coronal aspect of the root canal is flared, or the canal is oval or dumbbell shaped, it is a mistake to machine away dentine apically just to get a wide enough proprietary post to fit coronally. Instead, use a cast post and core which can be custom made for a good coronal fit. Alternatively, fibre posts can meet this requirement by using multiple "accessory" tapered posts or by using a separating medium and adapting a post with light-cured composite prior to cementation [61].

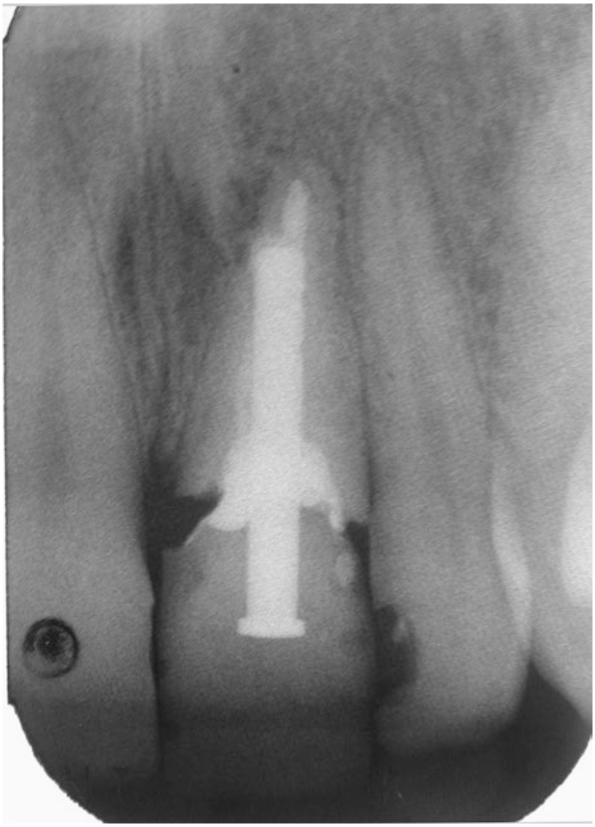

Fig. 19.12 A disastrous outcome for all: An overambitious assessment of restorability has been followed by an ill-advised post channel preparation. The post is too wide, too long and misaligned leading to catastrophic weakening and perforation of an already compromised root

A filled resin luting agent and meticulous dentine bonding are mandatory. In vitro strength tests [62] and finite element analysis [63] support this approach, but clinical trials are currently lacking. Proprietary metal posts are usually parallel and do not lend themselves to multiple post placement within the same canal.

As discussed in Chap. 11, a cast post may be preferred where there is limited ferrule available and the possibility of a fibre post or posts flexing.

Before progressing with post and core placement, it makes sense to prepare the cervical aspect of the tooth and define the margin for the intended crown. In this way, unacceptably thin areas of dentine can be identified and reduced. In addition, clinical time is saved because the dentist is clear where to build up a composite core. With a cast post and core, the technician can do exactly what is required and save the dentist from having to reshape a bulky metal core in the clinic.

The ideal time to prepare the post channel for any type of post (fibre, preformed metal or cast) is immediately following root canal obturation. Then, there is intimate knowledge and understanding of the root canal anatomy, its length and relevant reference points for making depth measurements. Preparation can also be made under rubber dam to minimise microbial ingress. There is also a further opportunity to condense the apical segment of root filling once the coronal GP has been removed.

To ensure optimum bonding with resin cements, choose a non-eugenol containing root canal sealer, because it is difficult to remove eugenol residue from the dentine. This advice is supported by a meta-analysis of nine bond testing studies [64].

Post preparation may of course be carried out on a tooth with an existing root filling. Here a long cone paralleling radiograph is advised. This is not only to assess the periapical condition but also to assess root length, angulation and curvature—bearing in mind not all curves will be visible on a periapical radiograph. Considering the magnification of the radiographic image, decide on the length of post channel required. In addition, choose a sufficiently wide diameter post to strike a balance between post strength and the risk of weakening a tooth by removing precious dentine or worse perforation. As a guide, to avoid disturbing the apical seal, leave at least 4 mm of apical GP. As mentioned in Chap. 11, conventionally cemented metal posts need to be longer (approximately two thirds of root length) than adhesively cemented fibre posts (approximately half of root length).

19.2.6.2 Gutta-Percha Removal

Before preparing a post channel for any type of post, the GP must be removed to the required post length. This is because proprietary post drills are end cutting, and the GP tends to deflect them off course, risking root weakening or perforation (see Fig. 19.12). To minimise this risk, carefully remove GP with a non-end cutting bur (e.g. Gates Glidden or Largo/Peeso reamer) or a heated instrument to the required depth. Use silicone stops on the burs to facilitate length control. Again, take care to keep post channels in straight portions of canals, avoiding canal curvatures and the risk of perforation.

Once the GP has been removed, then progressive enlargement of the channel can take place using a series of proprietary post preparation drills to an appropriate post size. To obtain a well-fitting post and a thin cement lute, keep the bur orientated in the same axis and prepare concentrically in the apical part of the post channel. Where there is a flared coronal aspect, remember the options of multiple fibre posts or a cast post and core to provide good adaptation.

19.2.6.3 Fibre Posts

A schematic of the practicalities of fibre post placement is shown in Fig. 19.13.

Manufacturers sometimes provide guides matching post size to tooth type. However, as described above, variations in root anatomy are such that post selection should be based on a combined clinical and radiographic assessment of the individual tooth.

After removal of GP (see above), preparation of the post channel should take place using a series of twist drills to provide sequential enlargement to the selected post diameter. Before moving to the next twist drill size, irrigate the channel to remove cutting debris. If resistance is met during preparation, check drill angulation and orientation, and go back to the previous size to ensure it passes passively to length. If there is any concern about channel depth, risk of perforation or the integrity of the apical seal being compromised, record a radiograph with the post drill in place. Before trying in a post, clean and dry the canal.

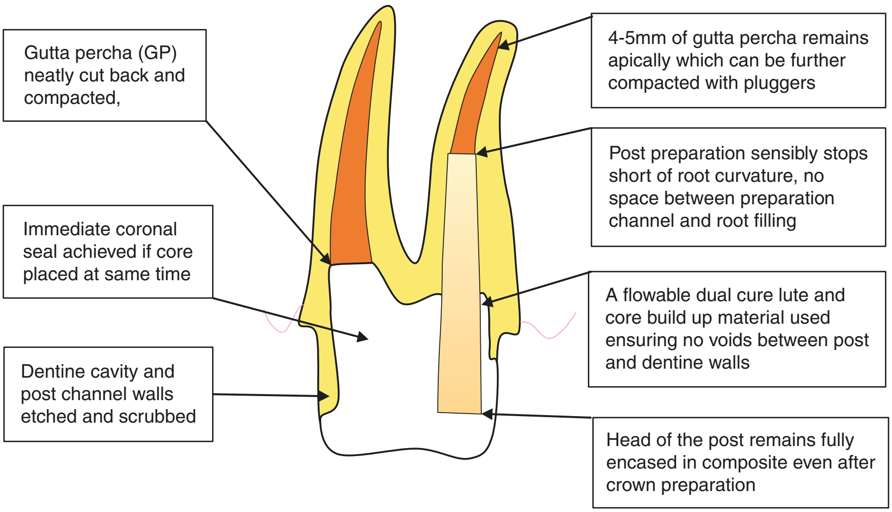

Fig. 19.13 Schematic diagram of a fibre post placed in an upper molar or premolar. Note how the post is placed in the canal most likely to direct occlusal forces axially

Invariably, a post will be too long and must be cut to size to ensure the head of the post remains fully covered by the composite core after crown preparation. If left exposed to the oral environment, as may occur if a provisional restoration is lost, the resin between the fibres absorb water. Water absorption in combination with thermocycling adversely affects the mechanical properties of fibre posts [65] and may result in the core debonding from the post or the post debonding from the tooth. Fibre posts must not be cut with wire cutters. To avoid damage to the fibres, use a diamond wheel or bur. To avoid surface contamination, handle posts with tweezers. If contamination does occur, use an alcohol swab to clean the post and remove cutting debris.

For most purposes, the pretreated surface of fibre posts is sufficient for retention. However, where only a short post can be accommodated, the retentiveness of resin to the post may be enhanced by a 3–4 s treatment of airborne-particle abrasion with alumina or silicoated alumina (Cojet™, 3M ESPE) [66–68]. Although its effectiveness within root canals is not yet entirely clear, there may be some merit in preconditioning the dentine in the same way where post retention is critical. Bear in mind the caveats regarding airborne-particle abrasion mentioned in the previous section. Ensure the post channel is dry beforehand; otherwise the abrasive particles tend to clog it up. Afterwards, wash the channel well and scrub with a Microbrush X™ (Microbrush).

Sodium hypochlorite (NaOCl), EDTA (ethylenediaminetetraacetic acid) and a combination of EDTA, chlorhexidine and detergent are reported to remove the dentine smear layer prior to use of a self-etching primer (see Box 19.2). Nevertheless, at least one manufacturer recommends only to use sodium hypochlorite as a preconditioning agent, so more research is needed—not only to address resin bond strength

Box 19.2: Smear Layer Removal Prior to Luting a Post

The classical method of removing the smear layer is the total etch technique using 32–37% phosphoric acid with either a three-bottle or two-bottle dentine bonding system (see Chap. 15). Etching is for 15–30 s followed by rinsing for a similar time. A recent study reports improved bond strength for a self-etching cement (RelyX™ Unicem™ Self-Adhesive Universal Resin Cement, 3M—ESPE) if the dentine is preconditioned with 37% phosphoric acid [69].

There are various other chemical treatments to remove the smear layer, e.g.

- 17% EDTA [70].
- EDTA followed by 0.2% chlorhexidine solution.
- QMix™ (Dentsply) a commercial mixture of EDTA, chlorhexidine and detergent.

Studies with only a short period of water storage (1–7 days) before bond testing report these solutions provide higher bond strength than sodium hypochlorite irrigation (NaOCl) where *self-adhesive resins* are used for luting posts [71, 72]. Nevertheless, one manufacturer (3M—ESPE) recommends dentists to precondition only with NaOCl (2.5–5.25%) when using their Self-Adhesive Universal Resin Cement (RelyX Unicem™) [73]. They claim that EDTA and disinfectant solutions leave residues which affect bonding and setting of the resin [74]. Furthermore, the recommended irrigation time with NaOCl is 2 min, so any time saved by using self-adhesive resin is lost by the long preconditioning time. Clearly to clarify the optimum preconditioning regime, further research is needed with longer storage times before bond testing.

but also the need to remove biofilm (dental plaque) from the post channel. As discussed in the following section, biofilm may be more of an issue with cast post and cores than with fibre posts.

The cementation of a fibre post should be conducted according to the manufacturers' protocols but frequently involve similar steps of conditioning, priming, and bonding. Some systems combine these steps (see Chap. 15), e.g. conditioning and priming with a self-etching primer. However, a commonly used approach is the "total etch" method using 32–37% phosphoric acid as conditioner. Apply the phosphoric acid to the post channel, coronal dentine and enamel with an applicator designed for root canal applications. A tapered cylindrical Microbrush X™ (Microbrush) is more effective than a normal brush at dispersing etchant along the full length of the post channel walls which gives better resin tags [75]. After the specified time rinse the etchant with saline or sterile water in a syringe. This is to ensure the etchant is fully rinsed from the base of the post channel. In addition, where root canals are incompletely sealed, it also reduces risk of introducing sequestered bacteria from inadequately purged water lines. Lightly air dry the post channel, but do not desiccate. Any pooled moisture can be removed with large paper points. The priming and bonding stages are system specific but often involve primer application to both the canal and to the post. Before light-curing, use a paper point to remove any pooled excess primer from the post preparation.

Lute the post in place with a dual-cure composite cement. To avoid voids, apply cement to both the post and the channel. Some operators use a Lentulo spiral to spin cement into the tooth, but this is not recommended. It may accelerate the set of some cements [74] and the steel spiral may fracture in the channel. Others prefer a long straight probe, but a better applicator is an "elongation tip" (3M—ESPE). This attaches to the nozzle of cement mixing gun and fills the post channel from its base, being withdrawn gradually not to trap air bubbles. Ensure the post is seated fully; hydraulic forces often act to push a post out of its channel. Therefore, hold the post in place while excess material escapes. The access cavity frequently provides a recess where cement collects, sometimes incorporating air bubbles. Before light-curing for 40–60 s, decide whether to:

- Agitate air bubbles gently out of the cement (if the same material is to be used for the subsequent core build-up)
- Remove unset cement from the access cavity with a Microbrush X™ (Microbrush) (if a different composite material is to be used for the core, this creates a space for a better mechanical interlock).

Once the post has been light-cured and is securely luted, the core can be built up. Examples of systems employing the same composite resin material for both the post lute and the core build-up include Build-It FR™ Fiber Reinforced Core Material (Pentron Clinical), Corecem™ (RTD) and Paracore™ (Coltene/Whaledent). Other systems comprise a lightly filled lute (e.g. Calibra™, Dentsply) with a more heavily filled core composite (e.g. Core-X™, Dentsply). Cores can be formed using a proprietary "core former" in the shape of a truncated cone. Alternatively, some dentists apply the core freehand in a manner reminiscent of a Mr. Whippy™ ice cream. This requires skill and a core build-up material of a suitable viscosity which flows smoothly from the syringe nozzle but resists slumping away from the post, e.g. Build-It FR™ Fiber Reinforced Core Material (Pentron Clinical).

The core build-up is then light-cured prior to crown preparation. Again, if the tooth is partly prepared prior to post placement, it makes shaping of the core much easier and saves on material.

19.2.6.4 Cast Posts: Three Appointments Versus two

The commercial drive for dentists to adopt fibre posts has rather overshadowed cast post and cores. This is a shame because, as discussed previously, cast posts and cores still play an important role.

Some dentists enjoy fashioning an acrylic pattern directly in the mouth to act as a burnout pattern for a cast post and core (e.g. with Reliance-Duralay™, Reliance Dental Manufacturing). However, most dentists prefer their technician to make the pattern, so record an impression of the post channel instead. They then follow either a three-visit or a two-visit approach for providing crowns retained by cast posts and cores:

- Three-visit option:
  – Prepare post channel, impression and temporise
  – Lute the cast post and core, record a second impression for the definitive crown and make new temporary crown
  – Fit and lute the definitive crown
- Two-visit option:
  – Prepare post channel, impression and temporise
  – Fit and lute both the cast post and core and the definitive crown.

We prefer the three-visit option because unlike the two-visit approach, the fit of the crown will not be jeopardised by any minor seating discrepancy of the post and core. In addition, the clearance needed to accommodate a crown occlusally and aesthetically can be checked and adjusted before taking the final impression with the post and core luted in place. Occlusal control is critical to avoid any post crowned tooth being overstressed by adverse occlusal forces and can only be achieved if the technician has sufficient space to develop occlusal contacts and guidance on the crown.

Clearly, a three-appointment process takes longer, but bear in mind attention to detail underpins success with post-retained restorations. A well-made cast post and core may be all that stands between the alternative of an implant crown or another prosthetic alternative.

A cast post and core restored with a provisional crown can be a real advantage if crown lengthening surgery is undertaken, e.g. to create a ferrule (see Chap. 10). This is because it provides a reliably retained provisional restoration during the healing period before recording an impression for the definitive crown.

19.2.6.5 Cast Posts and Cores: Clinical Technique

Preparation for cast post and cores should take in to account the same principles of preservation of tooth tissue as for fibre post preparation. Preparation of the post space is again carried out by initial removal of GP followed by sequential enlargement of the canal space but with a series of parallel-sided twist drills, e.g. ParaPost XP™ (Coltène/Whaledent).

Take care to strike a balance between preparing for a very narrow post that may fracture at the interface with the core and overpreparation that could lead to perforation or root fracture once the post is cemented. As mentioned in Chap. 11, cast posts often fracture in the coronal third of the root, so where a post channel is narrow, it is worth giving the preparation a slight coronal flare from the midpoint of the channel using a large Gates Glidden bur. This helps to thicken the post slightly where it is vulnerable to fracture and provides an anti-rotation feature, but without overthinning the root. If sufficient coronal flare has already been created during endodontic shaping, further flaring may be unnecessary.

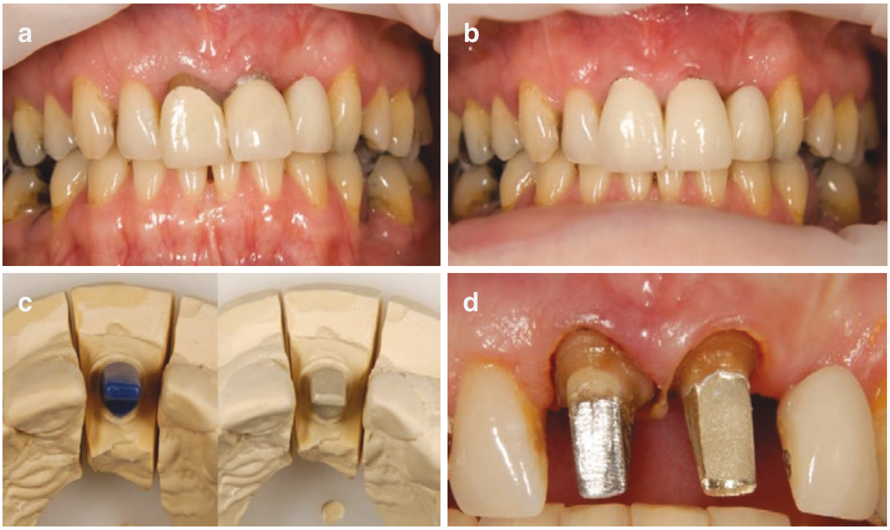

Fig. 19.14 Both upper central incisors require new post-retained ceramo-metal crowns (**a**). The result (**b**) hides the attention to detail in making the underlying cast post and core at 21 (the original post and core at 11 was retained). Note the clearly defined preparation margin on the die and excellent post fit resulting from an accurate impression (**c**). Following cementation of the post at 21, both cast cores were re-prepared for occlusal and aesthetic clearance (**d**). Note how both preparation margins are extended apically to leave them supragingival but with sufficient ferrule on both teeth

When cutting the preparation margins for the definitive crown, a ferrule should be preserved where possible (Fig. 19.14).

As with all laboratory work, the quality of a cast post and core is heavily dependent upon the quality of the impression taken. Dimensionally stable, addition silicone impressions should be recorded (Chap. 22) with an impression post in situ (see Fig. 19.15). A traditional technique of recording a post channel is to fashion a homemade impression post from a paperclip, but it is better to use a proprietary cast post system. The proprietary kits match a smooth-sided impression post to the last twist drill employed in the apical part of the post channel. In addition, proprietary kits have serrated plastic posts to make burnout patterns for the lost wax casting technique. These have a slightly smaller diameter than the post drill and impression post, to make space for the cement. Take care not to muddle a burnout post for an impression post—the serrations will prevent technicians removing the post from the stone die!

We recommend recording a full arch impression for the post and core, and for the opposing cast. In this way, the technician can gauge the occlusal clearance for the definitive crown not only in the intercuspal position but also in excursions. In addition, the core can be formed to optimise aesthetics and retention. This helps to minimise adjustments when fitting the post and core.

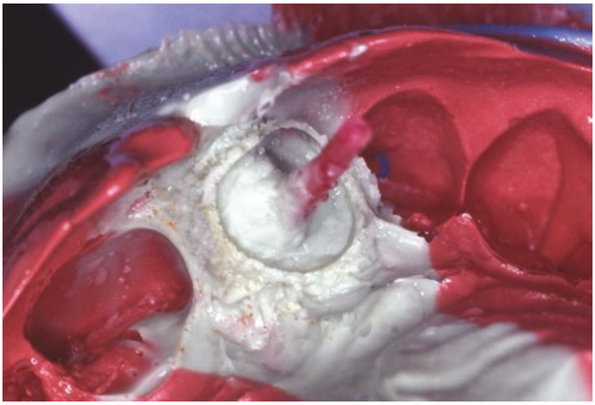

Fig. 19.15 A red impression post used to record a post channel. Note the flared coronal portion and the preparation margins. Electrosurgery was used beforehand for some minor crown lengthening and to create a trough for gingival retraction (see Chap. 21). A provisional restoration will allow gingival healing prior to recording an impression for the definitive restoration

Cementation of a cast post should consider the length and retention of the post. It may be perfectly acceptable to cement the post with a conventional cement (e.g. zinc phosphate or glass ionomer cement), alternatively if additional retention is required posts can be resin bonded. The choice will be at an individual tooth level, but note that the resin bonding of cast posts will likely reduce their retrievability should endodontic retreatment become necessary or should a cast post fracture.

19.2.6.6 Cast Posts and Cores: Limiting Microleakage

It is widely accepted that coronal microleakage is a major cause of endodontic failure [46]. Saliva and organisms from the oral environment migrate rapidly alongside poorly adapted restorations and root fillings—even those which appear to be well condensed [76]. The disinfection process during root canal treatment may well be undone if the coronal seal is not protected. Those microorganisms that traverse the root canal system will have a supply of nutrients from saliva and will establish a new biofilm within the canal system, eventually resulting in reinfection and establishment of further apical periodontitis. This may happen in teeth that have been poorly temporised pending core build-up or post and core placement or more commonly in anterior teeth that require temporary post-retained restorations which are prone to leakage [77]. This possible drawback of the indirect cast post and core technique should be avoided by having the interim restoration in place for the minimum amount of time. Even so, it may be wise to assume that there is biofilm on the walls of the post channel—another reason to use a Microbrush™ or, for larger canals, a small interdental bottle brush in combination with 2.5% sodium hypochlorite prior to bonding or cementation.

Microleakage during the provisional stage may be reduced by using a temporary removable partial denture instead of a post-retained provisional restoration. This approach allows the post channel to be sealed properly with a plug of temporary cement. Dentists may already be familiar with temporising in this way during root canal treatment when control of microbial ingress is particularly critical.

19.2.6.7 "Endo-Crown"

With an "endo-crown" the post is integral with the restoration, obviating the need for a separate post and core. These restorations are not always full-coverage crowns but usually cover the whole occlusal surface, e.g. an onlay for a posterior tooth made from alloy, ceramic or composite with a stub post engaging the pulp chamber (see Fig. 19.16). Such "endo-crowns" have been used for decades on a one-off basis for full-coverage metal restorations where retention is compromised by limited axial wall height (see Fig. 19.17). Now high-strength ceramics have fuelled a greater interest in this type of restoration, but as mentioned in Chap. 11, clinical studies are generally short-term. More extensive studies are needed to establish clinical guidelines defining the indications for these restorations and where they are at risk of failure. Currently, it is unclear which ceramic materials are best suited to making endo-crowns. There are also limitations in using CAD/CAM to mill a post which fits along its full length. As discussed in Chap. 14 CAD/CAM milling burs are

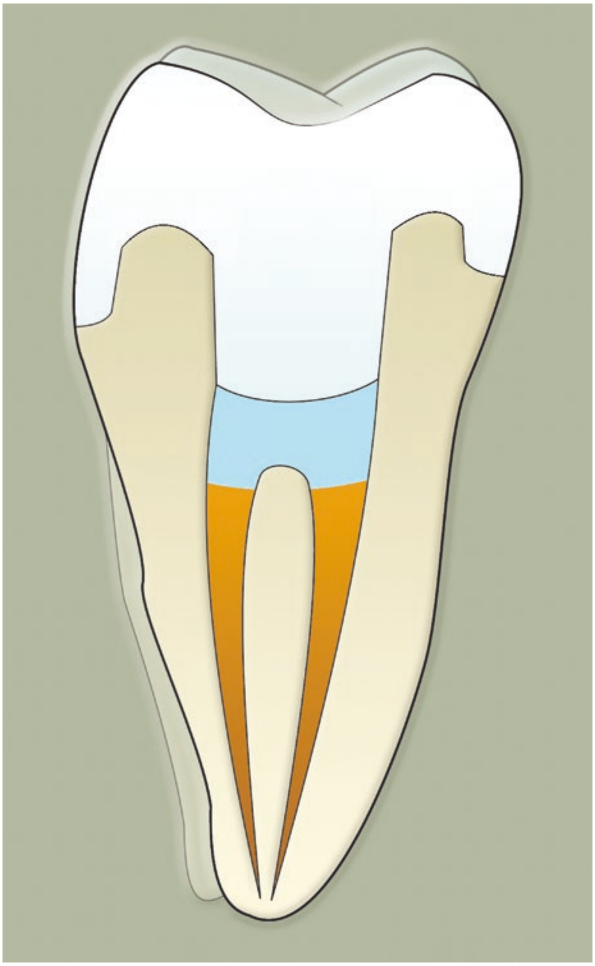

Fig. 19.16 The "endo-crown": A restoration incorporating a stub post which engages the access cavity for retention. The blue shading is a glass ionomer base between the root filling and the post

Fig. 19.17 An endo-crown made from cast gold alloy

stepped with the narrower diameter towards the tip. This means only the first 4 mm will conform accurately to the preparation walls.

It may in any case be counterproductive making too long a post for an endo-crown. Should it be necessary to reaccess the root treatment or if the crown fractures from its post, then cutting out a long post becomes a major trial—especially if made of monolithic zirconia. If there is sufficient remaining enamel to which the restoration can be bonded only a minimal post may be needed. In other words, the restoration resembles an indirect restoration of a vital tooth without a core build-up.

Conclusion

Few procedures are as technique sensitive as the restoration of the root-filled tooth. Provision of the extra-coronal restoration is often less demanding than creating an adequate core build-up or a post and core. Dentists who are aware of the many options and nuances involved with posts and cores will be in a stronger position to offer their patients a quality foundation for their extra-coronal restorations.

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Fundamentals of Tooth Preparation

20

James Field, Jimmy Steele, and Robert Wassell

20.1 Learning Points

This chapter will emphasise the need to:

- Consider extra-coronal restorations that require minimal preparation (veneers, onlays and ¾ crowns) instead of always prescribing crowns
- Plan your tooth preparation keeping in mind the space requirements and marginal configurations recommended for different restorations and materials
- Optimise *resistance* and *retention*, particularly in tooth preparations for zirconia restorations and restorations cemented with conventional cements
- Choose an appropriate preparation margin and marginal position to optimise gingival health and aesthetics
- Adopt a systematic approach for preparing teeth, evaluating the quality of the preparation and determining if adequate, but not excessive, tooth reduction has been achieved
- Ensure proper planning before tooth preparation and use a check list to develop an efficient work-flow.

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Box 20.1: Rationale for Choosing Restorations Requiring Minimally Invasive Preparations

- Less need to cut away sound tooth tissue to enhance resistance and retention form.
- More tooth tissue remains for structural durability.
- Resin-bonded restorations are best finished supra-gingivally with accessible margins helping to maintain periodontal health.
- A partial-coverage restoration is seated more easily than a full-coverage crown (less luting pressure).
- Pulp sensibility (vitality) testing is easier because not all the tooth is covered.

Much has been written about tooth preparations, and their intricacies continue to evolve, but, fundamentally, the recipe for a good preparation is still guided by the following principles [1]:

1. Conservation of tooth tissue whist optimising:
   (a) Resistance and retention form
   (b) Marginal form and structural durability
2. Preservation of the periodontium
3. Aesthetic considerations.

Clearly, the amount of tooth preparation should reflect the need to accommodate the thickness of the restoration. This will vary depending on the material chosen and the part of the restoration under consideration (e.g. occlusal, axial, or margin). Often there is a fine balance between conserving tooth tissue and providing sufficient space for a strong, aesthetic restoration. This is where dentists must use their skill in designing and executing the optimum preparation whether it be for a conventionally cemented restoration or an adhesively cemented restoration.

We will, of course, describe preparations for full-coverage crowns—but minimal preparations for adhesively retained restorations particularly veneers, onlays and partial-coverage crowns are just as important. It's always worth considering the merits of these less destructive options (Box 20.1).

In this chapter, we will first consider the different materials and the space needed for them, before dealing with the principles and practicalities of tooth preparation.

20.2 Space for Materials

A critical part of treatment planning is deciding on the type of restoration and the material from which it is to be made. Each material has specific thickness requirements and recommended types of margin (see Table 20.1). A detailed account of margins and finishing lines comes later in the chapter. At this stage, it is enough to

Table 20.1 Recommended reductions for tooth preparation and marginal configurations

Material	Reduction		Marginal depth and configuration
Metal and ceramo-metal			
Metal only	1 mm non-functional cusp 1.5 mm functional cusp		0.2–1.0 mm Fine chamfer preferred, but any of margins shown in Fig. 20.1 are acceptable
Ceramo-metal	Anterior	2 mm incisally 1 mm lingually	1.0–1.2 mm labial deep chamfer or shoulder, but less for small teeth and where metal collar used
	Posterior	2 mm non-functional cusp 2.5 mm functional cusp	
Etchable ceramics			
Feldspathic ceramic[a]	Anterior	2 mm incisally 1 mm lingually	0.4 mm chamfer (try and keep in enamel)
Lithium disilicate (*IPS e.Max*™, Ivoclar Vivodent)	2 mm occlusal/incisal May be pressed as thin as 0.3 mm for veneers		1.0 mm rounded shoulder[b]
Zirconia-reinforced lithium silicate (*Celtra duo*™, Dentsply)	2 mm occlusal/incisal May be milled as thin as 0.4 mm for veneers		1.0 mm rounded shoulder or heavy chamfer[b]
Non-etchable ceramics and resin composite			
Resin nano-ceramic (*lava ultimate*™, 3 M ESPE)	1.5 mm occlusal/incisal May be milled as thin as 0.4 mm for veneers		0.4 mm chamfer but 1.0 mm shoulder preferred
Glass-infiltrated zirconia (*in-Ceram*™, VITA Zahnfabrik)	1.4 mm occlusal/incisal		1.2 mm rounded shoulder or heavy chamfer
Densely sintered zirconia (*Procera*™, Nobel biocare)	1.5 mm occlusal/incisal		0.5–0.7 mm chamfer
Monolithic zirconia (*BruxZir*™, Glidewell laboratories)	Anterior	1.25 mm occlusal/incisal (0.8 mm minimum)	Feather edge allegedly possible but other manufacturers recommend chamfer >0.5 mm
	Posterior	1.0 mm occlusal (0.5 mm minimum)	

The products are examples of ceramic types and not endorsements for any manufacturer
[a]More durable ceramics have superseded feldspathic ceramic for occlusal restoration of posterior teeth
[b]The 1 mm margin is for crowns extended into dentine. With veneers margins can be 0.3–0.4 mm if finished in enamel

know how different margin configurations look in cross section (Fig. 20.1) and the margin thickness recommended by manufacturers.

In addition, with adhesive dentistry, try to choose materials that can be conditioned on their intaglio (fit) surface to maintain a reliable long-term bond (see Chap. 15). Materials are discussed in detail in Chap. 14, but important clinical considerations for metallic, ceramic and composite restorations are summarised below.

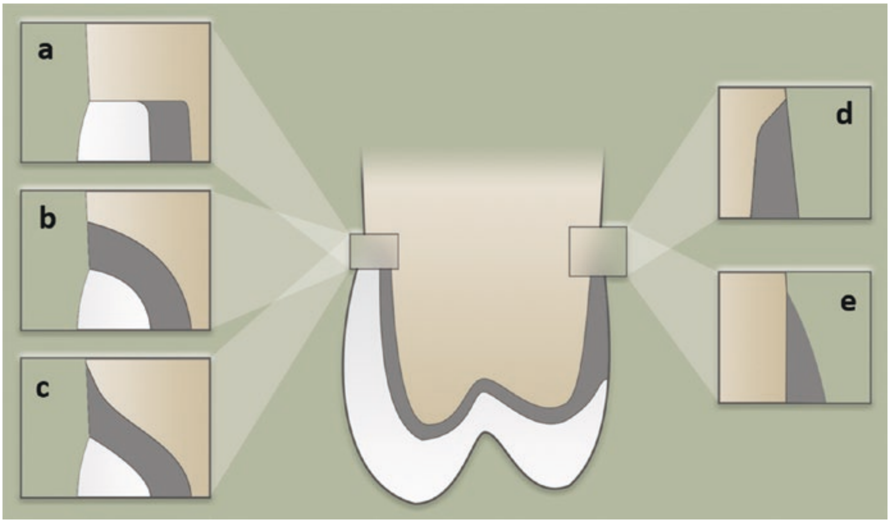

Fig. 20.1 Various types of restoration margin and preparation finishing line, shown for convenience through a bucco-lingual section of a ceramo-metal restoration (metal shown in grey): shoulder (**a**), deep chamfer (**b**), shoulder or deep chamfer with bevel (**c**), chamfer (**d**) and feather-edge (or knife) margins (**e**). The feather-edge margin is described as “vertical,” whilst the others are “horizontal”

20.2.1 All-Metal

In terms of conserving tooth tissue, the *full metal veneer crown* requires a relatively conservative preparation; a partial-coverage restoration requires even less tooth reduction. All-metal restorations are often limited to posterior teeth because of poorly perceived aesthetics, but bear in mind some patients have no concerns displaying metal—and some may even request it. Patients are often persuaded to accept a metal occlusal surface when they understand it is kinder to the tooth and more fracture-resistant. To improve micromechanical retention of conventional cements, the intaglio surface is typically airborne-particle abraded (sandblasted). To enhance resin bonding, the metal restoration can either be tribochemically silicated via airborne-particle abrasion, heat-treated or chemically treated with a metal primer (see Chap. 15).

20.2.2 Ceramo-Metal

These restorations (aka porcelain-fused to metal crowns) can provide a compromise between aesthetics and conservation of tooth tissue but only if designed appropriately (Fig. 20.2). Ceramo-metal restorations are relatively versatile and strong and can cater for patients with parafunctional or bruxist habits. They can provide good aesthetic results—with a skilled technician and sufficient space for ceramic and metal.

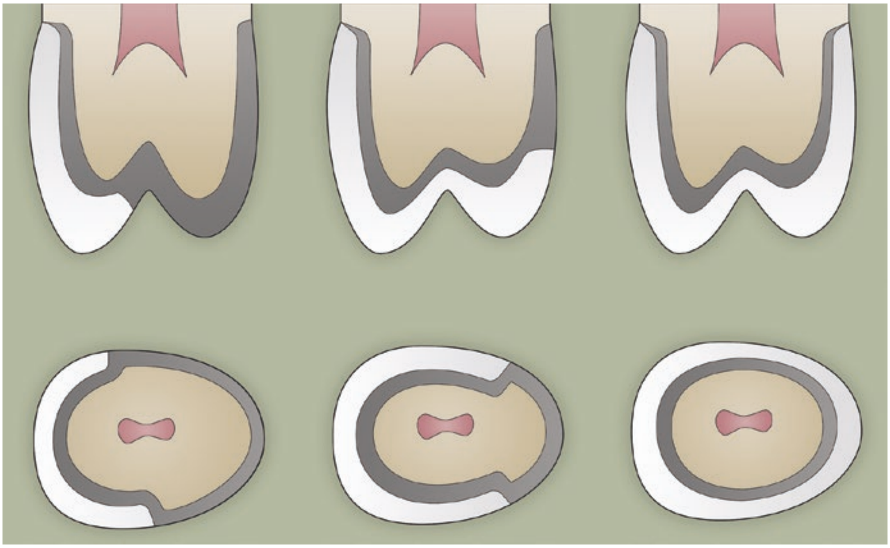

Fig. 20.2 Bucco-lingual (upper row) and occlusal sections (lower row) through ceramo-metal crowns with increasing amounts of ceramic coverage (from left to right). Note how tooth structure is conserved by designing the preparation and metal coping to confine ceramic coverage only to visible areas (left)

Conventional wisdom holds that a preparation margin for a ceramic butt fit should be 1.5 mm deep [2], but any dentist who has cut a margin that deep may feel perilously close to the pulp. In our opinion, a realistic aim is 1.0 mm with a little extra possible on substantial or root-treated teeth and a little less on smaller teeth. We will return to margin depth and how it is defined a little later.

An important advantage of metal-ceramic crowns is that features can be built into the metal part of the restoration, such as guide planes, rest seats, channels or shoulders to accommodate cobalt-chrome partial dentures (see Chap. 18). Although not used by many dentists, precision attachments may also be sited within a ceramo-metal crown (female) or extend from a crown (male) [3]. Female attachments may need a box cutting into the preparation to avoid making a bulky restoration.

20.2.3 Etchable Ceramic

These materials (see Table 20.1) are ideal for adhesive dentistry because their intaglio surfaces can be etched with HF- and silane-treated. This treatment enhances resin bond strength and the strength of the overlying restoration. Etchable ceramics are therefore an attractive option for veneers, onlays and partial-coverage and full-coverage crowns. Initially only feldspathic ceramics were etchable, but the approach of having a “dentine-bonded crown” [4] is now possible with stronger leucite and much stronger lithium silicate/disilicate. These materials have performed well clinically as discussed in Chap. 14. A new generation of lithium silicate and disilicate materials reinforced with zirconia materials is available also, but these have only been tested in vitro and, to date, have yet to be proven clinically in the longer-term.

The tooth preparation for any ceramic restoration requires rounded line angles to reduce stress concentration resulting in crack propagation and fracture within the relatively brittle ceramic. When ceramic restorations are resin bonded to a substrate of sound enamel, they can be used axially in thin section (>0.4 mm). When a preparation involves dentine, they need to be used in sections of >1 mm axially and 1.5–2 mm occlusally. The biomechanics behind this may relate to a less effective and less durable resin bond to dentine compared with the better bonding and support to the overlying ceramic offered by more rigid enamel.

For cementation, use a resin luting agent that forms a relatively thin film to prevent excessive hydrostatic forces forming within the restoration during seating [4]. A dual-cured resin may be needed where restorations are too thick or opaque to allow for only light curing.

Resin-bonded all-ceramic crowns are often a good option where aesthetics is critical. However, ceramo-metal crowns are a better option where occlusal forces are destructively high.

20.2.4 Non-etchable Ceramic

Initially, these ceramic crowns comprised high-strength cores made from densely sintered zirconia or alumina, veneered with a feldspathic ceramic. The densely sintered cores cannot be etched effectively with HF, so the resin bond is less reliable than for the etchable ceramics. This makes them unsuitable for veneers and unretentive crown or onlay preparations.

For aesthetic reasons, a restoration with a non-etchable core requires more space axially than etchable ceramics (see Table 20.1). However, the introduction of monolithic zirconia crowns has eliminated the need for a layer of veneer ceramic giving them relatively high strength in thin section. Some manufacturers suggest a featheredge margin can be used and that only 0.5 mm occlusal clearance is needed. Others recommend at least a 0.5 mm chamfered margin and at least 1 mm occlusal clearance. These recommendations are all very well but they do not specify the marginal thickness of the restoration. The intricacies of measuring marginal thickness are covered later.

20.2.5 "Resin Ceramic"

The least expensive material for restorations is resin composite, sometimes marketed at "resin ceramic". Until recently, this material was reserved for lab-made provisional crowns intended to remain in situ for longer than normal. As discussed in Chap. 14, there are several "resin ceramics" which can be CAD/CAM milled, some of which may hold promise as long-term restorations. For crowns, manufacturers recommend a 1.5 mm occlusal/incisal reduction with a buccal reduction incorporating a 0.4 mm chamfer, but a 1.0 mm shoulder is preferred. For veneers, these materials can be used in much thinner sections.

20.3 Preparation Principles

We have already highlighted the need for a preparation to provide sufficient space for restorative material. In this section, we consider how preparation geometry can influence retention and resistance. In addition, we precisely define margin options and advise on preparation principles that govern aesthetics.

20.3.1 Resistance and Retention Form

With conventionally cemented restorations, tooth preparation geometry is essential to ensure a restoration remains in place. The principles of retention and resistance also apply to resin-retained restorations but, with the exception of zirconia restorations, are not quite so critical [5]. This assumes the resin lute is well-bonded to tooth tissue and restoration (see Chap. 15) [6].

The *retention form* of a preparation relates to its ability to retain a luted restoration along the path of insertion. Of course, multiple paths of insertion and withdrawal are often possible, particularly with increasing preparation taper. However, where we refer simply to "path of insertion," we mean the path along the long axis of the preparation.

The *resistance form* of a preparation prevents dislodgement of a luted restoration when subjected to lateral and oblique forces.

At first glance, retention and resistance seem entirely disparate, but they are interrelated. To explain this further, we briefly need to revisit the mechanics of luting in relation to full coronal restorations (detailed in Chap. 15). Briefly, a thin lute combined with favourable preparation geometry will lessen the chance of cohesive failure within the cement and peeling of the lute at its interfaces. The important geometrical factors influencing both retention and resistance are:

- Surface area—the taller or wider a preparation, the better, with preparation height particularly important
- Near parallel axial walls but with a small amount of preparation taper for a restoration to seat fully
- Additional features (e.g. grooves and boxes) [7].

A preparation with short and tapered axial walls will adversely affect both resistance and retention. Consider first retention. If an axially directed force is applied to a restoration (e.g. by the patient chewing a toffee), the retention is challenged because of disruptive tensile and shearing stresses developed within the cement and

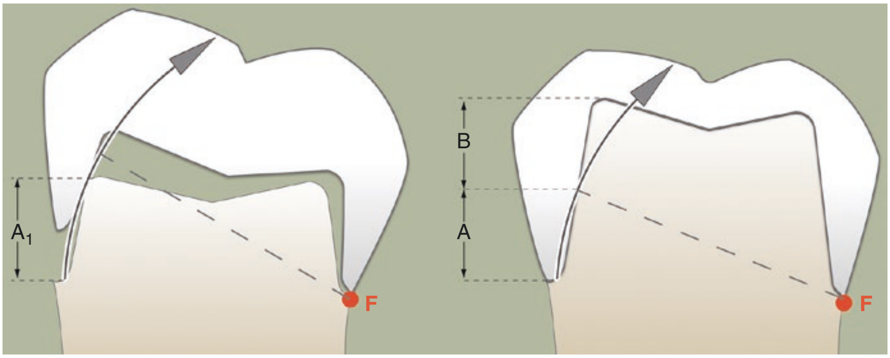

Fig. 20.3 Tooth preparations should include resistance form to prevent restorations being rotated off. A short preparation of height A_1 (left) allows easy rotation of the restoration around a fulcrum F. With a longer preparation, of height A + B, the rotation is resisted because the additional height B causes the inside of the crown to lodge against the opposing preparation wall. This will apply a favourable compressive load to more of the cement in this region

at its interfaces. With resistance, the situation is a little more complex but is best explained by considering how the lute behaves when the restoration is obliquely loaded (Fig. 20.3). Remember, lutes perform best when loaded in compression, but a short, tapered preparation gives less opportunity for the radius of rotation to intersect an opposing axial wall. So here the stresses in the lute will be largely tension and sheer. A longer, less tapered preparation resists rotation by loading more of the lute in compression.

In the previous paragraph for ease of explanation, we used the term “taper”, but to avoid confusion we will not use it anymore. The confusion occurs because the degree of “taper” (the angle of an axial wall from the long axis of the tooth/preparation) is sometimes incorrectly referred to as the “convergence angle”. Instead, we prefer the term “total occlusal convergence” (TOC—see Fig. 20.4) which makes clear it is the angle subtended between two opposing prepared surfaces [8]. Early experimental studies suggested the most effective TOC in relation to retention force for zinc phosphate to be between 0 and 6° [9], but this is rarely achieved clinically [7, 10]. Furthermore, detailed experimental analysis for this cement shows acceptable retention and restoration seating that both occur between 2 and 20° with an optimum at around 10° [11].

Clinically, realistic TOCs range between 10 and 22° [12], but there is merit in aiming for the lower end of this range because stresses increasingly concentrate within the lute with TOCs exceeding 20° [6]. Bear in mind that many tapered burs have a 5–6° convergence angle between opposing sides, so preparation taper can be surveyed with the handpiece and bur aligned parallel to the long axis of the tooth/preparation. Where scientific measurements are needed, these should be made in several planes aligned to the long axis of the preparation to capture the range of TOCs inevitably present in a tooth preparation [12].

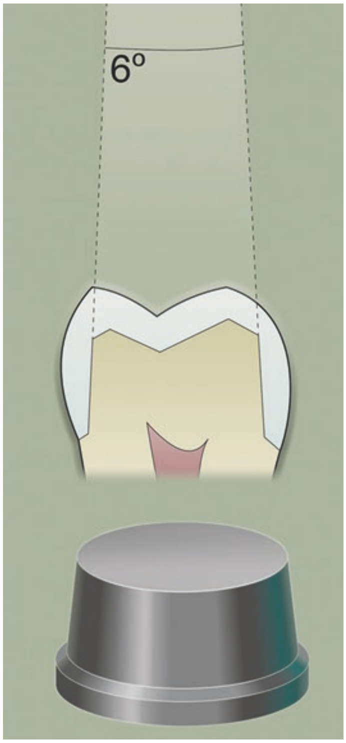

Fig. 20.4 Total occlusal convergence (TOC) refers to the angle subtended between opposing sides of a preparation. Here the TOC is 6°

In terms of preparation height, 3 mm is recommended as the minimum when using a conventional cement. However, a recent systematic review showed mean tooth preparation values reported within the literature from as low as 2.3 mm up to 6.9 mm for upper premolar teeth [12]. The authors suggest that this variation is unsurprising, given that preparation height is a feature a clinician has least control over. The same authors also conducted a direct clinical evaluation of preparation features from general dental practitioners in New Zealand and found that the shortest preparations were for mandibular molar teeth, at an average height of 1.87 mm [13].

As mentioned above, preparation of TOC and height may not be quite so critical with adhesively bonded restorations. Indeed, premolars in laboratory pull-off tests often fracture before resin lute failure [5]. Nonetheless, restorations must endure fatigue loading intra-orally, and resin bonds, particularly to dentine, often deteriorate with time; so preparation height and taper are still considered relevant [14]. We recommend optimising taper wherever possible, to minimise unnecessarily high stresses in the resin lute.

It is possible to improve the resistance form by preparing auxiliary features such as grooves and boxes. These features have been used for decades to help retain

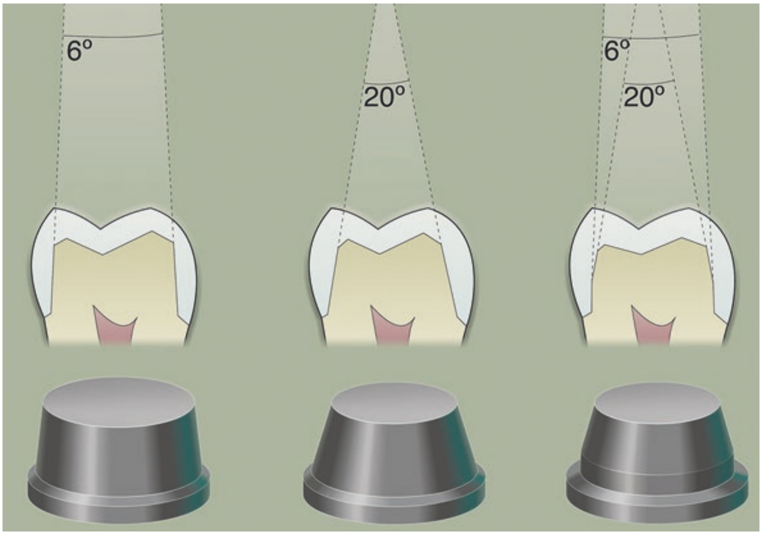

Fig. 20.5 Ideally, preparations should have minimal TOC along opposing axial walls (left), but with all other things being favourable up to 20° may be acceptable (centre). Where an existing preparation is considered over-tapered, it is better to reduce the TOC only in the cervical 1.5 mm (right) rather than destructively along the full length of the preparation

all-metal and ceramo-metal restorations. Grooves can resist torqueing effects and may strengthen (bolster) the crown at the margin and improve rigidity, particularly with traditional three-quarter crowns which otherwise tend to flex. An in vitro study by Roudsari explored the benefit of proximal grooves when the general TOC of the preparation was as high as 22°. The study also looked at the potential to reduce the TOC within the cervical 1.5 mm of the preparation, rather than attempting to refine the taper along the full length of the preparation (see Fig. 20.5). Whilst proximal grooves did improve the resistance form, it was the refined cervical TOC that had the greatest impact [15].

If grooves are to be placed, they should be cut with a tapered diamond or tungsten carbide bur. With ¾ crown preps, they should be sited as buccally/labially as possible without undermining the tooth tissue. Ideally a groove should finish axially 0.5–0.8 mm from the margin, but in short preparations the groove can extend the full length of the axial wall. If grooves are being used to compensate an over-tapered wall, they should be prepared parallel with the path of insertion which invariably causes them to be deeper cervically and shallower occlusally (Fig. 20.6). Groove depth at its deepest point should be no less than half of the bur's diameter to avoid the groove being obliterated by die spacer in the laboratory and for the

Fig. 20.6 Grooves are cut with a flat-ended tapered bur. They should be parallel with the path of insertion, sufficiently deep and sited in a sound tooth

corresponding rail in the restoration to engage the preparation effectively. There should be no conflict between the orientation of a groove and a restoration's path of insertion, and multiple grooves must run parallel. All these aspects can make for a particularly technique-sensitive procedure, and beginners are advised to practise cutting grooves on models/casts before attempting them intra-orally.

Boxes (Fig. 20.7) can offer a reasonable degree of resistance form and should be considered in cases where teeth already contain proximal restorations, but remember a large, deep box may predispose to metal casting porosities. This problem can be largely avoided if the deep part of the box can be lined, e.g. with GIC or light-cured GIC, leaving sufficient sound tooth to give resistance and retention. Another option is to use a pressable ceramic—if the occlusal loading is not too challenging. Care should also be taken if your restoration is to be milled; the CAD/CAM set-up may have difficulties with scanning and milling a detailed intra-coronal feature like a box or a groove. Your technician should be able to advise if the work is sent to a laboratory.

If coronal tooth tissue is at a premium, another approach is to consider a gingivectomy procedure or more formal "surgical" crown lengthening as outlined in Chap. 10 and detailed elsewhere.

Fig. 20.7 Boxes can offer a reasonable degree of resistance form and should be considered in cases where teeth already contain proximal restorations

20.3.2 Finishing Lines and Margins

20.3.2.1 Margins and Finish Lines

In an age where digital 3D imaging allows preparations to be scanned and visualised not just at the chairside and in the laboratory but also for scientific analysis, there is a need for clarity. Confusingly, the terms "finish line" and "margin" are often loosely defined and are sometimes used synonymously. Alternatively, they relate the margin only to the restoration and the finish line only to the preparation [16]. To clarify what we mean by finish lines and margins and how these terms relate to both the preparation and restoration, please look at Fig. 20.8. Look again at Fig. 20.1 to be familiar with common preparation margin configurations. In practice, the technician defines the inner marginal surface of a restoration by applying die spacer or programming a space using CAD/CAM to accommodate the restoration's lute. This is often to within 0.5–1 mm from a preparation finishing line.

Margin types are generally categorised into two groups—"horizontal" margins (where a distinct finish line is prepared) and "vertical" margins (where no horizontal finish line is prepared) [1, 17]. Most operators will recognise the finishing techniques associated with "horizontal" margins, such as shoulder, chamfer and bevel. These are often preferred because they allow the dentist to prescribe where the restoration should finish, so this can be replicated on the working model. Assuming

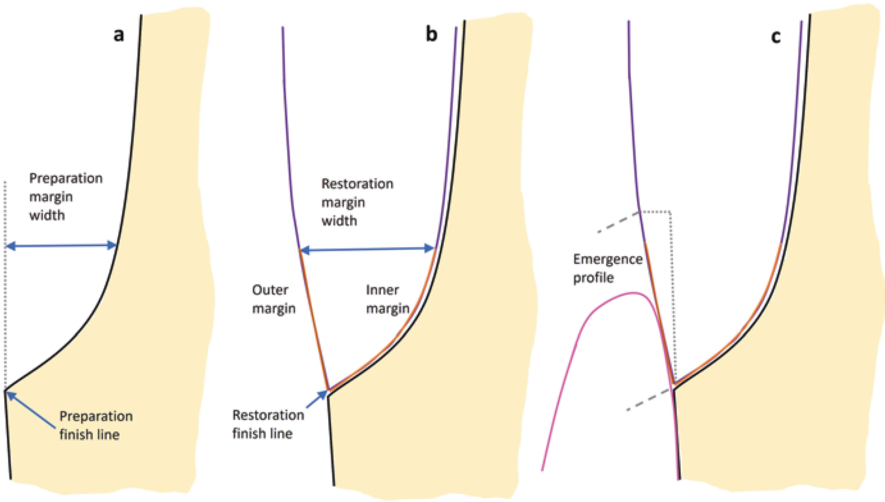

Fig. 20.8 Cross section through margin of a tooth prepared with a chamfered margin to illustrate terminology: (**a**) The *preparation finish line* is at its perimeter. Note how horizontal margin width of the chamfer increases coronally. So, to measure *preparation margin width*, a vertical (dotted) line is constructed from the finish line parallel with the long axis of the preparation. A horizontal measurement may be made between the vertical line and the axial wall at a specified distance (e.g. 1 mm) above the finish line [12]. This approach avoids any difficulties in deciding where the axial wall ends and the margin starts. (**b**) The *restoration finish line* is at its perimeter and, ideally, should correspond to the preparation finish line. The *restoration margin width* between its *outer marginal surface* and *inner marginal surface* can be measured along the same horizontal line as for the preparation. (**c**) The *emergence profile* describes the restoration contour relating to the gingival tissues [37] and includes the outer marginal surface of the restoration

good impressions and quality assurance procedures, there should be little room for ambiguity on the technical side.

Feather-edge margins, however, are described as "vertical" and are generally considered to be more conservative, whilst maintaining a reduced taper [17]. They are particularly useful when a restoration margin is necessarily located on an exposed root with a need to hide black triangles in the gingival embrasure spaces. This is done by moving the restoration's margin further apically than the natural clinical crown and providing an emergence profile which thickens the restoration margin. However, as discussed below there may be issues when feather-edge preparation margins are used subgingivally.

20.3.2.2 Margin Location

Deciding the location of a preparation's finishing line in relation to the gingival margin will depend on the following requirements [18]:

- Aesthetics
- Retention and resistance
- Maintenance of gingival health

- Management of existing restorations
- Development of a ferrule for endodontically treated teeth
- Elimination of caries and defects/cracks.

The further apically a margin is extended, the more coronal tooth tissue must be removed. To conserve tooth tissue, use supra-gingival margins where possible in combination with adhesively retained restorations. However, aesthetics can dictate a margin is placed at or below gingival level, particularly where restoration margins may be in the smile line (e.g. anterior teeth and upper premolars).

Placement of a subgingival margin will slightly increase preparation length which may be helpful to improve the retention and resistance form. However, it is best to be realistic and plan a crown lengthening procedure with adequate time for gingival stabilisation (see Chap. 10) if more than 1 mm of additional preparation height is needed.

In preparing a subgingival margin, it is important to be mindful of the biologic width [19]. A 26-year-long study has clearly demonstrated that restoration margins more than 1 mm subgingival have a detrimental effect on periodontal health, including gingival inflammation, recession, increased probing depth and loss of attachment [20]. Indeed, subgingival crown margins have been shown to have a 2.65 times higher chance of recession than margins placed supra-gingivally [21], which may well result in subgingival margins becoming supra-gingival. A 15-year follow-up of full crowns used as bridge retainers reported approximately one third of subgingival margins became supra-gingival after 5 years rising to one half after 15 years [22]. Patients with specific aesthetic demands who are insisting on subgingival margins need to be aware of this risk.

Preferably, margins should be finished on sound tooth tissue wherever possible. If you feel the need to cut a finishing line in an existing restoration, make sure you know it's a sound restoration. If in doubt, consider replacing it before proceeding.

20.3.2.3 Preparation Margin Issues

As mentioned at the beginning of the chapter, the choice of restoration margin will depend on the restorative material being used, for example, a chamfer for metal restorations and ceramic veneers and a deep chamfer for all-ceramic crowns. It is worth noting that operators tend to underprepare margins. With ceramo-metal crowns, a survey reported the preparation margin rarely exceeded 1 mm [23]. With ceramic crowns, mean horizontal reductions measured 0.4–0.83 mm compared to the 1–1.5 mm recommendation [13]. However, recommendations are based on manufacturers' advice and in vitro studies to determine an aesthetic thickness of ceramic. A systematic review has attempted to relate the depth and type of finish line to clinical success but was hampered by poor reporting and lack of consistent measurement criteria [24].

The periodontal tissue response is not only influenced by subgingival margins but also by the type of margin. A randomised controlled trial of ceramic crowns showed that after 1 year, a knife edge preparation finish resulted in more bleeding on probing, but less recession, than a chamfer [18]. The increased bleeding with the knife edge preparations may have been caused by overbulky and less well-defined crown margins. The decreased recession may have been associated with oedematous gingival inflammation. On the other hand, the chamfer provided both a clear preparation finish line and space for the technician to create a more natural emergence profile, resulting in less plaque accumulation and less bleeding [18]. These results do not support the use of the "biologically oriented preparation technique" (see Box 20.2) which systematically finishes restorations subgingivally on a vertical preparation margin.

When preparing relatively tall crowns on narrow teeth (typically lower incisors), prescribing deep horizontal margins is not only destructive of cervical tooth tissue but also risks pulpal exposure further occlusally. In these situations, where a ceramo-metal restoration is chosen, a metal collar can greatly reduce the amount of tooth reduction (Fig. 20.9). Similarly, in teeth with furcation involvement, a metal collar can reduce the severity of the preparation. Further, the finish line should conform to the furcation concavity, to avoid the crown being bulky in this area. An alternative to a metal collar may be to use a high-strength ceramic that allows a less deep restorative margin. In this respect, monolithic zirconia looks promising (see Chap. 14) but needs to be trialled clinically in the longer-term.

Box 20.2: The "Biologically Oriented Preparation Technique" (BOPT)

This advocates placement of a vertical, feather-edge margin and intentional "gingitage" (removal of the inner aspect of the gingival margin) with a flame-shaped bur [17]. It has long been claimed that this approach can improve operative accessibility of a subgingival margin [36], but the BOPT technique further advocates the removal of any existing marginal anatomy or emerging tooth anatomy. The concept is to create a smooth intra-sulcular tooth surface allowing the restoration's margin to be placed within a zone, rather than on a prescribed finish line. A successful outcome relies on a technician prescribing margin location and emergence profile using the now altered soft tissue as a guide. It also assumes the preparation is sufficiently smooth not to be a plaque trap in those areas left uncovered by the restoration. Inevitably, there is a risk that crown margins may be overbulky or invade the biologic width.

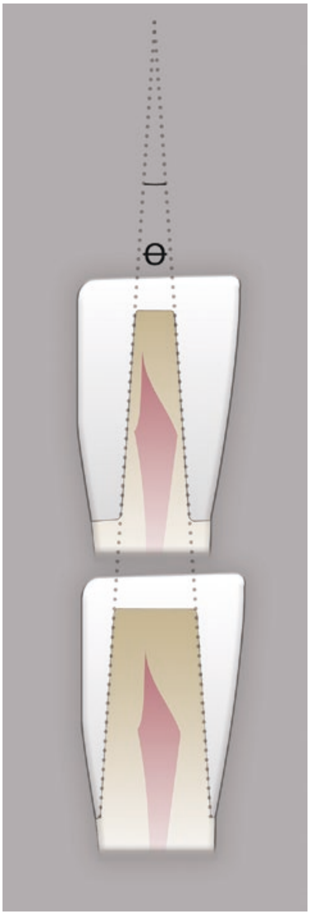

Fig. 20.9 Teeth with long preparations are prone to pulpal exposure especially if a deep finish line is cut. Teeth with narrow roots are most vulnerable. A metal collar or a monolithic zirconia restoration reduces the need for a deep finish line

20.3.3 Aesthetic Considerations

The preparation will play a major role in determining the aesthetics of the final restoration. We have already mentioned the important role of finishing line placement and margin configuration. In addition, most materials need a minimum thickness to obtain optimum aesthetics and strength (Table 20.1). Clearly, there is a balance to be struck between conserving underlying tooth tissue and providing sufficient space for the technician to build an aesthetic restoration. This is no more apparent than in the multiplane buccal reduction of crown preparations considered below.

20.4 Preparation Technique

20.4.1 Full-Coverage Crowns

Many texts depict ideal preparations on intact (or previously unprepared) teeth. Whilst this is useful to appreciate individual features, it is a poor representation of many of the teeth dentists must work with. Often crowns must be replaced, and there is a need to revisit an existing preparation, for example, to alter marginal placement and change the type of restoration, after treating caries or providing root canal treatment. In these situations, preparations are best designed to fulfil the requirements of the chosen material rather than conform to an ideal shape which may be unachievable or inappropriate. In addition to being conservative of tooth tissue, the most important things to remember are:

- The materials that are available
- The space required to accommodate them
- The marginal requirements of each material
- What you can do to ensure the restoration stays in place.

Even if you know the amount of reduction required for a material (see Table 20.1), checking whether your preparation provides enough room can be tricky. If you underprepare, then you run the risk of having an overbulked crown fabricated, which may cause occlusal or periodontal problems. Overpreparation may risk the vitality of the tooth and compromise its structural integrity (Fig. 20.10). If it is unclear how much reduction is required, consider asking your technician to wax-up the intended restoration. With tooth surface loss, some teeth need only limited or no tooth preparation.

To gauge and progressively monitor the necessary amount of reduction, putty matrices can be used in the bucco-lingual or occlusal planes. The matrices are formed over the wax-up. They can also be formed intra-orally over a well-contoured unprepared tooth or provisional restoration. After removing the set matrix, section it bucco-lingually through the centre of the tooth to be prepared with a straight scalpel blade (e.g. Bard Parker™, Number 11). A sectioned matrix can be reseated in the mouth several times during preparation (Fig. 20.11). Depth cuts can also be used to estimate the amount of tooth preparation, but be wary of tapered burs and the need on the buccal aspect to reduce in several planes, rather than a single plane (Fig. 20.12). Using these methods, you can conserve tooth tissue and provide sufficient space for a good aesthetic result.

Try and follow a set sequence when preparing teeth. This helps develop a consistent approach making sure each element is complete before moving on to the next with less chance of omitting stages. Many dentists carry out a broad range of preparations with a selection of only two or three burs. However, when confronted with having to prepare long teeth, grooves and smooth away rough corners and marginal lipping, the need for additional bur types becomes apparent. A set of six burs covers most eventualities (Fig. 20.13) with a supplemental set of three for less common procedures (Fig. 20.14).

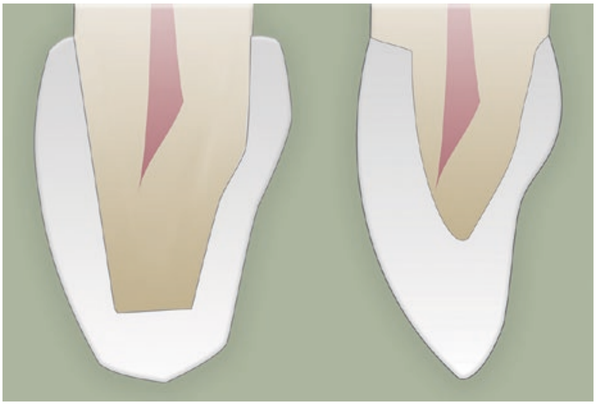

Fig. 20.10 Under-preparation (left) results in a bulky crown with potential periodontal or occlusal problems. Overpreparation (right) risks pulp vitality and structural integrity of the tooth

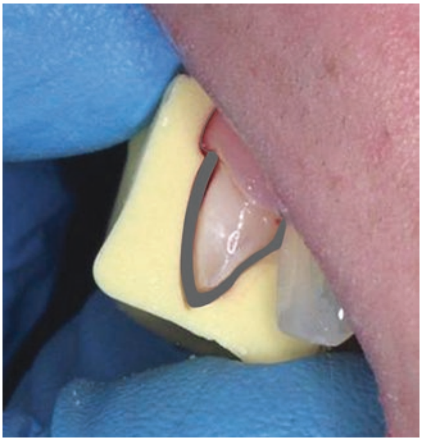

Fig. 20.11 This putty matrix has been sectioned bucco-lingually and gives an excellent estimate of the amount of tooth reduction (shaded grey for clarity)

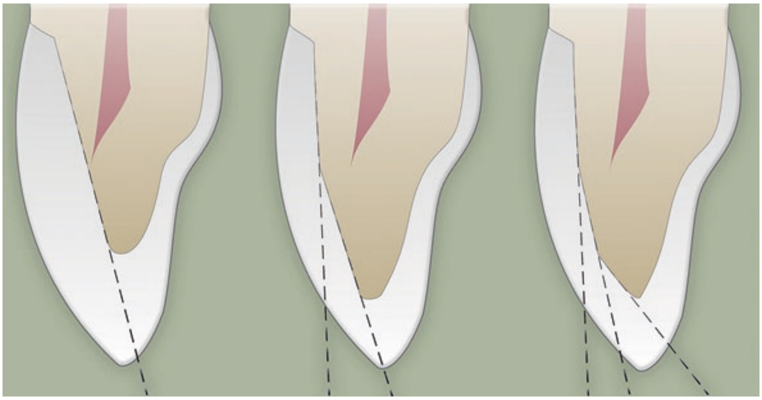

Fig. 20.12 Single-plane reduction (left) can result either in pulpal damage if angled lingually or insufficient space to accommodate ceramic if angled buccally. A two-plane reduction usually solves this problem (centre), but for long preparations a three-plane reduction is a better option (left)

Bur		Preparation of the following features and surfaces:
Parallel-sided flat-ended		Depth grooves: Occlusal Buccal
Flat-ended tapered		Occlusal surface (for limited access) Axial surface (for limited access) Box preparation Large groove (e.g. for molar)
Long round-ended tapered		Occlusal surface Axial surface Proximal surface (after long needle)
Long needle		Proximal slice to make room for round-ended tapered diamond bur
Rugby bur		Lingual/palatal surfaces
Smooth round-ended tapered		Refine margins and finish line and round the sharp junctions between prepared surfaces

Fig. 20.13 A set of six burs commonly used for crown and veneer preparation

Bur		Preparation of the following features and surfaces:
Long flame-shaped fine diamond		Proximal margin and finish line for the boxes of gold onlays. The bur creates a “hollow ground” bevel
Tapered flat-ended tungsten carbide		Axial retention grooves (small diameter) - e.g. in premolars
Torpedo tungsten carbide		Chamfer margin particularly where access limited for tapered round-ended diamond

Fig. 20.14 These three burs are used less often but are indispensable for preparing conventional gold onlay preparations

Most operators in the UK use air rotor handpieces, but across Europe speed-increasing handpieces are favoured. Either are acceptable, but to avoid overheating water-coolant must be used with a gentle, sweeping motion of the bur across the tooth surface. Water-coolant jets in handpieces often get blocked, so check that the bur is receiving the spray along its full cutting length. Speed-increasing handpieces and finer grit burs and discs can be useful for refining or finishing the preparation.

20.4.1.1 Occlusal Reduction

There are several ways of ensuring adequate but not excessive occlusal reduction:

- Putty matrices and depth cuts (see Fig. 20.15) as described previously
- A silicon feeler gauge with leaves of various thickness (e.g. 1.0, 1.5, 2.0 Flexible Clearance Tabs™, Kerr) is popular with some dentists. These are placed between the preparation and opposing tooth
- Overerupted teeth which require the occlusal plane corrected in the definitive restoration are best recontoured to the desired level before preparing depth cuts for the restoration
- Tilted molars may require little or no preparation in areas where the tilt has already created sufficient inter-occlusal clearance.

With all these approaches, knowing your intended endpoint is critical and should be thought through with study casts and wax-ups beforehand.

A functional cusp bevel is important. Functional cusps (aka “holding cusps”) are typically the palatal in the upper and the buccal in the lower. Placing a bevel between the occlusal and axial surface of the functional cusp(s) will ensure:

- Sufficient inter-occlusal clearance in this area of heavy occlusal load. Be sure to check adequate clearance both in the intercuspal position and in excursions
- The axial walls retain a low TOC with adequate height for resistance and retention.

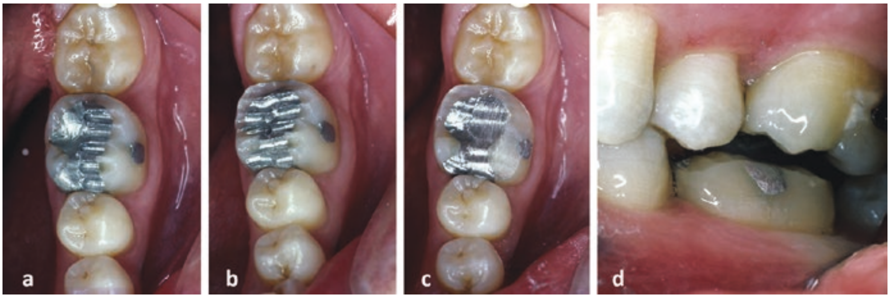

Fig. 20.15 Sequence of occlusal depth cuts as used for a gold crown prep: buccal cusp (**a**); lingual cusp (**b**); cuts joined emulating previous cuspal contour and incorporating functional cusp bevel (**c**); desired occlusal clearance, viewed buccally (**d**)

Once occlusal reduction is complete, the remaining tooth reduction is considerably more efficient, because there is less tooth tissue to prepare axially, and visibility is somewhat improved interproximally.

20.4.1.2 Lingual/Palatal and Buccal Reduction

Lingual preparation on lower molars can be particularly difficult because of restricted access and vision. As a rule, it is best to prepare the most inaccessible wall first. In this way the remaining, more accessible, walls can be prepared (and further altered) to complement it, rather than ending up with the most inaccessible wall requiring most refinement. View the prepared axial walls along at least three axes (occlusally, along the line of the arch and from the buccal) to ensure correct planes of adjustment have been made. This is important both with crowns and veneers, particularly if the clinical crown is long.

A straight bur can be used to prepare most axial surfaces, but a rugby ball-shaped bur is invaluable for concave palatal reductions on anterior teeth. Remember to check the amount of tooth reduction and planes of buccal reduction (look again at Figs. 20.11 and 20.12).

20.4.1.3 Proximal Reduction

It is easy to understand why this aspect of tooth preparation causes most trepidation. The tip of the bur can be difficult to see, and adjacent teeth are easily damaged. To facilitate matters, a narrow-tapered diamond bur (needle bur) can be used to create clearance proximally before switching to larger burs such as a tapered round-ended diamond or a parallel-sided chamfer bur (torpedo) where clearance is limited. Rather than cut right up to the proximal contact and risk collateral damage, try to leave a fine slither of tooth tissue approximally which can then be fractured away before the margins are refined. The trick with this approach is to place the bur tip at the intended marginal level, held in the correct orientation before confidently making the cut as a single operation. Because the tip of a needle bur cuts less quickly, then the wider part must trail slightly behind as the cut progresses to avoid problems.

Sadly, problems with visibility and hesitation in revisiting the area commonly create poorly defined or ragged margins and may result in a more destructive preparation. Trainees often experience these issues whilst developing handpiece skills, but most overcome them. Some dentists are more comfortable carrying out the initial proximal reduction with the bur held perpendicular to the long axis of the tooth rather than parallel with it. Here, it is important to use a narrow diameter parallel-side bur.

Whatever method is employed, ensure you maximise direct vision of the area. This might mean moving around to the 10 o'clock or 2 o'clock position with the patient's head slightly tilted in the opposite direction, ensuring that your back is still straight and supported by the backrest (if you have one).

20.4.1.4 Final Checks and Finishing

To help visualise the finish line on subgingival preparations, consider placing retraction cord during the later stages of preparation. This approach can also minimise gingival trauma but only if the cord is placed carefully; a heavy-handed technique may result in unwanted gingival recession. Take care also not to snag the cord, or it will end up wound around the bur!

With wider preparation margins, we commonly see a degree of lipping at the finish line. This problem occurs both with supra- and subgingival margins and is caused by not taking the tip of the bur sufficiently over the edge of the preparation. Consequently, the bur digs a trough leaving a thin outer band of unsupported tooth tissue. Unless the lipping is removed before recording the final impression, it may fracture later leaving a defective margin. Depending on operator preference, the preparation can be revisited with a fine diamond bur in a high-speed or speed-increasing handpiece. Another option which is useful for final margin finishing is to use hand instruments (e.g. an enamel hatchet or a proprietary margin finishing instrument) to plane the periphery with a subtle sweeping action.

In trying to obtain an optimal taper, it is easy to misjudge handpiece orientation leaving aspects of the preparation slightly undercut. Commonly, undercuts occur at the corners of a preparation (the axial junctions between a proximal surface and buccal or lingual surfaces). To check, view the preparation from the occlusal surface down its long axis (this usually requires a front surface mirror to avoid a double image). Keep one eye closed, as using binocular vision at close range can allow undercut opposing axial surfaces to appear satisfactory. So, with one eye closed, the margin should be entirely visible around the preparation's entire periphery.

Sometimes the junction between the margin and the axial wall is difficult to identify, especially with a deep chamfer or shoulder. One remedy is marking the full depth of the margin with a Chinagraph pencil, but this can be messy. The easiest way is to survey the preparation using a tapered diamond bur in a handpiece. For example, to check the angulation between lingual and buccal walls, first hold the bur against the lingual axial wall and, maintaining handpiece alignment, transit the head of the handpiece and bur around to the buccal wall. Look along the buccal aspect. If the preparation is undercut, the bur will contact towards the occlusal leaving a gap apically between bur and the axial wall. If it is too tapered, the bur will contact cervically leaving a significant gap occlusally.

Now make a final check with a matrix, if one has been made. If not, recheck occlusal clearance using wax or silicone mousse and view the axial surfaces directly. Of course, it is also possible to measure the thickness of provisional restorations with an Iwanson gauge, although at this stage, significant changes may necessitate the fabrication of a new provisional restoration or at least a reline using chairside resin (see Chap. 23).

To improve a restoration's resistance to rotation and seating accuracy, Shillingburg [1] advocates placing a seating groove within the axial surface having the greatest bulk. This is not always needed but is good advice for metallic restorations where there is any doubt over a preparation's inherent resistance and retention form.

Some dentists like to finish preparations by polishing with discs, cups and cones. However, the authors prefer not to. There is a risk of overheating or desiccating dentine and reducing the effectiveness of traditional luting cements by removing micromechanical surface imperfections. Nonetheless, it's always worth rounding off sharp corners between the occlusal and axial surfaces with a fine diamond bur under water spray. This helps avoid these edges being rubbed off stone dies. In addition, it may reduce stress concentration and crack propagation in ceramic or composite restorations.

Of course, the most sophisticated approach to checking preparation features is to scan the preparation with a 3D intra-oral scanner as would be used for recording a digital impression (see Chap. 22) and view the image from all aspects on a computer screen. This is a great teaching aid for students, and some patients are fascinated to see their prepared tooth.

Finally, you may wish to consider "immediate dentine sealing" (IDS), whereby a dentine bonding agent is applied before making the provisional restoration and recording the impression [25, 26]. As discussed in Chap. 15, this technique may have benefits but must be carried out extremely carefully to avoid problems with the applied layer of dentine bonding agent. These include pooling of the bond at or over the finishing line, provisional restorations adhering so they become difficult to remove and adverse interactions of impression materials with the uncured resin surface. Unless you are prepared for all the various nuances, IDS may be an encumbrance when undertaking a retentive crown preparation. However, it is worthy of consideration with veneer preparations and preps for other adhesively retained restorations with a substantial area of prepared dentine. If using loosely attached provisional restorations, bear in mind the need for a quick return of the definitive restorations (discussed further in Chap. 23).

20.4.2 Veneer Preparations

Veneers are a popular means of providing cosmetic treatment for patients. They are also a conservative way of restoring teeth which in the past may have been crowned, e.g. trauma cases (see Fig. 20.16). In most cases a veneer will need some tooth

Fig. 20.16 Veneers are not just for cosmetic dentistry. Here they combine conservatively with an implant-retained crown to repair traumatic damage (**a**). Veneer preps at 11 and 21 with a custom zirconia abutment at 21 (**b**). Incisal overlap of veneer ceramic (**c**). Completed case at 6-month review (**d**). Courtesy of Dr. Margaret Corson

preparation to avoid it being overbulky. However, some of the new "resin ceramic" materials may offer the option of non-preparation veneers in selected patients (Fig. 20.17). The thin veneer profile avoids a bulky emergence profile. Patients need to understand that long-term performance of these new materials is not yet understood. Nevertheless, a few dentists are already finding them useful for interim restorations (e.g. in teenage amelogenesis patients).

Veneers can correct minor tooth misalignments, but the current trend is to consider using orthodontics either before or instead of veneering [27]. Patients may be keen to explore having a short course of orthodontics, but not every case is amenable to this approach. Not surprisingly, many dentists feel the need for specialist orthodontic support [28].

If you intend to use multiple veneers to change existing tooth contours, we recommend a preoperative diagnostic wax-up from which a matrix can be constructed. The matrix is used with a bis-acryl provisional composite in the patient's mouth to create a mock-up simulating the proposed appearance. If the patient is happy, stick the mock-up to the teeth with a clear temporary cement. By having a correctly contoured mock-up in place during tooth preparation, your depth cuts can be made to the appropriate depth. After tooth preparation, remove any residual provisional composite from the teeth and reuse the matrix to make linked provisional restorations.

Fig. 20.17 Non-preparation veneers made from a "resin ceramic" (Enamic™, VITA Zahnfabrik) in a 40-year-old man. Following non-surgical periodontal management, bleaching of the lower incisors, and replacement of the composites, only the overlapping mesial aspect of 21 required preparation. Veneers were milled to 0.3 mm and polished to 0.2 mm making them quite delicate until cemented. Their opacity is helpful in masking the underlying patchwork of composite (Courtesy of Dr. Andrew Keeling)

20.4.2.1 Incisal Veneer Margins

With veneer preparations, several approaches are possible for finishing the incisal edge, and the choice, which largely hinges on involving or not involving the existing incisal edge, should be made beforehand (Fig. 20.18):

1. *Window*: Here the veneer is taken close to, but not involving, the incisal edge. Although it is relatively conservative, avoiding the incisal edge when preparing the window is technically quite demanding. It is also rather difficult to hide the

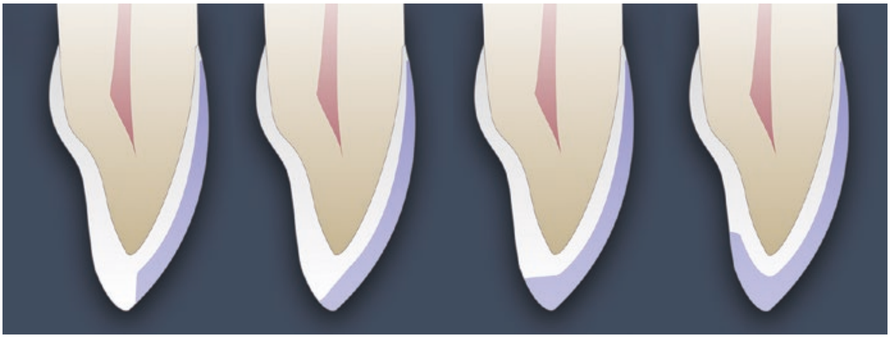

Fig. 20.18 Options for incisal veneer margins: from left to right—window, feather, bevel (or butt), incisal overlap

incisal lute. In addition, the incisal margins may become vulnerable if the enamel is subject to erosion, attrition or abrasion causing tooth surface loss

2. *Feather*: Here the veneer is taken up to the incisal edge, but the incisal edge itself is not reduced. Practically this is prepared by many operators intending to prepare a window. Anterior guidance is maintained on natural tooth tissue, but the veneer may be more vulnerable mechanically at a feather edge during excursions, particularly during excursions when the lower anterior teeth cross over the upper incisal edges from lingual to buccal
3. *Bevel (or butt)*: Here there is reduction of the incisal length to provide a positive seat during try-in and a better result in terms of hiding the incisal lute. The preparation is less conservative but provides more resistance in nearly all movements, apart from perhaps protrusion. This is the design preferred by one lithium disilicate ceramic manufacturer [29] who recommends a preparation designed to accommodate 1.0–1.5 mm of incisal ceramic. Remember that if increasing the height of an incisal edge, no or minimal reduction is needed
4. *Incisal overlap*: Here the incisal edge is reduced and the preparation extended onto the palatal aspect. Whilst this provides a positive seat, it is the most extensive preparation type. A definite path of insertion is now required from the occlusal, but it is easy to create an undercut between the palatal extension and the prepared gingival embrasures (see below). If a palatal overlap is used, it should be minimal. A 2D finite element analysis reports that long palatal extensions during loading have greater tensile stress concentration, predisposing to failure [30].

Some dentists have their favourite incisal veneer margin which in the absence of evidence can lead to furious debate. However, a recent meta-analysis of eight clinical studies reports no difference in survival between preparations which involve the incisal edge compared with those that don't [31]. There is less information to inform the choice of bevel/butt versus palatal chamfer; in vitro studies (3D finite element analysis and "crush the crown tests" where the restoration is loaded until it fails) have reported the chamfered palatal finish to be slightly stronger [31], but the choice of margin appears to make little difference clinically: A trial of 66 veneers placed in 25 patients to treat fractured or worn teeth reported that after 7 years, the choice of incisal margin (butt versus palatal chamfer) did not influence survival. However, both designs had similar amounts of chipping and other deterioration [32].

20.4.2.2 Buccal Reduction

When preparing teeth for veneers, try to remain within enamel where possible and provide a chamfered preparation margin 0.4–0.6 mm deep with the finish line at the crest of the free gingival margin. This will help ensure an optimal resin bond and give the technician a definite margin to work to, with sufficient space to create a harmonious and unbulky emergence profile. The main exception to the rule would be when the preparation margin is in root dentine and extra space is required to accommodate the resin bond thickness associated with the IDS technique mentioned above. Here a preparation margin depth of 0.7–0.8 is recommended [25]. Severe intrinsic staining may also require a deeper margin, but it will depend on whether a ceramic can be chosen which is sufficiently opaque to prevent the stain shining through. Of course, bleaching can help reduce discolouration in these cases [33]—often to the extent that a veneer is not needed.

To avoid a bulky buccal contour, some enamel reduction is often required. If the existing tooth contour is satisfactory, a minimal preparation (0.4–0.6 mm) can be marked out with depth pits made with a round diamond bur rather than depth grooves.

20.4.2.3 Proximal Reduction

When preparing for veneers, the proximal contact should be maintained wherever possible—otherwise to prevent unwanted tooth movement, a well-retained provisional restoration will be needed, which can be tricky with veneers. So, maintaining proximal contact is good, but care is needed to avoid displaying unsightly proximal margins, particularly when a veneer is used to mask a discoloured tooth. To keep the proximal margins out of sight, dip the finishing line into the gingival embrasure beneath the interproximal contact (see Fig. 20.19). This approach can provide excellent aesthetics, but as mentioned above there is a risk of creating an undercut if an incisal overlap is used. It can be avoided by attention to the angle of the overlap onto the palatal surface and not extending it too far. Alternatively, some operators prefer simply to use a butt joint instead.

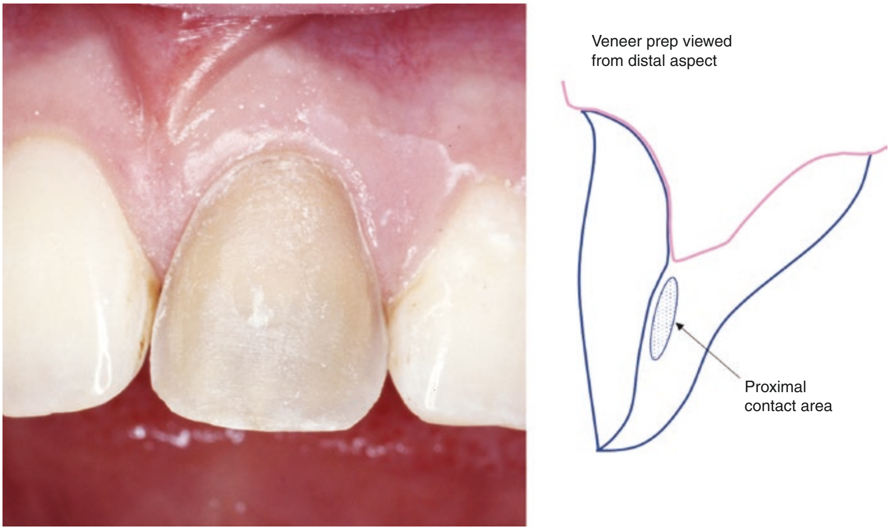

Fig. 20.19 Veneer prepared for a discoloured central incisor where bleaching gave only slight improvement. To hide an otherwise unsightly junction, the proximal finish lines have been tucked into the gingival embrasures beneath the interproximal contacts. To show this more clearly, the diagram views the prep from its distal aspect. Incisally, a feather-edge margin has been used

20.4.3 Onlay and Partial-Coverage Crown Preparations

Often the option of prescribing an onlay or a partial-coverage crown is overlooked. This is a shame as they can be particularly effective in conserving tooth tissue. In addition, an onlay providing cuspal coverage may effectively restore a root-treated posterior tooth instead of using a full-coverage crown.

Traditionally, these restorations were made of gold and relied on preparation retention and resistance form (typically grooves and boxes) to prevent dislodging forces. Boxes can provide a great deal of retention and resistance form but are destructive and should only really be considered when existing restorations are present (see Fig. 20.20).

Gold restorations have always been perceived as requiring a high level of operator skill with much credence given to the geometry, sharp internal line angles and finish of the cavity. An almost perfect fit can be obtained by pre-cementation burnishing of the gold margins—at least in accessible areas. Whilst a well-fitting and properly contoured restoration is still desirable, the move from conventional cements to adhesive luting agents has released the onlay from the realms of the perfectionist, and it made it a do-able option for most capable dentists. Nowadays, onlays and partial-coverage crowns can be made in a variety of alloys with the intaglio surface treated to improve resin bonding (see Chap. 15), so they no longer rely on intricate preparation features (see Fig. 20.21) for retention.

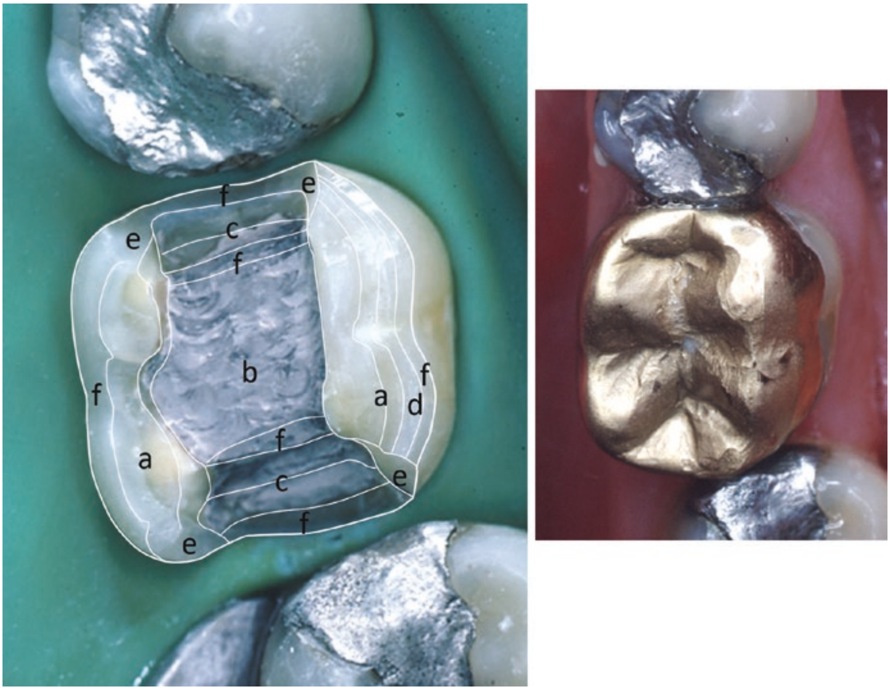

Fig. 20.20 Classical MOD gold onlay preparation for a root-treated lower molar with a glass ionomer core build-up (left) and the resulting restoration (right). Preparation features are outlined in white: (**a**) Occlusal reduction with functional cusp bevel on the buccal cusp. (**b**) Occlusal isthmus preparation into the GIC. (**c**) Mesial and distal box preparations with minimally convergent outward-facing walls and minimally divergent inward-facing walls. These allow the restoration to "draw" whilst providing retention for conventional cementation. (**d**) Buccal shoulder preparation to give adequate bulk of gold over the functional cusp. (**e**) Proximal walls flared with fine flame-shaped bur to give a hollow-ground (concave) bevel. (**f**) Finish line bevelled buccally, lingually and gingivally. Bevel also applied at junction of the axial and pulpal walls

Preparations for *ceramic onlays* differ from all-metal onlays in that they require rounded internal line angles to avoid stress concentration within the restoration. To give sufficient strength for lithium disilicate onlays, one manufacturer [29] recommends the following minimum preparation dimensions:

- Isthmus width: 1.5 mm
- Isthmus depth: 1.5 mm
- Gingival floor width: 1.0–1.5 mm
- Cusp reduction: 1.5–2.0 mm.

As a rule, onlays require a similar amount of occlusal reduction as would a crown of the same material. The ceramic margin should finish with a 90° cavo-surface angle.

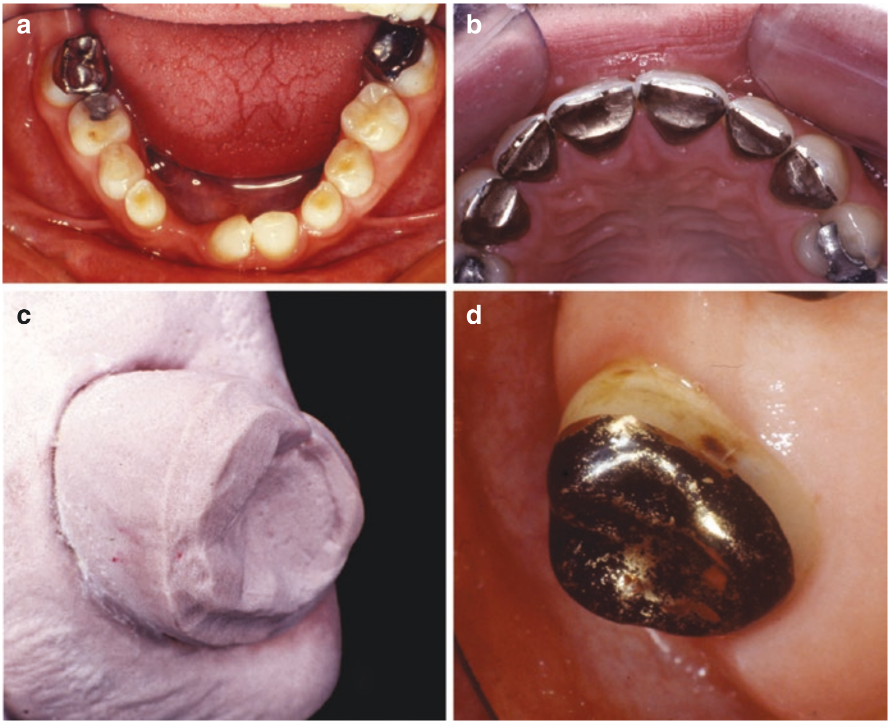

Fig. 20.21 Adhesively retained metal onlays: (**a**) Metal onlays used on lower first molars to increase vertical dimension in a hypodontia case. (**b**) Metal onlays used on worn palatal surfaces of anterior teeth. The palatal shelves provide occlusal stops to produce the Dahl effect for space creation [38] (**c**) Stone die showing chamfered margin with minimal axial wall height for gold onlay. (**d**) Cast gold onlay in situ. Note the blackened surface following oxidisation to enhance resin bonding. This is polished off after luting

Some dentists recommend occlusal reduction for an adhesively retained ceramic onlay should emulate the concave curves typical of the amelo-dentinal junction in that region. This is to provide a "compression dome" restoration which, per architectural theory, better transfers the occlusal stresses to the ring of surrounding enamel [34]. This idea certainly merits further research, but whilst we wait it is worth noting that the "compression dome prep" is remarkably like the metal onlay prep shown in Fig. 20.19c, only with a slightly wider chamfered margin.

20.4.3.1 Three Quarter Crown

With full-coverage crowns, tooth preparation may weaken a cusp critical to retaining the core. Traditionally, the favoured way of preserving an aesthetic and sufficiently robust cusp was a conventionally cemented ¾ crown, often in combination with a pinned restorative core build-up.

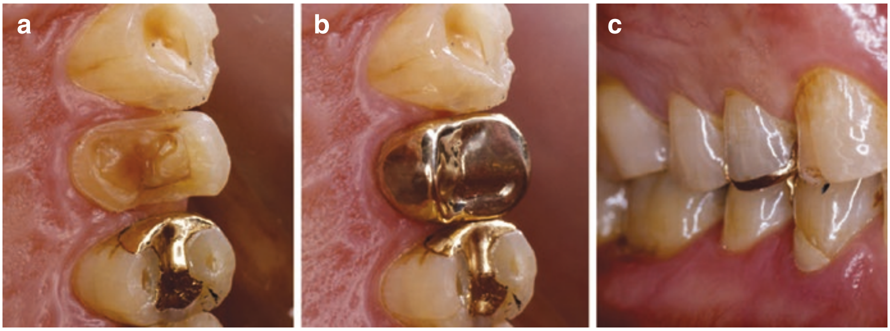

Fig. 20.22 A 64-year-old bruxist with tooth 14 palatal cusp fractured; the tooth was previously restored with an MOD gold inlay. The buccal cusp has been reduced by 1 mm and a chamfered finishing line prepared at the base of the fractured cusp and gingivally with hollow-ground bevels on the buccal proximal walls (**a**). The cast gold ¾ crown luted adhesively (**b**). Viewed buccally, a minimal display of gold at the cusp tip (**c**). This approach avoids the need for a core build-up and retention grooves. The restoration continues in service after 15 years. An etchable ceramic restoration would need a similar preparation except the buccal cusp would have been reduced a further 1 mm

The preparation for a ¾ crown demands a high level of skill to remove sufficient but not excessive tooth tissue and to accurately orientate the proximal retention grooves needed for retention and resistance. Dentists who enjoy a technical challenge or are faced by the need to replace a conventionally luted ¾ crown are best advised to visit a classic text [35].

Nowadays, we prescribe very few conventional ¾ crowns, but we still recognise the need to retain sound cusps. With adhesive dentistry, a core build-up is often unnecessary, so an onlay-type restoration can be resin bonded directly to tooth tissue with occlusal reduction of the remaining cusp to give sufficient occlusal clearance. The amount of cuspal reduction and the horizontal depth of the finish line will depend on the type of material—etchable ceramic, metal (see Fig. 20.22) or ceramo-metal.

20.5 The Preparation Appointment

Most experienced dentists will have developed an efficient routine to navigate this busy appointment. For students and trainees, it often helps to have a check list (see Box 20.3). Of course, the case must be properly planned before the tooth preparation appointment (see Chap. 18).

Not surprisingly, students new to tooth preparation often find themselves running out of time, so we advise making the provisional restoration (see Chap. 23) before recording the working impression (Chap. 22). If necessary, the impression may then be delayed until the following appointment.

Box 20.3: Check List for the Preparation Appointment

1. Before the appointment gather study models, preparation matrices and provisional restoration matrices.
2. Ensure consent is given for the procedure and any photographs to be taken.
3. Record shade using indirect daylight or a daylight-corrected lamp.
4. Administer local anaesthetic.
5. Record alginate or silicone putty impression of tooth to be prepared (for provisional restoration matrix). In addition, record impression of the opposing dentition.
6. Prepare tooth/teeth.
7. Decide on gingival retraction technique and implement if retraction needed (Chap. 21).
8. If the preparation finish line is obscured by the gingiva, pack retraction cord; the cord can be left in place if providing sufficient retraction.
9. Use matrix to form provisional restoration.
10. Repack retraction cord(s) and then trim the outer margins of the provisional restoration.
11. Wash and remove cord. Wash again and dry—without desiccating the tooth.
12. Record the working impression, check for accuracy, and retake if necessary. *Check no cord remains in the gingival sulcus*.
13. Record jaw registration if needed (e.g. with silicone mousse or wax) and confirm which opposing pairs of teeth have shim stock contacts. NB jaw registration may need to be delayed until the following appointment if a wax block is to be used. The block must be made on the working cast.
14. Record facebow, if needed, to mount working casts on a semi-adjustable articulator.
15. Cement the provisional restoration(s) and *clean away all excess temporary cement*.
16. Provide post-operative instructions.

Conclusion

Preparations for most types of full-coverage crown are destructive of tooth tissue and may affect pulp vitality. Other less destructive extra-coronal restorations are available, many of which are adhesively bonded. Ultimately, the choice of restoration must address a patient's functional and aesthetic needs. So, dentists should be familiar with tooth preparation for all types of restorations and which suit the materials from which they are made. From a technical perspective, a skilfully executed tooth preparation which conserves tooth tissue is fundamental to a predictable outcome. So too are an accurate impression, well-fitting provisional restoration and effective cementation. These aspects are considered next.

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Gingival Management and Retraction

21

Jenna Trainor, Andrew Keeling, and Robert Wassell

21.1 Learning Points

This chapter will emphasise the need to:

- Ensure the gingivae are healthy and have had time to stabilise following periodontal treatment or surgery
- Discuss with patients the possibility that subgingival margins may eventually become visible
- Be aware of the medicaments and techniques used for gingival retraction in conjunction with gingival retraction cords and gingival retraction pastes
- Use a gentle technique for retraction cord placement to avoid unnecessary gingival recession
- Consider using electrosurgery or laser surgery to help with more difficult cases
- Delay retaking impressions for at least 3 weeks where gingival bleeding is an issue.

Before recording an accurate impression, we need good gingival management, particularly with preparation finishing lines either at the gingival margin (equigingival) or subgingival. Indeed, studies report critical impression defects at the finish line in over a third of cases [1, 2]. These defects reflect inadequate gingival management in the presence of inflammation, bleeding, subgingival finish lines, and

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gingival overgrowth. So, gingival management is not only about retraction techniques for subgingival margins but needs to be thought about well in advance of the impression appointment to control gingival inflammation.

We will use the term “retraction” to refer to “downward and outward movement of the free gingival margin that is caused by the retraction material and the technique used” [3]. Some authors use retraction and “displacement” synonymously [4], but other authors have defined displacement differently [3, 5]. To avoid confusion, we will avoid the term “displacement”.

21.2 Gingival Inflammation and Bleeding Tissue

The golden rule is to *start healthy*. As outlined in Chap. 4, periodontal treatment should be completed and stabilised before recording impressions for definitive restorations, otherwise bleeding may displace impression material and cause inaccuracies. Resolution of gingival inflammation should also improve stability of the gingival margin, although in some patients, recession may eventually expose a subgingival restoration margin (see Chaps. 10 and 20), and this should be made clear when obtaining consent to treatment. If from the outset, patients understand the health benefits of a supra-gingival margin, they may be less agitated if a restoration margin becomes visible.

To ensure stability of the gingival margin following periodontal or crown lengthening surgery (see Chap. 10) in an aesthetically critical region, we recommend waiting 3–6 months before recording impressions for definitive restorations.

Any pre-existing restorations with defective margins are best replaced with well-contoured core build-ups or provisional restorations. Once a defective restoration is removed, always check for subgingival calculus which can be probed easily and removed from otherwise inaccessible proximal root surfaces. Where gingival overgrowth hampers construction of well-fitting provisional restorations, consider localised surgical methods to improve gingival contour (see Chaps. 10 and 23).

If bleeding is not controlled by gingival retraction techniques (see below), dentists often abandon the impression and reappoint the patient in 3 or 4 weeks to allow healing. To improve resolution of gingival inflammation, an antimicrobial rinse (e.g. chlorhexidine gluconate 0.12%) for 2 weeks is particularly helpful. At the next appointment, it is normally possible to record the impression or remake any still defective provisional restorations.

21.3 Subgingival Finish Line

Preparation finish lines that are supra-gingival can be recorded without any gingival retraction. However, subgingival finish lines and many equi-gingival finish lines require some form of gingival retraction, and the more subgingival, the more difficult they are to record. Marginal gingival tissue can be retracted in various ways: Mechanical, chemical, or surgical [6]. The mechanical and chemical approaches are summarised in Table 21.1, and the surgical approaches are summarised in Table 21.2. Whilst these techniques can all be used in isolation, they are sometimes combined—particularly for more difficult cases.

Table 21.1 Gingival retraction using cord, solutions, and pastes to capture subgingival finish lines

	Description	Indication	Comments	Hazards
Retraction cord	Standard method of retraction using twisted or knitted cord	Equi-gingival finish lines (single-cord technique) or subgingival finish lines (two-cord technique)	Two-cord technique advised where the first cord if left in sulcus during impression recording to improve definition. Wetting the second cord before removal helps control haemorrhage even when solutions used (see below). Occasionally, the first cord provides sufficient retraction, and a second cord is not needed. No remaining cord should protrude from the sulcus, whilst the impression is recorded	Trauma and recession from excessive packing pressure and length of time in the sulcus Contamination by gloves may prevent impression of the gingival sulcus from setting Florid inflammation if first cord not removed
Medicament solutions	Used to soak retraction cord prior to insertion and may be applied topically to stop gingival bleeding Solutions include: Epinephrine (1:1000 conc.) Aluminium chloride Alum (e.g. aluminium potassium sulphate) Ferric sulphate (15.5% w/v)	Best used routinely with retraction cords as plain cords result in bleeding on removal in >50% cases [12]. Impregnated cords twice as effective if first soaked in solution [13]. With ferric sulphate the initially soaked cord can be removed from the sulcus and further solution applied with a special applicator to help stabilise the coagulum	Alum and epinephrine similarly haemostatic [13], retractive [14] and both give minimal postoperative inflammation [15]. Clinically, ferric sulphate appears a better haemostatic agent but needs to be rubbed firmly onto the bleeding gingival sulcus. Solutions must be washed off before impression recorded	Concerns over "epinephrine syndrome" (raised heart rate, respiratory rate, and blood pressure) when epinephrine solution used on lacerated gums in susceptible patients [16]. Concentrated solutions of alum can cause severe inflammation and tissue necrosis [17]. Solutions will concentrate if top left off bottle Ferric sulphate can stain the gums yellow-brown for a few days

(continued)

Table 21.1 (continued)

	Description	Indication	Comments	Hazards
Medicament pastes	Consist of viscous pastes (e.g. kaolin or addition silicone foam) injected into the sulcus Active ingredient: Aluminium chloride (Astringent™, 3 M ESPE 15%) (Expasyl™, Kerr 10–30%)	Used as an alternative to cords and solutions for routine cases. The amount of retraction and subsequent sulcus closure make it suitable for single rather than multiple preparations [18]. Needs to be used in combination with cord for more difficult cases as cord gives more effective retraction [18]	Claimed by manufacturers to be faster than cord. Less likely than cord to cause bleeding during placement and removal [19]. Like other medicaments can interfere with setting of addition silicones and polyethers and must be washed off completely	Contraindicated in patients with periodontal disease, open furcations or exposed bone

Table 21.2 Surgical methods to augment gingival retraction

	Description	Indication	Comments	Hazards
Electrosurgery	Controlled tissue destruction by rapid heating from radio frequency (>1.0 MHz) electrical current passing from wire tip (high current density) as a spark into the tissues. The current then travels through patient's body into large area collecting electrode (low-current density)	Uses: 1. Widen gingival sulcus (troughing) before cord placed. *N.B. avoid using on thin gingiva as unwanted recession can result* 2. Gingivectomy for overgrown tissue or for crown lengthening 3. Coagulation (ball electrode) but produces most tissue destruction and slow healing	Current types: Troughing—"cut/coag" setting (fully rectified, filtered) Gingevectomy—"cut" setting (fully rectified) Coagulation—"coag" setting (unrectified, damped)	Do not use in patients with mastoid implant hearing aids or with relative analgesia (burn risk from O_2). Contraindicated in patients with cardiac pacemakers [11]. Modern pacemakers are relatively well shielded [20] but still good practice to evacuate pacemaker patients from adjacent cubicles

(continued)

Table 21.2 (continued)

	Description	Indication	Comments	Hazards
Soft tissue laser	Neodymium-doped yttrium aluminium garnet laser: (Nd:YAG) [9] Diode laser: aluminium gallium arsenide (AlGaAs)	As for 1 and 2 above	Cuts a trough ranging from 0.25 to 0.65 mm Generally considered to be quicker than cord and lower collateral heat generation than electrosurgery, with good haemostasis and patient comfort [21]	Lack of tactile feedback Possible pain, postoperative inflammation, and recession of the tissue [17]
Rotary curettage (Gingettage)	Use of chamfered diamond bur to remove epithelial tissue within healthy sulcus to expose subgingival finish line during its preparation [22]	For subgingival preparations in healthy gingivae. Gingival sulcus depth must not exceed 3 mm, and there should be adequate keratinised gingivae [23]	Palatal tissues respond better than thinner buccal tissues [24].Not suitable technique if a periodontal probe in the sulcus can be seen through the gingiva	A slight deepening of the sulcus may result [24] Poor tactile sensation during instrumentation gives high potential for overextension and damage

21.3.1 Retraction Cords and Medicaments

The most commonly practiced approach is the one- or two-cord technique using an astringent solution (e.g. ferric sulphate solution) [7]. Cords come in a variety of presentations, but the main difference is that some cords already have impregnated medicaments, whist others are plain. Cords may be twisted, braded, or knitted. The choice is down to operator preference; we prefer knitted cords, acknowledging they pack down to a much smaller volume so tend look wider in diameter than needed.

Cords (plain or impregnated) are often dipped into a medicament solution before placement and the excess blotted off. A recent survey in the USA and Canada [4] of 696 dentists reports 92% use retraction cord with the majority using impregnated cords. Although, epinephrine solution is now used much less because of concerns of causing cardiac problems in susceptible patients, other medicament solutions may cause local problems if not handled properly (see Table 21.1).

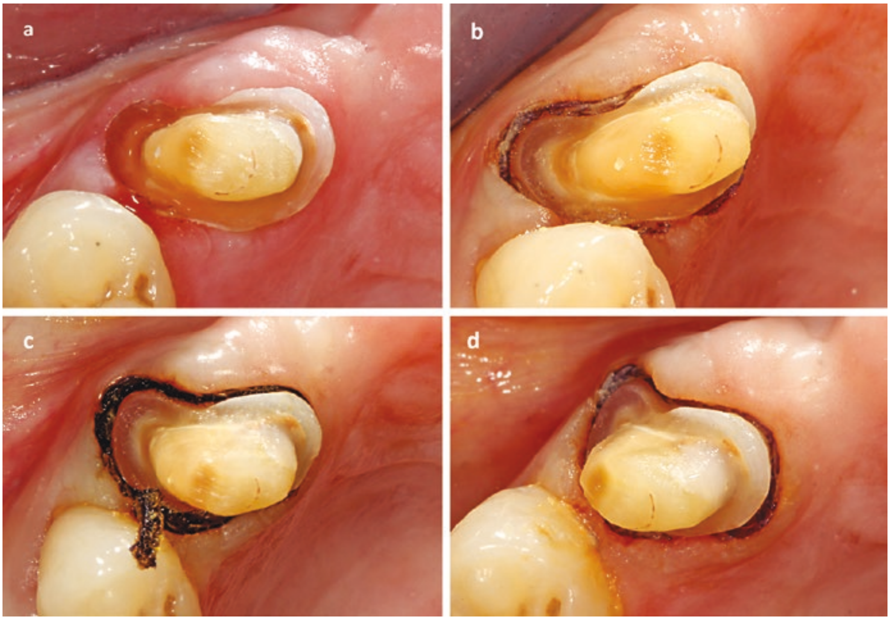

Fig. 21.1 Two-cord technique. The finishing line is partly obscured by gingival tissue (**a**) A small diameter cord is packed into the sulcus with no overlap (**b**) A second larger diameter cord is packed on top of the first one leaving a tag for removal (**c**) After rinsing away the ferric sulphate solution, the second cord is removed. The first cord is then gently dried and left to maintain gingival retraction (**d**)

The general advice for cord packing is to use a half Hollenback amalgam carver (the edge of the blade rather than the tip) or a proprietary cord packing instrument. Ambidextrous dentists can use a second instrument to help retain the cord already packed. It is best to avoid flat plastic instruments with a thick blade that cannot penetrate the gingival sulcus easily.

To avoid traumatising the gingival attachment, some dentists prefer, where possible, to pack only one cord, but there are times when a two-cord technique (see Fig. 21.1) comes into its own: For example, when bleeding and exudate needs to be controlled or when gingival recoil is likely to displace impression material from the sulcus after removing a single cord. In addition, leaving the first cord in the sulcus whilst the impression is recorded provides a cuff of material below the finish line thick enough to avoid tearing on removal. Very thin cuffs of material are prone to distortion and as a rule of thumb should be >0.15 mm [8].

A complication of any packing technique is subsequent unwanted gingival recession exposing a restoration margin, particularly in the anterior region. Fortunately, for most patients the amount of recession is small (around 0.25 mm after 2 months) and generally not of clinical significance [9], but in susceptible patients a marked recession is sometimes seen in just a few weeks, emphasising the need for gentle

Box 21.1: Gingival Retraction Using Cord with Ferric Sulphate Solution

- Ensure adequate isolation and moisture control—a flanged salivary ejector is needed for impressions of lower posterior teeth.
- Consider need for electrosurgery (either “troughing” or gingivectomy or both) in combination with the one- or two-cord technique. If gingival inflammation needs to be resolved, temporise with well-fitting margins.
- Soak cord in ferric sulphate solution (15.5% w/v) and pack.
- Apply further solution using syringe applicator or pledget of cotton wool (beware—solution tastes foul).
- After 5 min wash cord well and remove carefully so that lining of sulcus is not stripped out causing bleeding.
- Continue to wash prep with atomised spray and dry well, especially the more inaccessible parts of the preparation. The inner aspect of the sulcus will often appear black with stabilised coagulum. Remove any coagulum adhering to tooth preparation or finish line.
- Only start mixing the impression if the gingivae are adequately retracted and dry.
- If bleeding starts, reapply ferric sulphate solution and repack with soaked cord for a further 5–10 min before reattempting impression.

handling of the tissues. With the two-cord technique this risk can also be minimised by selecting a small diameter for the first cord and the next size up for the second cord. Advice on packing technique is covered in Box 21.1. To be effective, leave cords in place for 5 min but not much longer than 10 min to minimise risks (see Table 21.1). The risk of bleeding on cord removal can be reduced by washing beforehand with a water spray and then removing the cord from the sulcus whilst still wet (see Box 21.1). Always check all cords have been removed before dismissing a patient.

21.3.2 Medicament Pastes

These viscous pastes (Table 21.1) which are syringed into the gingival sulcus provide a convenient, non-cord method of gingival retraction. Some rely simply on applying pressure to the area (e.g. with a polysiloxane foam), whilst others contain an astringent (e.g. aluminium chloride). Clinically, they do not offer as wide a range of applications as retraction cord, particularly for subgingival preparations. However, a systematic review has advised their use for equi-gingival finish lines where the tissues are thin and likely to be traumatised by cord placement [10].

21.3.3 Surgical Techniques

Electrosurgery and soft tissue laser are two methods of creating a fine gutter or trough 0.2–0.5 mm wide around a subgingival finish line (Table 21.2). These techniques both remove a thin layer of soft tissue from the inner aspect of the gingival cuff. Rotary curettage also removes tissue from the inside of the cuff but does not create a clearly defined trough beneath the finish line. Inevitably bleeding may occur, particularly with rotary curettage but less so with electrosurgery and laser. So, supplemental use of cords and medicaments is best anticipated.

Electrosurgery is currently more popular than laser; one study reporting 32% of dentists using it compared with 20% using laser [4]. Despite there being some contraindications to using electrosurgery (see Table 21.2), it is remarkably useful but surprising that it has not been adopted by more dentists.

Once mastered, the electrosurgery tip can be directed around sections of the sulcus in a smooth sweeping motion for each cut. Take care not to penetrate more than 1 mm into the sulcus or to return to the cut area for at least 10 s. This is to prevent a damaging heat build-up in the tissues which may cause unwanted recession, particularly in thin gingival tissues.

To avoid soft tissue burns use plastic mirrors/retractors, and check integrity of the electrode tip insulation. Similarly, do not touch against metal restorations which causes unwanted arcing and pulp damage. Be cautious not to cause localised bony necrosis as may occur after touching the electrode against exposed bone or implants or metallic implant abutments. Be aware there is a small risk of causing skin heating if the collecting electrode contacts metal rings, fasteners, buckles, etc. Further technique detail can be found elsewhere [11].

There is some limited review data supporting electrosurgery and laser surgery to assist with gingival retraction. However, comparisons between them are impossible because measurements of the trough and subsequent gingival response were not standardised but clearly need to be for future studies. Nevertheless both techniques, in common with other retraction methods, normally show rapid healing of the gingival sulcus with signs of inflammation unusual beyond 2 weeks [6].

Despite the paucity of trial data, there is no doubt that electrosurgery and lasers, when used with care, are invaluable for dealing with difficult subgingival margins and other tissue retraction issues.

21.4 Other Retraction Issues

21.4.1 Retraction Cord Displacement from the Sulcus

How frustrating when gingival tissue conspires to eject the cord from the sulcus almost immediately after placement. Healthy gingival tissue can sometimes be very tightly bound to the tooth adjacent to preparations. Rather than inflict trauma from brutally packing retraction cord, consider using electrosurgery or a laser to create a trough. This may be sufficient, but if there are issues with haemostasis, a single cord with ferric sulphate solution can then be gently packed. If the gingival tissue biotype is thin, electrosurgery and laser troughing may result in recession. Instead we advise either a small diameter cord packed carefully with a sustained, controlled force or, as already mentioned, the use of a syringed medicament paste.

21.4.2 Localised Gingival Overgrowth

An ingrowth or overgrowth of inflamed gingival tissue is often seen when replacing crowns with open subgingival margins or where a crown with a subgingival margin has been lost. Anyone who has removed a poorly fitting provisional crown will know tissue invasion does not take long where a margin is subgingival (see Chap. 23). Simply using retraction cord to displace inflamed gingival overgrowth often results in frustration and failure. A better approach is to remove excess tissue with either electrosurgery or laser, and then create a sulcular trough into which a retraction cord may be placed (Fig. 21.2). If bleeding still prevents taking an impression, the finishing line is usually sufficiently clear to make a well-fitting provisional restoration Fig. 21.3.

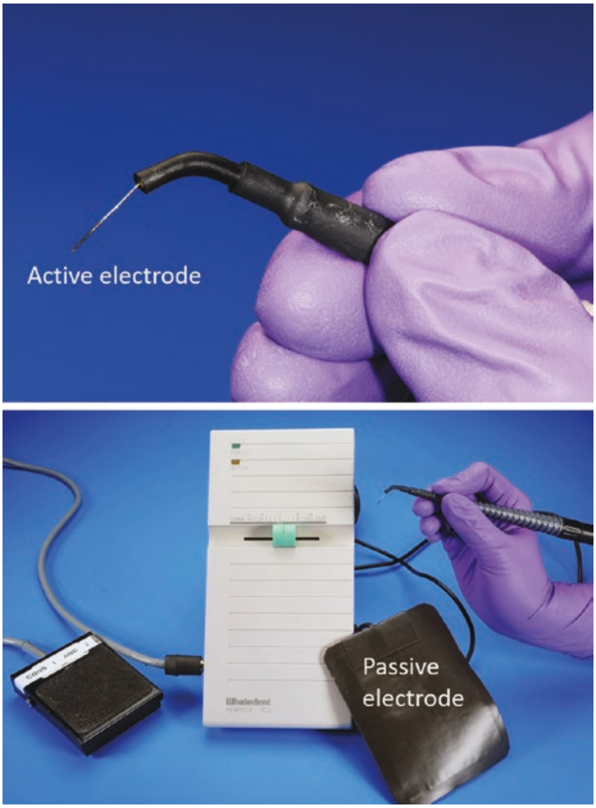

Fig. 21.2 An electrosurgery machine with a fine wire active electrode and the "passive" collecting electrode which can be placed under the patient's shoulder. The green slider controls the current: Either cutting (for troughing) or coagulating (occasionally used for haemostasis)

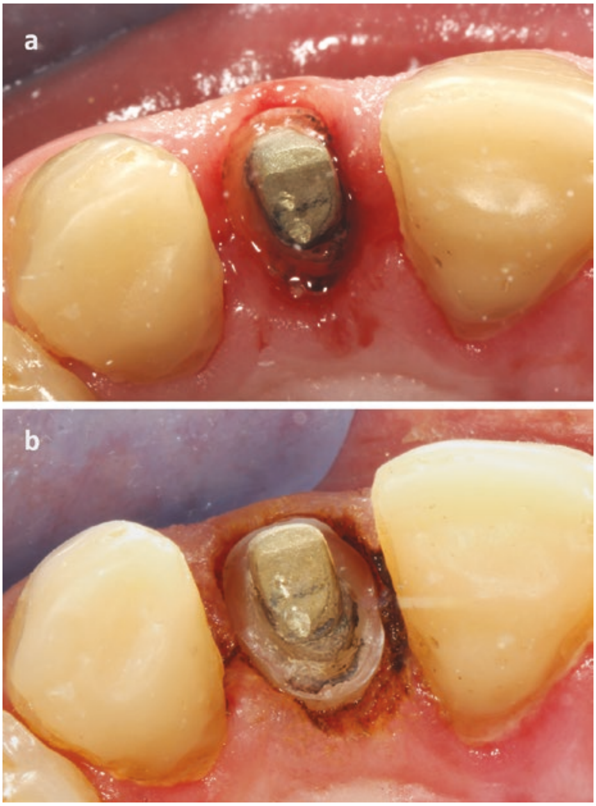

Fig. 21.3 Gingival electrosurgery: Overgrown gingivae requiring removal prior to impression (**a**) Tissue excision on palatal and mesial aspects followed by the creation of a small trough for the retraction cord to sit (**b**) Haemostasis achieved with ferric sulphate solution

Conclusion

Successful restorative dentistry requires good gingival management both prior and during the preparation appointment. Elimination of existing inflammation and allowing the gingivae time to stabilise helps create a frame for fine restorations, particularly where equi-gingival or subgingival margins are planned. Dentists should be familiar with a range of gingival retraction techniques, including their indications, contraindications, and potential hazards. Most dentists still use retraction cords and medicament solutions for gingival retraction but may wish to consider using electrosurgery or laser for more difficult cases. Sufficient time should be allocated during the impression appointment to allow for a gentle cord placement technique, adequate retraction, and complete haemostasis. If bleeding prevents an impression being recorded, make a further appointment in 3–4 weeks to allow for gingival healing and try again.

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Impression Materials and Techniques

22

Jenna Trainor, Andrew Keeling, and Robert Wassell

22.1 Learning Points

This chapter will emphasise the need to:

- Ensure your technician can feedback on defective impressions
- Choose an appropriate impression material based on an understanding of its properties
- Wash and disinfect impressions before sending them to the laboratory
- Identify impression defects and have strategies to remedy them
- Differentiate between impression techniques for cement- and screw-retained implant crowns
- Decide on what technical basis to buy a digital impression scanner.

22.2 Introduction

'First impressions count', thought the fourth-year student waiting endlessly for an impression to set. Then heartsink, after a cursory glance the teacher reminded him 'Inaccurate impressions lead to poorly fitting restorations'. That's how it is at dental school. In practice, it is up to you.

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Even when impressions appear satisfactory, it may only be after casting up that defects are discovered [1, 2]. The technician is then faced with a dilemma—either press on and make a possibly defective restoration or feed the problem back to the prescribing dentist. Understandably, technicians anticipating an angry response may well take the path of least resistance. So, we recommend nurturing a good working relationship with laboratories allowing problems to be fed back without fear of reproof. Where a repeat impression is necessary, dentists shouldn't be embarrassed to recall patients, it being in everyone's interest to have a well-fitting restoration. Despite the occasional inconvenience, most patients appreciate there being a system of quality control.

But, if your first impression is accurate, life is easier for everyone. This chapter is designed to give an understanding of the materials and techniques available. We will first briefly cover material history and classification. Secondly, we look in more detail at the materials available focusing first on addition silicones—considered by many to be the gold standard for producing indirect restorations. Before being sent to the lab, impressions need disinfecting, and this deserves special mention. Thirdly, we will troubleshoot impression errors and consider strategies for recording multiple preparations and impressions for implant-retained restorations. Finally, we discuss an important new development—digital impressions.

22.3 History and Classification

Many students are surprised that rigid dental plaster was used in the early 1800s to record tooth impressions [3]. These had to be fragmented intra-orally to remove them and then painstakingly stuck together with sticky wax before casting up.

Not until the 1930s were impression materials available with reasonable elastic properties. These were the hydrocolloids, agar, which is a reversible hydrocolloid (i.e. it goes from gel to sol on heating and vice versa on cooling) and alginates, which are irreversible hydrocolloids (once set the process cannot be reversed). Agar was used for many years for crown and bridgework—and a few specialist practices still use it. Although quite accurate and with better detail reproduction than alginates, agar impressions are not ideal. They need heating in expensive water baths and water-cooled impression trays. They also need to be poured up almost immediately to avoid distortion due to syneresis (loss of water). Alginates on the other hand continue to be used widely, particularly for study models and opposing casts for indirect restoration production. Ingenious attempts have been made to combine agar and alginate [4, 5]. The more viscous alginate is placed in the tray with the agar injected around the preparation, but this has not proven particularly popular.

In the early 1950s, synthetic elastomers were introduced to dentistry from polysulphide sealants in the building industry. Then in the mid-1950s came the condensation (type I) silicones. The dimensional stability of these materials was better than the hydrocolloids, but they still needed pouring up within a few hours because of the release of condensation products (water from polysulphides and alcohol from type I silicones) resulting in impression shrinkage. Two approaches were taken to reduce the effects of impression material shrinkage:

1. Special trays to reduce the bulk of material (e.g. with polysulphides)
2. Putties incorporating a high concentration of filler particles. The putty filled the tray, whilst a lightly filled wash was syringed around preparations to record detail (e.g. with type 1 silicones). An unintended consequence of using putties was tray wall recoil affecting impression accuracy. This important factor is considered later in the chapter.

In 1965 came polyethers. These were developed specifically as a dental elastomeric material with no condensation products on setting. However, polyethers are relatively hydrophilic which is good for wetting the dental tissues, but when stored wet causes the material to swell slightly due to imbibition of water.

The addition of (type II) silicones followed in 1975, and in the last 10 years, the most recent innovation is a hybrid of polyether and addition silicone.

A classification of hydrocolloid and elastomeric impression materials is shown in Fig. 22.1.

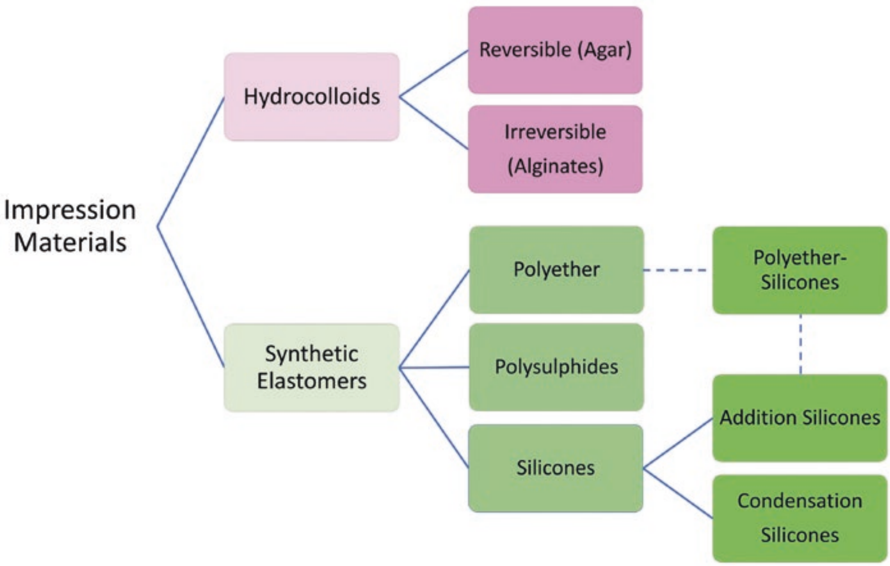

Fig. 22.1 Classification of impression materials showing the five types of synthetic elastomer (dark green) and two types of hydrocolloid (dark pink). The polyether-silicones are a hybrid of the two respective materials

22.4 Elastomeric Impression Materials for Indirect Restorations

22.4.1 Addition Silicones (Polyvinyl Siloxanes)

Many dentists wanting to record accurate, detailed, and dimensionally stable impressions choose a polyvinyl siloxane (PVS). When the two pastes are mixed, a platinum catalyst effects an addition reaction between the silane and vinyl groups, producing a cross-linked silicone rubber. Table 22.1 summarises the advantages and disadvantages of addition silicones.

Silicones are inherently hydrophobic, but many PVS products are now much less so than previously. The better wetting reduces air entrapment during syringing, and casts are less likely to be blighted by air bubbles. This happily results in reduced restoration remakes [6]. Manufacturers are understandably coy about their hydrophilic material formulations, but medical grade surfactants or hydrophilic copolymers are two possibilities. These do not appear to have a detrimental effect on the material's physical properties [7, 8]. However, it is best not to immerse impressions for long periods in water or disinfection solutions as the light-bodied wash may swell slightly [9].

Another development has been the introduction of 'addition silicone alginate substitutes'. These have better dimensional stability than alginate and may be an

Table 22.1 Advantages and disadvantages of addition silicones

	Advantages	Disadvantages
Accuracy	• Less hydrophobic than previously • Low polymerisation shrinkage on setting • Excellent surface detail reproduction • Minimal permanent deformation on removal from undercuts in the mouth—generally it tears before it distorts • Excellent dimensional stability as no condensation by-products (e.g. water or alcohol)—a boon if there is a delay in pouring up • Minimal effects of water absorption	• Setting inhibited by some, but not all, latex rubber gloves • Claimed setting inhibition for haemostatic agents, but not a consistent finding [43] • Putties may deform impression tray on seating which recoils on removal causing impression distortion • Occasionally difficult to remove impression from the mouth and from casts without breaking the stone
Handling	• Wide range of viscosities (putty, heavy, medium, light) and monophase (the same material is used for the tray and for syringing) • Available in regular set for multiple preps and fast set (for single prep) • Auto-mix formulation avoids air bubble entrapment seen with hand spatulation	• Sets too quickly if material stored before use in a very warm environment • Storing material in refrigerator may result in water condensing on impression surface preventing light-bodied wash bonding to heavy-body
Patient-friendly	• Biocompatible (not toxic or allergenic) • No unpleasant taste	
Cost		• Expensive (uses a chloroplatinic acid catalyst)

economic alternative when alginates cannot be poured up in time. However, they are not sufficiently accurate for indirect restoration construction and as described later can be affected by disinfection.

22.4.1.1 Vinyl-Polyether Hybrids

The newest class of impression material is the vinyl-polyether hybrids. This new class of impression material attempts to combine the best properties from addition silicone and polyether impression materials. They are supplied as putty, heavy, medium, and wash materials. An additional benefit is that they do not have the bitter taste of polyether materials. These materials offer a blend of hydrophilicity and hydrophobicity which may improve impression making but needs to be supported by clinical studies. Lab studies suggest that they are similarly accurate to PVS in the short-term but less dimensionally stable in the long-term when stored in disinfectant [10].

22.4.2 Polysulphides, Type I Silicones, and Polyethers

These three materials are still commercially available. Their advantages and disadvantages are summarised in Table 22.2.

Table 22.2 Advantages and disadvantages of polysulphides, condensation silicones and polyethers

	Advantages	Disadvantages
Polysulphides	• Variety of viscosities • Long working time (good for multiple preps but slow for single preps) • Flexible so relatively easy to remove from mouth and casts • Good tear resistance • Long shelf life	• Reaction by-product (water) • High polymerisation shrinkage • Dimensionally unstable • Sticky to handle • Long setting time • Toxic if trapped subgingivally • Unpleasant smell and taste • Needs a special tray with uniform 4 mm spacing and must be poured up within 48 h [44]
Condensation silicones	• Easy handling • Variety of viscosities • Good elastic recovery • Good tear resistance • Good surface detail	• Reaction by-product (alcohol) dimensionally unstable unless poured up within 6 h [44]
Polyethers	• Only one viscosity, but whilst syringing the material undergoes 'shear thinning' allowing it to flow easily • Accurate – Dimensionally stable – Good tear resistance	• Bitter taste • Occasional allergies • Rapid setting time • Stiff when set, so often difficult to remove from mouth and casts • Imbibes water, so avoid storing in wet bag or leaving in disinfectant for too long

22.4.2.1 Polysulphides

There remains a niche market for practitioners who like this material's handling properties, particularly for recording multiple preparations due to its long working time and excellent tear resistance. Patients may be less enthusiastic about its long setting time and bad taste but unlikely to be aware of the possibility of toxicity from the lead oxide catalyst. This is unlikely to be an issue unless some of the material is retained (e.g. in a molar furcation or deep periodontal pocket).

To optimise elastic recovery, the impression should be removed with one swift single pull—taking care first to break the suction and then avoid levering the tray across the tips of the anterior teeth (see later). This method of removal should be adopted for all impression materials.

22.4.2.2 Condensation Silicones

Technicians frequently use condensation silicone putty for making matrices and other lab procedures for which it is entirely fit for purpose. Dentists may prefer condensation silicones to addition silicones for economic reasons, but should not expect the same level of accuracy, particularly if there is more than a few hours delay in pouring up.

22.4.2.3 Polyethers

Polyethers still command a loyal following despite many of its characteristics being available with modern PVS materials. It is relatively hydrophilic and records preparation finishing lines well, but not necessarily any better than the 'hydrophilic' PVS materials. When recording only a single tooth preparation, its short working time and setting time are advantageous but comparable with PVS fast set options. Once set, the material is quite rigid which combined with its hydrophilicity sometimes makes it difficult to remove from the mouth or after pouring up may snap teeth from casts. Nevertheless, this rigidity has made polyethers popular for pickup impressions of implant impression copings (discussed later). Again, PVS materials can be used for the same purpose with comparative accuracy [11].

A fascinating property of polyether is 'shear thinning'. The mixed material is so viscous that it doesn't slump, but when forced through a syringe nozzle, the apparent viscosity decreases substantially. These characteristics allow the same material to be used in the tray and for syringing around preparations.

22.4.3 Disinfection of Impression Materials

Inevitably, on removal from the mouth, impressions will be contaminated with saliva and often with blood. So, unless an effective infection control protocol is followed, surgery and laboratory staff are at risk of infection, particularly from patients with blood-borne viruses.

Visible contamination needs rinsing with water before disinfection solutions are used. Common methods of disinfecting are by spraying or by immersion. A UK survey found practices use a wide range of disinfectant solutions at different dilutions. Disappointingly almost 60% did not rinse with water before disinfection, perhaps explaining why 95% of dental technicians had received impressions contaminated with blood and why 50% of dental technicians disinfected all impressions received [12]. The British Dental Association provides guidelines on decontamination and disinfection of dental impressions in their advice sheet A12 [13].

Impression materials can generally be disinfected without affecting accuracy, but disinfection may cause softening and loss of surface detail on stone casts poured up from alginates and addition silicone alginate substitutes [14]. Impressions should therefore not be soaked for longer than recommended by manufacturers, particularly for alginates and alginate substitutes.

22.5 Problem Solving

At Newcastle University School of Dental Sciences, impressions are checked before sending to the lab and after pouring up casts. Alas, a cast sometimes reveals an impression fatally flawed requiring the patient to be recalled. This process applies to everyone—not even senior staff are exempted. We would similarly encourage dentists to audit their own work alongside the laboratory with peer review providing the best stimulus for improvement.

This section aims to improve impression technique by addressing the following issues:

- Visible flaws
- Invisible flaws
- Problems of recording multiple preparations
- Impressions for implant-retained restorations.

22.5.1 Visible Flaws

22.5.1.1 Finish Lines Not Visible

As mentioned in Chap. 21, subgingival and epi-gingival margins are often associated with impression defects [1, 2]. Healthy gingivae are therefore a prerequisite for recording reliable impressions. So too are the various gingival retraction techniques, including electrosurgery or laser tissue troughing for more difficult cases. It is worth re-emphasising that if uncontrolled, crevicular fluid and haemorrhage will displace impression material resulting in voids and rounded, indistinct finish lines.

22.5.1.2 Air Bubbles, Drags, and Voids

Air bubbles in the impression can form during mixing, tray loading, syringing, or tray seating. Compared with hand spatulation, syringe mixing significantly reduces air bubbles, but may not eliminate them [15]. A hand-held gun or a bench top machine can be used for syringe mixing. Syringe cartridges have two chambers; one containing the base paste and the other the catalyst. Prior to placing the mixing nozzle, a small amount of material should be extruded onto a napkin from both chambers to ensure no blockage is present. A partial blockage will make extrusion difficult and detrimentally alter the base catalyst ratio. A complete blockage could cause the cartridge to rupture. Blockages can usually be cleared with a Briault probe.

Syringing impression material requires skill. Air can easily be trapped at the gingival sulcus as the syringe tip circumnavigates a tooth preparation (Fig. 22.2). Air bubbles are also easily trapped occlusally, so dry the occlusal surfaces and syringe material over them immediately before seating the tray.

To obtain a void-free impression, the material must wet the teeth and soft tissues. In addition, the tray must effectively constrain the material to prevent it flowing away from critical areas, thus inducing impression drags commonly seen on the distal aspects of teeth adjacent to edentulous spaces and in undercut regions. The teeth need to be adequately dried with a 3-in-1 syringe, or the relatively hydrophobic elastomer material will be repelled and, much like a lorry on a wet motorway, aquaplane away from the tooth.

An all too familiar scenario is repeating an impression only to find that an offending void or drag has reappeared in the same place. The cause is usually a poorly adapted tray. Your options are either to adapt the tray with a rigid material (e.g. compound) to give a more consistent spacing in the critical area or have a special tray constructed by the lab. Special trays are best avoided for putty-wash impressions, as there is a significant risk of the rigid set impression locking into the undercuts and the tray having to be cut free from the patient's mouth.

Another cause for a void is premature syringing of impression material intra-orally, prior to seating the tray. The warmth of the mouth accelerates the set of the syringed material, resulting in a poor bond between it and the impression material in the tray, giving a characteristic appearance of a fissure at their interface. This appearance also occurs if the syringed material is contaminated with saliva before the tray is seated. The skilful use of cotton wool rolls, saliva ejector, and high-volume aspiration is critical to effective moisture control. Another tip is to wait until the tray is nearly fully loaded before syringing light-body around the preparations. With the right timing, your nurse will be handing over the loaded tray as you complete syringing.

Fig. 22.2 Syringing light-bodied PVS. Start in the least accessible area and syringe through proximally. Follow the margin but to avoid incorporating air bubbles make sure the tip is kept in the extruded material and not removed from the tooth until syringing is complete

Whilst air blows, voids, and drags are of little consequence if they occur in non-critical areas, they can ruin an impression when they occur on tooth preparations. However, a common problem is to focus on the preparation and ignore the recording of the teeth further away. Dentists focussing solely on having "captured the margin" may forget to check (or ignore) an error on the occlusal surface of a distant tooth, which will probably lead to a high crown being fabricated. Technicians may also struggle to provide an aesthetic restoration if a large air blow obliterates adjacent teeth or soft tissues.

It may be tempting to correct marginal air blows and voids with a little localised reline of light-bodied material, but this is not good practice; seating pressures can result in impression recoil and significant distortion [16]. Moreover, the addition may bond poorly and subsequently peel away. Without question—if an impression is unsatisfactory—it should be retaken.

22.5.1.3 Unset Impression Material

This problem usually becomes apparent as a tell-tale smear of unset material on the surface of the stone die and surrounding cast. In addition, the affected cast often has a characteristic granular appearance. Alternatively, the putty in a putty-wash impression may refuse to set. The most likely cause of both these problems is contamination of the impression by ingredients of latex rubber gloves, which poison the chloroplatinic acid catalyst of addition silicones [17, 18]. Not all brands of latex gloves are responsible, and the simple expedients are to change brands or to use non-latex gloves (e.g. polyethylene) for impression procedures [19]. When the stringy variety of retraction cord is used, twisting it tight with gloved fingers also has the potential to contaminate and prevent impression setting [20]. This is less a problem with knitted or woven cords, which should not be twisted prior to insertion. Perhaps surprisingly, retraction solutions have not been shown to effect impression setting significantly [20].

22.5.2 Invisible Flaws

22.5.2.1 Tray and Impression Recoil with Putty-Wash Techniques

The take-home message here is that despite their popularity, putty-wash impressions in non-rigid trays can result in undersized dies from tray wall recoil or impression material recoil or both. The issue only shows itself when a restoration from a seemingly perfect impression fails to seat properly.

There are essentially three ways of recording a putty-wash impression, and all of them are more prone to problems:

1. One-stage impression—putty and wash are recorded simultaneously
2. Two-stage unspaced impression—putty is recorded first and after setting relined with a thin layer of wash

3. Two-stage spaced impression—as for 2 except a space for the wash is made by:
   - Placing a polythene spacer over the teeth prior to making the putty impression
   - Recording the putty impression prior to tooth preparation
   - Gouging away the set putty and providing escape channels for the wash.

A putty impression requires a relatively heavy seating force which can deflect the tray walls outwards, particularly towards the posterior part of the tray which is structurally less rigid. On removal of the impression, the tray walls recoil resulting in an impression space that is narrower bucco-lingually. Similarly, the seating forces can develop residual stresses within the setting impression material. On removing the impression, the material rebounds and again causes distortion not obvious to visual inspection [21]. This problem often occurs with one-stage impressions recorded in plastic stock trays but can be minimised with more rigid metal trays [21–24].

Even the two-stage technique is not immune to distortion which may occur as follows:

- Unspaced: hydraulic pressures can be generated during the seating of the wash impression causing deformation and subsequent putty recoil on removal [25]. This can even occur with rigid trays. It may be reduced but not necessarily eliminated by spacing
- The putty impression is not reseated correctly causing a stepped occlusal surface of the cast which may result in a restoration requiring excessive occlusal adjustment.

In summary, the most reliable way of recording a putty-wash impression is to use a one-stage technique with addition silicone in a rigid metal tray. Plastic stock trays are convenient but are best used with heavy-light-bodied materials rather than run high risks of distortion with putty-wash impressions [23, 24]. Special trays are only essential for heavy-light-bodied PVS impressions where stock trays are of poor fit.

22.5.2.2 Detachment of Impression from Tray

When an impression detaches from its tray during removal from the mouth, the result is often a grossly distorted cast. However, detachment may often go unnoticed, so is best prevented by choosing a tray with adequate perforations and proper use of adhesive [26]. Painting the tray with adhesive immediately before recording an impression is not a good idea. Much better to select the tray and apply adhesive *before* preparing the tooth which gives time for adhesive solvent to evaporate and for good bond strength to develop [27]. This advice applies to all impression materials. Alginates are quite easily debonded from the tray, so it is good practice (as detailed in Chap. 9) to cut away excess alginate with a scalpel from the tray heels to fully inspect this vulnerable area. The excess should be trimmed before putting the impression down, or the impression may distort.

Elastomeric impressions may need to be poured up more than once, particularly if critical air blows blight the stone cast and die. Any repour will be grossly inaccurate if the impression material has lifted away from the tray because of the lack of effective adhesive [28].

Where a special tray is made using a cast with a wax spacer, the wax must not contact the tray acrylic; otherwise it will melt during polymerisation of the tray and cause contamination which reduces adhesive's bond strength. Technicians may need to be advised to place a layer of foil over the surface of the wax before forming the tray [27]. Furthermore, a self-cured acrylic tray should be made at least a day in advance to allow for its polymerisation contraction to complete.

22.5.2.3 Permanent Deformation

Withdrawal from an undercut will test an impression material's elastic recovery. As already mentioned the addition silicones have good resistance to permanent deformation; however there are situations where an impression can become deformed and the small but significant deformation is unlikely to be detected. In this respect, gingival embrasure spaces cause difficulty in two situations. Firstly, significant gingival recession with 'black triangles' from the loss of interproximal papilla will lock in set impression materials. The impression material will either be torn on removal from mouth, or deformed, or both. This problem is best dealt by blocking out embrasure spaces with soft red wax or a proprietary blocking material. By painting the tooth surface with a thin layer of glass ionomer varnish, the wax can be made to stick reliably. Secondly, where a preparation finish line has significant triangular interproximal space below it, consider extending the finish line gingivally. The space is thereby opened to allow the impression to be withdrawn without tearing or distortion.

To avoid creating undue strain in the impression material on removal from undercuts, there should be sufficient thickness of material between the teeth and tray walls. With a special tray, this is created by proper spacing (at least two layers of baseplate wax).

Bear in mind the elastic properties of impression materials may not be fully developed at manufacturers' stated setting times. There is a significant improvement in resistance to permanent deformation if addition silicone impressions are left a further minute or two before removal from the mouth [22].

22.5.3 The Problem of Recording Multiple Preparations

It is always distressing when recording multiple preparations if one or two areas of the impression have critical defects. There are several strategies for dealing with the situation:

- Retake the whole impression
- Retake sufficient impressions to ensure that there is an adequate impression available of each preparation. The patient is reappointed for a transfer coping pick up impression [29]. In the interim individual dies are made by copper or

silver plating, remembering that only addition silicones can be plated with either metal. On each die is formed an accurately fitting acrylic transfer coping. At the next appointment, the transfer copings are tried onto the preparations and fit checked. Copings having the same path of insertion are linked together with wire and acrylic so that stability of coping position is ensured within the pickup impression. Alternatively, excrescences of acrylic can be added to each coping to ensure it is retained within the pickup impression. After recording the pickup impression, individual dies can be secured in their copings using sticky wax before the master cast is poured. The technique can also be used with stone dies, but the construction of the acrylic coping may risk the die being abraded. This problem can be overcome by double pouring each die. The coping is made on one die, which is then discarded, and the other die is used for the master cast
- If the planned extra-coronal restorations are to be constructed using CAD/CAM techniques, then the first stage in the laboratory will be to digitally scan the poured casts. Most modern software allows for several such casts to be scanned and merged, taking the best parts of each.

If it is going to be a problem to record multiple preparations on a single impression, this should be considered in advance and planned for. There are few clinical cases that cannot be broken down into smaller more manageable stages—even if this means using provisional restorations to stabilise the occlusion. When it is necessary to record simultaneously more than six teeth in one arch, there is merit in planning to use the transfer coping and pickup impression technique from the outset.

22.6 Impression Techniques for Implants

With implant-retained restorations becoming increasingly popular for tooth replacement, dentists should be aware of how impressions are recorded. As mentioned in Chap. 16, dentists wishing to undertake prosthodontic procedures for implants should attend an appropriate course.

Essentially, there are two main methods of recording an impression for implant crowns depending on whether a crown is to be cemented/luted on an implant abutment or screw retained to the implant head:

- For a cemented crown, the implant abutment (see Chap. 16) simulates a tooth preparation, so routine impression techniques involving cords and pastes (see Chap. 21) are used. Care is needed to avoid pushing these materials too deeply into the gingival sulcus which is less firmly attached than with teeth. If the attachment is disrupted, it may cause problems at cementation (see Chap. 24). A carbon dioxide laser may be used to create a trough around an abutment or implant as the metal reflects it rather than absorbing the energy and heating up. It is best to check with manufacturers before using other types of laser as not all lasers are effective and some are contraindicated. Electrosurgery should not be used where there is a risk of arcing, for example, against a metal abutment [30]

- For screw-retained crowns, an impression is needed of the implant head and surrounding soft tissues. Two techniques are available: the open tray technique and the closed tray technique which are described below.

22.6.1 Open Tray Technique

The open tray is generally regarded as the most accurate impression technique [31]. It uses specially machined impression copings and guide (locating) pins (see Fig. 22.3). To see how it works, look at Fig. 22.4. Here, a patient presented at the healing abutment stage and a special tray, with a window over the fixture area, had been ordered in advance. The impression copings fit the fixture head perfectly and are held by the guide pins which protrude through the tray. After trying in the tray, the window is closed by sealing with pink modelling wax. When seating the impression, the heads of the guide pins perforate the wax allowing easy access for unscrewing after the impression has set. In this way, the pickup impression captures the position of the impression copings and the surrounding tissues. After removing the impression, the dentist attaches metal abutment analogues to the fit surface of the impression copings using the guide pins. The technician then incorporates these analogues in the poured stone cast taking care to avoid any small discrepancies which may lead to a misfitting restoration.

If there are multiple adjacent implants, some dentists prefer to splint impression copings together. First, floss is wound and criss-crossed between abutments and then impregnated with flowable composite. To reduce problems with the composite's polymerisation shrinkage, the splinted links between copings must be sectioned and then rejoined with more composite. Previously, self-cured polymethyl methacrylate pattern material was used, but it undergoes considerable polymerisation shrinkage, and the technique takes much longer than with light-cured

Fig. 22.3 Implant head impressions are recorded using impression copings secured to each implant with a guide pin. Guide pins are available in different lengths to enable access through the impression tray window (see Fig. 22.4)

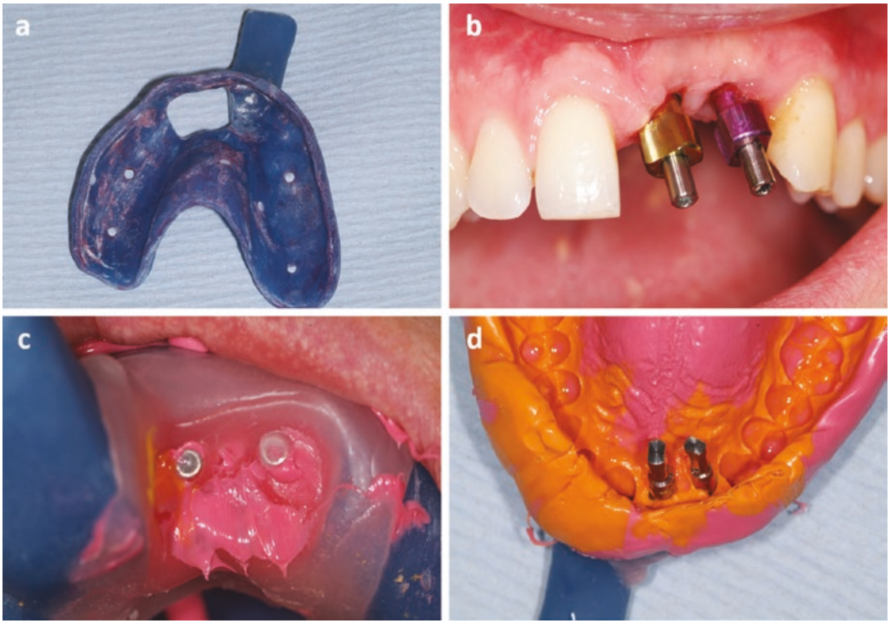

Fig. 22.4 Implant head impression using an open tray: (**a**) Special tray with window cut over the implant area. (**b**) Impression copings held in place by guide pins screwed into each implant. (**c**) Tray seated with PVS impression material. Note the guide pins penetrating the wax sealed over the tray window. (**d**) After the impression sets, the guide pins are unscrewed and the tray removed. Then an abutment analogue is screwed to each coping prior to casting up in stone

composite. A systematic review of implant impression accuracy studies reports that splinting in this way can improve accuracy [31], but clearly, only if carried out competently.

22.6.2 Closed Tray Technique

In cases where intra-oral access is difficult for screwing in guide pins, a closed tray method can be used. Here the impression copings are tapered allowing them to remain on the implant heads after the impression has been removed from the mouth. They are then unscrewed from the implant and reseated in the impression. This approach has an inherent risk of losing accuracy, particularly where implants are angulated [31] such that removing the impression causes strains leading to permanent deformation within the impression material. In addition, there may be errors from imprecisely reseating the copings back into the impression. Consequently, we prefer to use the open tray method where possible.

Some operators use digital scanning systems to record implant impressions, but research in digital impressions has been mainly focused on tooth abutments and preparations.

22.7 Digital Impression Systems

Digital impression systems have been emerging as an alternative to traditional techniques, since their inception in the 1980s [32]. They aim to record the three-dimensional surface morphology of the teeth and surrounding tissues, using non-invasive imaging techniques.

All commercially available devices operate on the principles of optical triangulation, confocal microscopy, optical coherence tomography, or subtle variations thereof [33]. In the future, other non-invasive media, such as high-frequency ultrasound, may add to the range of choice available to the clinician [34].

Early systems were marketed by only a single manufacturer and proved expensive and of limited functionality. Despite this, the clinical outcomes they produced have been shown to be comparable to gold standard alternatives of the time [35, 36]. More recently, rapid improvements in the field of digital imaging (as evidenced by the ubiquitous use of ‘digital’, rather than ‘film’, cameras) have led to a reduction in the cost of intra-oral 3D scanning equipment (Fig. 22.5) and an explosion in the choice available to the clinician. This increase in choice originally came with the problem that data from one manufacturer would be ‘locked’. As mentioned in Chap. 14, this forced the clinician to use that manufacturer’s entire workflow, from impression through to crown manufacture. More recently, several ‘open’ scanners are available, which freely allow access to the scanned data. This is desirable as it allows the clinician the choice of how to use the scan data. Some previously locked systems are becoming open, perhaps in response to this market trend, and it would be prudent to check this prior to purchasing a system.

From a clinical perspective, scanners can be broadly divided into those that require the dentition to be powdered and those that don’t. Titanium dioxide powdering is generally used to reduce undesirable inter-reflections in the imaged scene. In some cases, only a light powdering is used. This is not for reducing reflectivity, but rather to impart a unique surface topology, to aid the 3D reconstruction algorithms. However, there is a definite move towards powder-free scanning, driven by the clinical desire to avoid this stage. Currently there are reports of statistically inferior model quality when using some powder-free systems, dependent upon the material being scanned [36].

A second difference between scanners relates to whether they take static images or video. Generally, video-based systems capture a smaller field of view and stitch together many hundreds of images to create a full impression. Static imaging systems often have larger wand heads but capture more teeth with each image. A full arch impression can be captured with a few tens of images.

When assessing accuracy, practitioners should be aware of the terms ‘trueness’ and ‘precision’. Trueness quantifies how closely a measure lies to the actual value. Precision describes how closely a series of repeated measures align to each other (see Fig. 22.6). Another important metric is the ‘mesh density’. All 3D models comprise many thousands of 2D primitive shapes (usually triangles). Smaller triangles will represent a surface more accurately than larger triangles. In areas of continuously varying gradient, such as chamfer margins, undesirable faceting may

Fig. 22.5 Intra-oral scanner recording 3D image of dentition and soft tissues

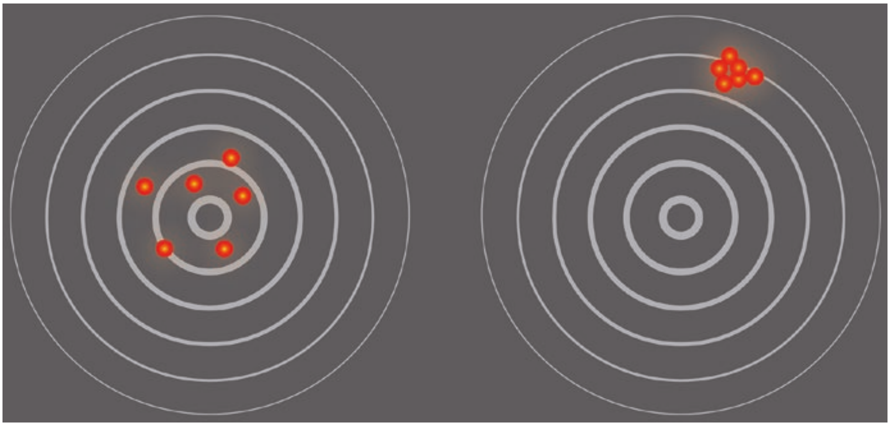

Fig. 22.6 The difference between trueness and precision. On the left good trueness but poor precision. On the right good precision but poor trueness

occur if the triangle size is too large [36]. This highlights a key difference between digital and conventional impressions. The former is created from a series of discrete samples, whilst the latter constitute a continuous record of the surface. The sample density, and not just the trueness and precision, will ultimately affect the quality of the digital impression (Fig. 22.7). A well-informed practitioner, when considering which scanner to purchase, would do well to compare these specifications.

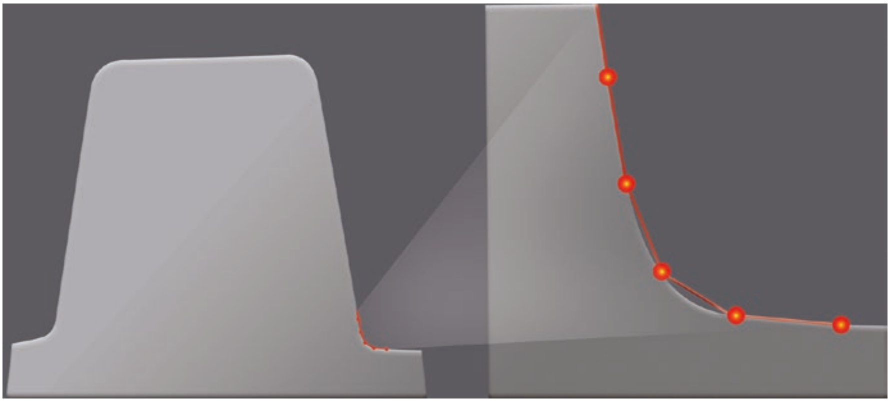

Fig. 22.7 Digital images consist of a meshwork of points. Where these are not closely spaced, it can result in a faceted, imperfectly fitting margin

There have been numerous in vitro studies investigating the accuracy of intra-oral scanners, relating to both single tooth and full arch impressions [37–40]. The results are variable, but, in general, a pattern is emerging of high accuracy in local regions (e.g. a crown preparation) comparable to conventional techniques. However, when considering full arch scans, the accuracy of digital impressions decreases. This is probably due to cumulative errors when stitching together multiple scans and may result in unwanted occlusal consequences or changes in arch width.

There is a need for more in vivo studies on intra-oral scanning, but recent reports suggest that the accuracy of scanning decreases in the oral environment, when compared to scanning dental models [39]. That caveat aside, digital techniques offer the advantage of re-scanning areas which are missed, or poorly recorded, without the need to repeat the entire impression. There are also reported benefits regarding patient comfort and chairside time [40].

Gingival retraction is still required for all current intra-oral scanners. Retraction pastes, or astringent-impregnated cords, are most commonly used, whilst electrosurgery and the use of lasers are also options. Occasionally, retraction can be more demanding compared to traditional impressions. This is because the traditional wash (syringed around the preparation margin) can displace 'loose' gingivae, exposing the margin, whilst with optical techniques the gingivae may relapse over the margin, obscuring the camera's view. Conversely, some manufacturers claim their colour scans can aid the discrimination of the tooth-coloured margin from the surrounding soft tissues. Ultrasonic 3D imaging has the possibility of penetrating soft tissue, negating the need for gingival retraction, though such devices are highly experimental at present [34].

Disadvantage of digital impressions includes the inability to record tissues in compression or to record the functional sulcus depth. Therefore, a traditional approach will still be required for many removable prosthodontic cases, although some success is being reported in selected cases [41]. Scanning is also technique sensitive [42], with different systems advocating different scanning protocols. Therefore, as with traditional impressions, there is a definite learning curve before optimal digital impressions will be obtained by a user.

Given the progress of this technology over recent years, it seems highly likely that the twenty-first-century dentist will eventually be using intra-oral scanning as his or her first-choice impression technique However, the hybrid approach of recording a conventional impression and scanning the cast in the laboratory with a highly accurate 3D laser scanner currently allows dentists to access CAD/CAM constructed restorations (see Chap. 6).

The challenge for the future will be to ensure optimal accuracy with intra-oral scanners over the full arch at an affordable price. Other features such as shade matching and kinematic articulation are already being integrated into these systems, although work is still required before such features can be shown to match traditional gold standards. Ultimately, this will result in highly accurate, nondegradable, records of the patient's dentition.

Conclusion

The ability to record a consistently good impression is both a science and an art. It is worth bearing in mind that the future holds a less invasive technique, and perhaps in years to come, we may routinely be saying, "First image counts"? Until then, impressions will influence not only the quality of the subsequent restoration but also the technician's perception of a dentist's skill. We are not perfect, and there is much to be said for welcoming the technician's feedback when a substandard impression is received.

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Provisional Restorations

23

James Field and Robert Wassell

23.1 Learning Points

This chapter will emphasise the need to:

- Provide a provisional restoration following tooth preparation to protect the pulp; secure positional stability, function and aesthetics; and maintain gingival health
- Consider using long-term provisional restorations to assess aesthetic, occlusal and periodontal changes before embarking on definitive restorations
- Distinguish between preparations for conventional and adhesive restorations when providing provisional restorations
- Determine in advance the type of provisional restorations and materials to be used, ideally, whilst treatment planning
- Be aware of materials for making provisional restorations and how to control potential hazards
- Make provisional restorations to a high standard to ensure a predictable restorative outcome.

After completing tooth preparation (Chap. 20), you will routinely want to provide your patient with a provisional restoration.

The terminology surrounding this stage of treatment can be confusing. The Glossary of Prosthodontic Terms [1] considers the terms 'provisional, temporary and interim' to be used interchangeably and describes a prosthesis that is 'designed

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to enhance aesthetics, stabilisation and/or function for a limited period of time, after which it is to be replaced by a definitive prosthesis'. For the purposes of consistency, we will use the terms 'provisional restoration' or 'provisional'.

Not only can good provisional restorations help to produce better final restorations, they can also save a lot of time and expense at subsequent appointments. This article discusses the need for provisional restorations, the various types and the many materials available for construction. Provisional restorations for adhesive definitive restorations often pose a difficult problem, and these are considered towards the end of the chapter, along with other commonly encountered problems.

23.2 Functions of Provisional Restorations

The various functions fulfilled by provisional restorations are described in Table 23.1. When constructing provisional restorations for a full crown preparation, the two essentials are to cover freshly cut dentine (strangely not emphasised in the above definition) and prevent tooth movement. With minimal preparations for adhesive restorations, protection of prepared enamel is usually less of an issue, and often a provisional restoration is not needed unless it is important to prevent unwanted tooth movement or maintain aesthetics.

Table 23.1 The functions of provisional restorations

1. Protection	To prevent dentine hypersensitivity, plaque accumulation, caries and pulpal degradation from bacterial, chemical and thermal insults
2. Occlusion and positional stability	To prevent unwanted tooth movement by the maintenance of intercuspal and proximal contacts. It may be necessary to establish a holding contact on the provisional restoration. Depending on the patient's occlusal scheme, the provisional restoration may need to provide guidance in protrusive and lateral excursions or disclude to prevent working or nonworking interferences. Interproximal contacts also need to be maintained to prevent food packing
3. Mastication	To allow patients to chew food. The provisional restoration should be robust enough to withstand normal masticatory function
4. Gingival health and contour	To facilitate oral hygiene and prevent gingival overgrowth, provisional restorations require accurate margins and cleansable contours. They can be used when the level of the gingival margin has yet to stabilise (e.g. after crown lengthening, apicectomy or removal of a crown with defective margins). In addition, provisional restorations can improve the emergence profile of implant-retained restorations
5. Aesthetics	To provide an adequate appearance, provisional restorations should either mimic the tooth just prepared or the final intended restoration
6. Diagnosis	To assess the effect of aesthetic and occlusal changes. The ability to reshape can also be used to overcome phonetic or occlusal problems before construction of the definitive restoration. The palatal contour of provisional restorations can then be copied using a custom-incisal guide table approach
7. Other practical uses	To measure tooth reduction; to isolate during endodontics; to assess prognosis; to act as a matrix for core construction

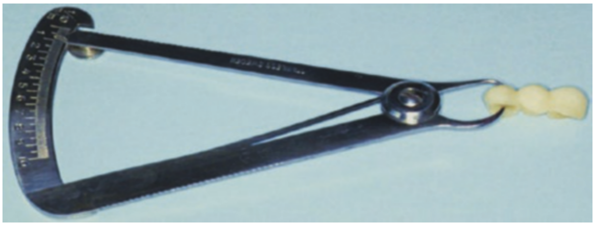

Fig. 23.1 Provisional restorations have many functions. Here an Iwanson gauge is used to assess sufficient tooth reduction to accommodate the definitive restoration

Provisional restorations have other practical applications. For example, callipers may be used to test the thickness of a provisional restoration to ensure sufficient tooth preparation to accommodate the definitive restorative material (Fig. 23.1). Occasionally, a provisional restoration may be used to provide a coronal build-up for isolation purposes during endodontic treatment. A period of long-term provisional restoration may also be advisable to assess the teeth of dubious prognosis.

Dentists sometimes forget provisional restorations can help stabilise periodontal condition prior to definitive restoration. They also have diagnostic uses, e.g. testing aesthetic and occlusal changes before they are incorporated in a definitive restoration. These important uses are considered next.

23.2.1 Periodontal Changes

It may be necessary as part of a patient's periodontal management to remove overhanging restorations to allow access for cleaning and resolution of inflammation (see Chaps. 4 and 10). Long-term wear of properly fitting and contoured provisional restorations allows the health of the gingival margin to improve and its position to stabilise before impressions are recorded for definitive restorations, bearing in mind that this will occur faster in some patients than others (Fig. 23.2).

Following periodontal or apical surgery, the tissues will also need time to stabilise before the final finish line is cut for definitive crowns. Where surgical crown lengthening is used to increase clinical crown height, try to leave 6 months before definitive restoration, particularly if the aesthetics are critical (see Chap. 10). Provisional restorations can be provided soon after crown lengthening, but make sure they are durable and avoid finishing the preparations subgingivally as this may set up a chronic gingivitis which is difficult to resolve.

With implant abutments (see Chap. 16), the surrounding gingival tissues may be 'sculpted' 4 months after implant placement to improve aesthetics by enhancing the emergence profile and interproximal papillae [2]. This is done with screw-retained provisional restorations which are contoured chairside by adding flowable composite [3] or acrylic resin [4] to the subgingival portion of the provisional restoration (Fig. 23.3). This exerts 'dynamic pressure', in other words a sustained but

Fig. 23.2 Improvement of gingival health and contour after removal of defective crowns (**a**) and only 3 days of well-contoured provisional restorations being in place (**b**). Other patients may take weeks or months for the gingivae to stabilise

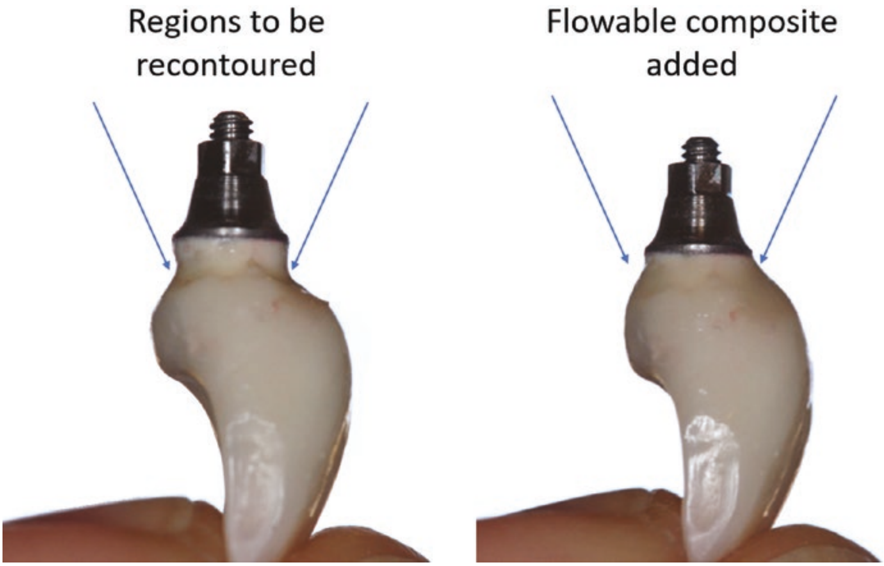

Fig. 23.3 Flowable composite added to the provisional implant abutment and crown for 'tissue sculpting'

diminishing pressure, against the inner aspect of the tissue. Whilst undoubtedly a useful technique, there are limits to what can be achieved which are covered in Chap. 17.

23.2.2 Diagnostic Uses

Provisional restorations, especially those used for crown preparations, are invaluable where aesthetic, occlusal or periodontal changes are planned. The principles behind such changes are discussed below.

23.2.2.1 Aesthetic Changes

Proposed changes to the shape of the anterior teeth are best tried out with provisional restorations to ensure patient acceptance and approval from friends and family. It's much easier to trim or add acrylic than for ceramic. Once happy, an alginate is recorded so that the technician can copy the desired shape into the definitive restoration. If only one or two teeth are involved, some dentists prefer to contour provisional restorations at the chairside, but with multiple restorations, clinical time can be saved by having a diagnostic wax-up and matrix made in the laboratory (Fig. 23.4). Alternatively, indirect provisional restorations can be prescribed which will be described later.

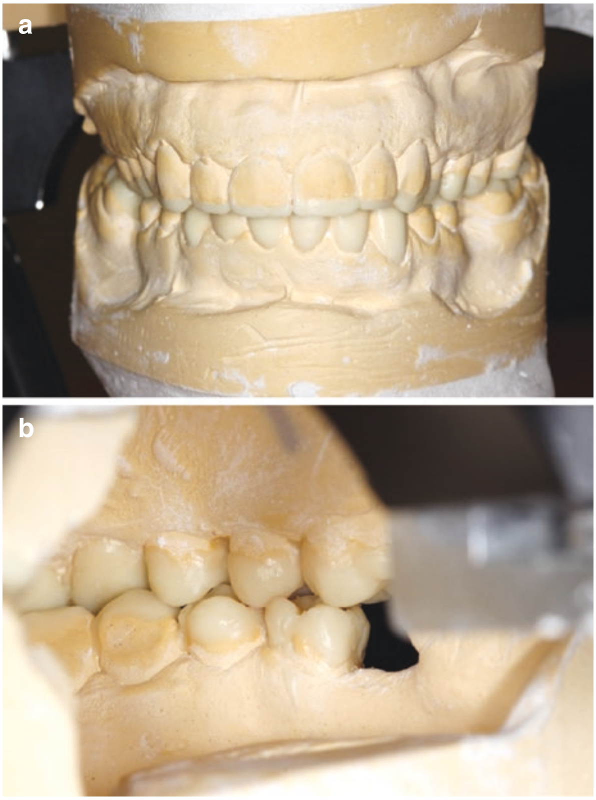

Fig. 23.4 A diagnostic wax-up is an invaluable way of planning aesthetic and occlusal changes. These changes can be viewed buccally (**a**) and lingually (**b**) and tested intra-orally with provisional restorations

23.2.2.2 Occlusal Changes

If you want your extra-coronal restorations to change a patient's anterior guidance or increase the occlusal vertical dimension, it's worth trying out the changes first with provisional restorations. The occlusal changes are best planned (see Chap. 12) with a diagnostic wax-up using casts mounted on a semi-adjustable articulator (Fig. 23.5). From the wax-up a matrix can be made to mould diagnostic provisional restorations either directly or indirectly. After fitting and adjusting, they are temporarily cemented. The adjustment should provide even occlusal contact in the intercuspal position and guidance or disclusion as required. The patient can then be examined at a further appointment and the occlusal surfaces copied if the following criteria are met:

- Restorations remain cemented and have not fractured or perforated
- Occlusal contacts have been maintained
- The teeth are not mobile and have not drifted or existing mobility is not increasing
- There is no discomfort.

There are several ways of copying guidance surfaces between provisional and definitive restorations. We prefer to use a custom guidance table as described in Chap. 12.

Where a patient's occlusal vertical dimension needs to be increased, it is often wise to make an initial assessment (e.g. with a stabilisation splint) before the teeth are irreversibly prepared. However, this stage is less important if the teeth are to be restored with direct composite restorations. This is because composite can easily be adjusted and added to intraorally.

Fig. 23.5 Casts need to be mounted on a semi-adjustable articulator to wax occlusal changes

23.2.3 Changes in Tooth Shape: Avoiding Problems

For most people, minor adjustments in tooth shape are unlikely to cause any problems, but for others, e.g. singers and wind instrument musicians, the eventual restorations, if poorly planned, may interfere with a patient's "embouchure". This term describes the fine mouth movements and lip/tooth contact required for speech production or sound generation in the case of a musical instrument. Also, the incorporation of wider cervical embrasure spaces, to facilitate interproximal cleaning, may occasionally cause embarrassment due to air leakage. Therefore, it makes sense to copy the features of successful provisional restorations to avoid patient dissatisfaction and expensive remakes.

23.3 Provisional Restorations for Conventional Preparations

As a guide to the maze of different provisional restorations, we first need to consider the materials and then the techniques by which they are formed. Most provisionals are formed directly in the mouth, but for long-term wear or diagnostic use, indirect provisional restorations have advantages and can be fashioned either in the lab or, where facilities exist, in the surgery. Impressions can either be conventional or optical (Chap. 22).

It is worth emphasising that the time between preparation of the teeth and cementation of final restorations can vary from a few days for straightforward cases (short-term) to several weeks (medium-term) or even, in the case of complex reconstruction, several months (long-term). The longer provisional restorations are in the mouth, the greater are the demands on the material from which they are made.

23.3.1 Materials

There are materials for direct use intra-orally and materials for making provisional restorations indirectly, either in the lab or in suitably equipped dental surgeries. Materials for direct use comprise preformed crowns (made of plastic or metal) and an increasingly wide range of specially formulated resins and resin composites (see Table 23.2). In the lab, provisional restorations are generally made in self-cured or heat-cured acrylic, composites or cast metal. CAD/CAM may also be used to mill provisional restorations from polymerised resin blanks (see Chap. 14).

Cements to lute provisional restorations (Fig. 23.6) are detailed in Chap. 15. To avoid bacterial contamination of cut dentine and to improve retention, we recommend luting provisional restorations. Some composites contain antibacterial agents such as triclosan (e.g. Systemp Inlay/Onlay™, Ivoclar Vivadent) and are designed to be used without a lute, but their antibacterial activity may not be entirely effective for other than short-term use [5].

Look again at Table 23.2 and we will consider materials from an historical perspective.

Table 23.2 Resins and composites used clinically for provisional restorations

Resin type	Examples	Presentation	Curing method
Resins			
Polymethyl methacrylate	Duralay™ (Reliance Dental)	Powder/liquid	Self-cure
	Alike™ (GC)		
	Trim Plus™ (Keystone Industries)		
Polyethyl methacrylate	Snap™ (Parkell Inc.)	Powder/liquid	Self-cure
	Trim I™ and II™ (Keystone industries)		
Composites			
[a]Bis acryl	Protemp 4™ (3M ESPE)	Syringe mix	Self-cure
	Quicktemp II™ (Schottlander)	Syringe mix	Self-cure
	TempSpan™ (Pentron Clinical)	Syringe mix	Dual-cure
[a]Urethane dimethacrylate (UDMA) and bis acryl	Quicktemp Cosmetic™ (Schottlander)	Syringe mix	Self-cure
[a]UDMA and trimethacylate	Revotek LC™ (GC)	Putty stick	Light-cure
[a](Trimethoxysilyl) propyl methacrylate	Protemp™ Crown Temporization Material (3M ESPE)	Preformed malleable crown	Light-cure
[a]UDMA or Bis-GMA	Generic restorative composites	Composite can be heated to reduce viscosity	Light-cure
[a]UDMA	Quicktemp Cosmetic Flowable™ (Schottlander) or generic flowable composites	Flowable composite (used in conjunction with other materials to repair, recontour or veneer)	Light-cure

Note the variety of presentations and methods of polymerisation
[a]NB These materials could all be regarded as bis-acryl composites [11]

Fig. 23.6 Kerr's Temp Bond™ and Temp Bond NE™: the modifier (central tube) can be mixed with Temp-Bond Base and Accelerator to ease crown removal with retentive preparations. Regular Temp Bond contains eugenol, which may soften composite cores. Temp-Bond NE (shown to the right of photograph) does not contain eugenol and will avoid this problem

23.3.1.1 Polymethyl Methacrylate (PMM)

In the 1960s provisional crowns were made from self-cured PMM—a material which continues to be used by some dentists. PMM is strong, has relatively good wear resistance, can be easily added to, and has good aesthetics which lasts well for long-term use. However, it does have significant disadvantages:

1. An unpleasant smell
2. Polymerisation shrinkage which can affect fit and require the restoration to be relined
3. Polymerisation exotherm [6] which may damage pulp [7]
4. Free monomer which may cause pulp and gingival damage.

It is, however, a good material for indirect provisional restorations made either chairside or in the laboratory. To reduce porosity self-cured acrylic can be polymerised under pressure in a hydroflask [8]. Alternatively, the lab can use heat-cured acrylic.

23.3.1.2 Polyethyl Methacrylate (PEM)

PEM (see Fig. 23.7a) was introduced in the 1970s specifically for intraoral use because it shrinks less and is less exothermic than PMM. However, strength, wear resistance, aesthetics and colour stability are not as good. Most presentations come with a wide colour range (e.g. Trim II™, Keystone Industries, has six shades). These materials contain a phthalate plasticizer which may leach out of the set material [6, 9]. Phthalates are considered as endocrine disruptor chemicals that can cause estrogenic behaviour and are possible carcinogens [10]. The level of risk posed to patients by eluents from temporary restorations is unclear.

23.3.1.3 Composite Resins

Over the past two decades, manufacturers have introduced several developments in the formulation and presentation of composite materials used for provisional restorations.

Bis-acryl composites gained popularity in the 1980s largely due to the convenient mixing system: Automix syringes (see Fig. 23.7b), which provide a consistent and air-free product. Unfortunately, it is difficult to define exactly what is meant by bis-acryl. A broad-brush definition says it comprises.

"Monomers such as bisphenol-A-glycidyl methacrylate (bis-GMA), triethylene glycol dimethacrylate (TEGDMA) or similar monomer systems derived from Bowen resin" [11]. Clearly, there is endless scope for manufacturers to adjust constituents and their concentrations—so one bis-acryl material may have very different properties to another. Indeed, the early materials (e.g. Protemp™, ESPE-Premier) produced less heat and shrinkage during polymerisation than other resins, making them more pulp friendly and resulting in a better marginal fit [7]. However, despite being reasonably strong, they were brittle in thin section and difficult to add to. They also stained easily if the unpolymerised surface layer was not removed with an alcohol wipe and polishing.

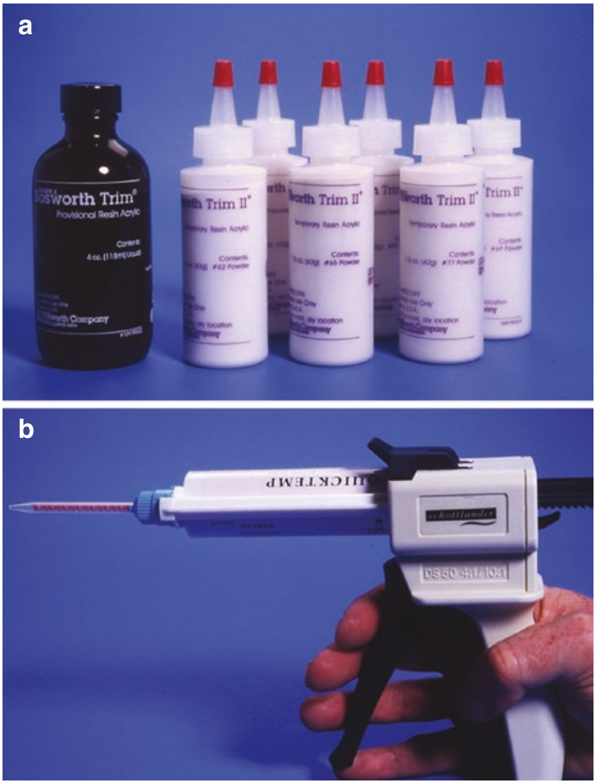

Fig. 23.7 Examples of resins used for provisional restorations: (**a**) Polyethyl methacrylate: powder-liquid presentation (**b**) Bis-acryl composite: syringe mixed pastes

To illustrate how some bis-acryl materials have changed over the past 10 years, Quicktemp™ (Schottlander) provides a good example evolving first into Quicktemp II™ and then Quicktemp Cosmetic™. The manufacturer claims Quicktemp II™ has a revised formulation giving improvements in strength, hardness and aesthetics [12] but seemingly at the expense of an exotherm approaching 50 °C [6]. Quicktemp Cosmetic™ is claimed to have further significant improvements in mechanical properties by including a large component of urethane diacrylate (UDMA). Whilst tempting to use the stronger 'cosmetic' material for all purposes, it has an even higher exotherm than Quicktemp II [13]. So, to avoid overheating a vulnerable pulp, it is important to remove the partly set material from the mouth before reaching the exothermic reaction.

As a rule, bis-acryl resins appear more colour stable than PEM materials and better suited for use as long-term provisionals [7]. However, they will not form a reliable chemical bond to themselves or to flowable composite resins which may be needed for repairs and additions after intraoral curing. Nevertheless, priming the defect with a resin bonding agent provides a reliable solution to this problem [14]. Indeed, Quicktemp Cosmetic™ provides an unfilled resin and a light-cured UDMA composite in a range of four shades. The resin bonding agent can also be used as a surface glaze [13].

Bis-acryl composite (dual-cured): The development of stronger bis-acryl resins has not only involved reformulations of resin and filler content but also method of setting. TempSpan™, SYNCA, is a syringe-mixed material which can also be light-cured. Such dual curing is popular as it saves clinical time, but take care not to lock in restorations and cause a seared pulp: light-curing generally creates a higher exotherm than self-curing because of the greater speed of reaction and the additional heat from the curing light [15].

Maleable composites: These are light-cured composites with a clay- or dough-like consistency allowing them to be moulded over a tooth prep and then cured. The simplest system, Revotek LC™, GC, consists of a UDMA putty stick from which a portion can be cut. A more sophisticated approach is for the composite dough to be supplied preformed as a crown (e.g. Protemp™, 3M ESPE Crown Temporization Material, made, in part, from Bis-GMA) [11].

Restorative composites: These are normally used for definitive restorations but can be used as a provisional material for adhesive preparations (e.g. for veneer preps), as described later. Dentists sometimes heat composites to reduce viscosity and make them easier to mould [16] or use with a matrix. There are also light-cured and dual-cured composites designed for laboratory fabrication which may also be useful for long-term provisional restorations.

All the above resin-based materials have an exothermic reaction and if used directly may have implications for the pulp, particularly if the material is not removed from the mouth at the appropriate time. Currently, there is no ISO standard specifying an upper limit to the exotherm from these materials, which some may find surprising.

23.3.1.4 CAD/CAM

Dentists enthusiastic about CAD/CAM technology (see Chap. 14) will be delighted to know that highly accurate provisional restorations can be milled from blanks made from a variety of prepolymerised resins including PMM, polyetheretherketone (PEEK) and acetate [17]. Some materials may perform better than others; under conditions of simulated crown loading, the fracture strength of PMM and PEEK was significantly higher than for acetate and the comparator—a syringe-mixed bis-acryl composite.

23.3.1.5 Cast Metal

Cast metals are hardly ever used for provisional restorations but are mentioned for completeness. They are very durable and may occasionally be used for long-term provisionals in bruxists.

23.3.2 Techniques for Direct Provisional Restorations

Most provisional restorations are made directly in the mouth. As mentioned earlier it is worth taking time in their construction. To achieve good fit and contour, allow a similar time to temporise a tooth as to prepare it. The techniques available are listed below:

- Preformed crowns
- Custom shells
- Matrices (either formed directly in the mouth or indirectly on a cast)
- Direct syringing
- Malleable composite.

To avoid confusion with terminology, a shell is incorporated into the provisional restoration, whereas a matrix is merely used to form it.

23.3.2.1 Preformed Crowns

Known also as proprietary shells, these come in a series of sizes but usually need considerable adjustment marginally, proximally and occlusally. Plastic shells are made from polycarbonate or acrylic and, with good aesthetics, are commonly used for the anterior teeth including premolars (Fig. 23.8). Metal shells may be made from aluminium (Fig. 23.9), stainless steel or nickel chromium and are only used on the posterior teeth. Both plastic and metal shells can be relined with self-cured resin to improve their fit. To prevent the resin locking into proximal undercuts, use a sharp hand instrument (e.g. a half Hollenback) to remove material from the gingival embrasures whilst it is still soft, taking care not to disturb the margin.

23.3.2.2 Custom Shells

Some operators favour custom shells for multiple tooth preparations. The shell is made in advance of tooth preparation by first cutting minimal crown preparations on a stone cast. A pre-preparation matrix is then filled and placed over the preparations. The trimmed and adjusted provisional crowns are relined in the mouth. This approach may become more popular with shells made by CAD/CAM.

23.3.2.3 Matrices

Many operators prefer matrices (Fig. 23.10) to shell crowns for making single or multiple provisional crowns. This is because matrices closely duplicate the external form of the existing teeth, or, if changes are required, a diagnostic wax-up. If the matrix is carefully seated, minimal adjustments are generally needed other than trimming flash at the crown margin.

There are three main types of matrix:

- Impression (alginate or silicone putty)
- Vacuum-formed thermoplastic
- Proprietary celluloid.

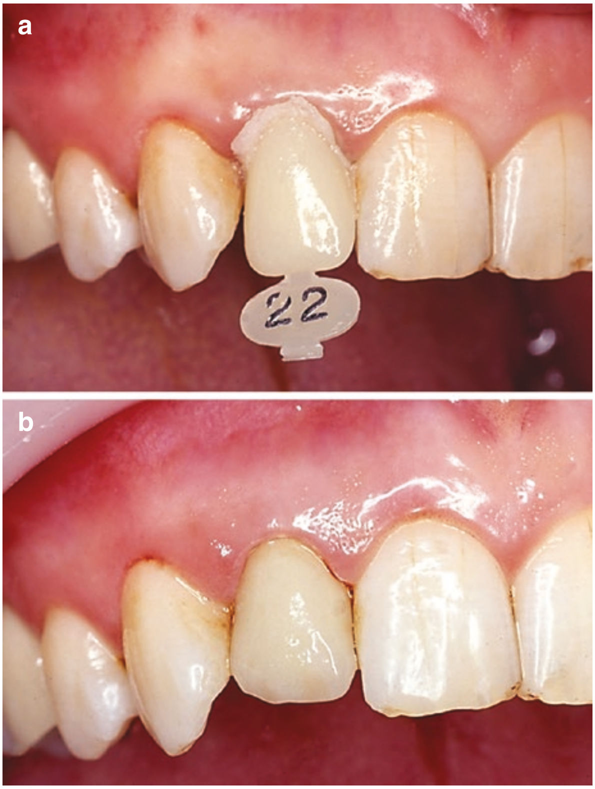

Fig. 23.8 A familiar polycarbonate shell crown relined with Trim II™ (**a**). The provisional is carefully trimmed to help secure gingival health (**b**)

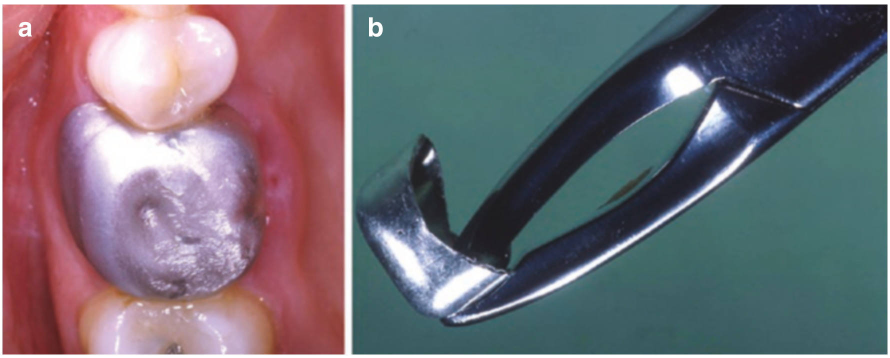

Fig. 23.9 Aluminium shell crowns are convenient but suitable only for short-term use on the posterior teeth (**a**). Crimping of the crown margins will improve retention and fit (**b**)

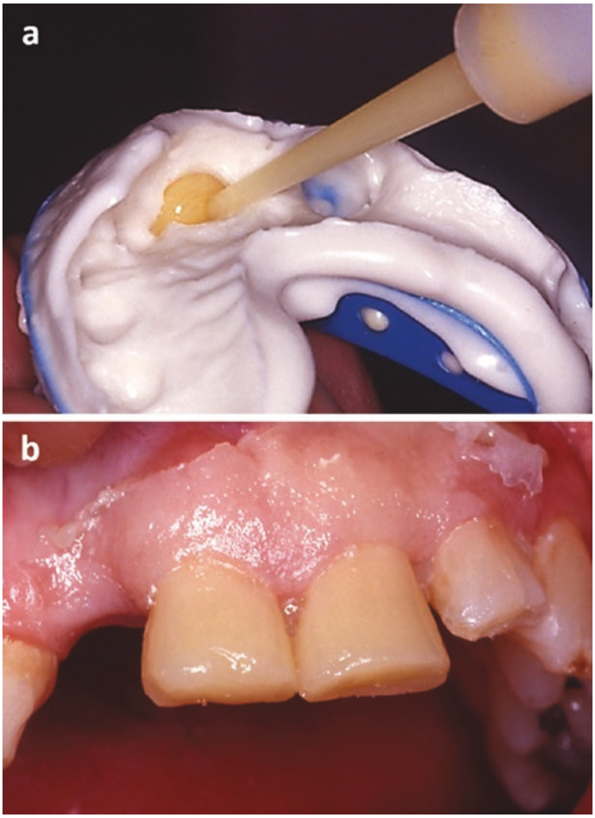

Fig. 23.10 An alginate impression is commonly used to make a matrix from the unprepared tooth (**a**). The flash must be removed and the linked provisionals trimmed prior to cementation (**b**)

The simplest way of making a matrix is to record an impression of the tooth to be prepared either in alginate or silicone putty. Impression matrices are quick, easy and inexpensive and can be formed whilst the local anaesthetic takes effect. When impression matrices are used, some judicious internal trimming may be helpful to improve seating and bulk out critical areas of the provisional restoration. These aspects are covered later when we deal with problem-solving. Putty matrices are better than thermoplastic matrices at absorbing some of the resin exotherm [18], and alginates should be good also—although the provisional restoration should have been removed from the mouth before this stage of set. Silicone putty matrices have the advantage of being reusable, allowing them to be disinfected and stored in case they are required again for that patient.

If a tooth is broken down or its shape needs to be modified, it can be built up in a variety of materials before making the matrix, for example, nonbonded composite resins or temporary inlay/onlay materials such as Systemp™ or Telio™ (Ivoclar Vivadent). Alternatively, with multiple crowns, it is better to carry out a diagnostic wax-up beforehand on mounted casts (Fig. 23.5). The intended aesthetics and occlusion can be formed much more efficiently, and patients appreciate being able to see a "blue print" of the proposed restorations on the articulator. Moreover, the wax-up can be used to form a suitable indirect matrix.

Indirect matrices can be made from impression material (see Fig. 23.11a), or you can ask your laboratory for a vacuum-formed matrix made of clear vinyl (see Fig. 23.11b). If you decide to make an indirect matrix from impression material, remember to first soak the cast for 5 min; otherwise the set impression will stick.

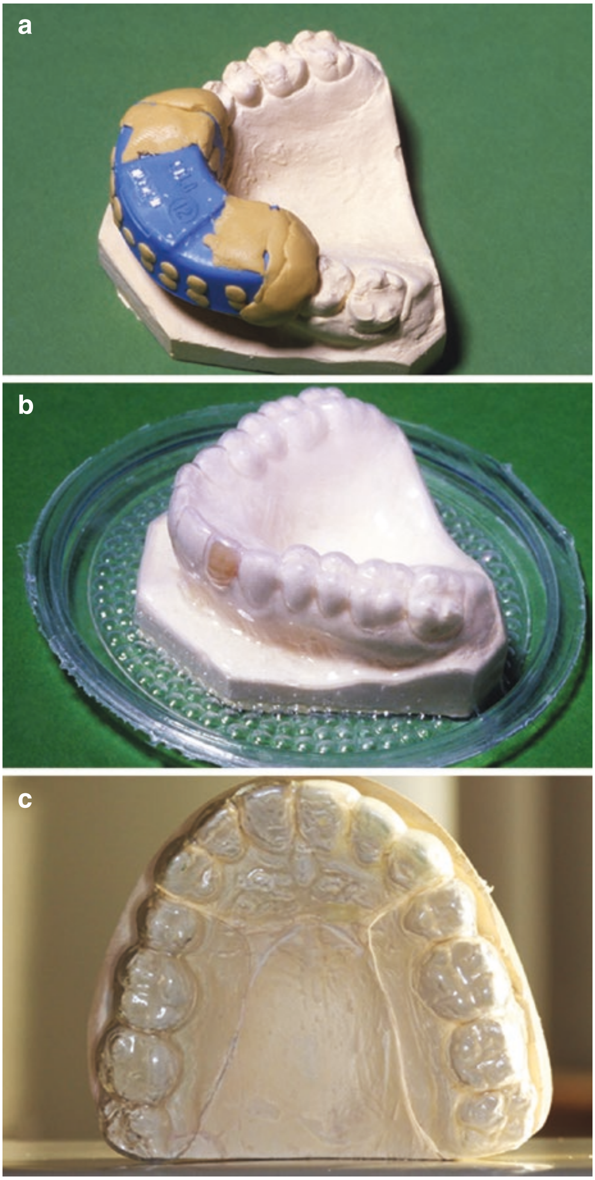

Fig. 23.11 Where aesthetic or occlusal changes are proposed, lab-made matrices are useful to form provisional crowns in the mouth. A putty or alginate matrix can be made directly on the wax-up—but remember to soak cast first (**a**). A vacuum-formed matrix (shown prior to trimming) is made on a stone duplicate of the wax-up (**b**). A thinner but more rigid matrix made over the upper right posterior teeth using Essix™ (Dentsply) thermoformed clear retainer material (**c**)

Immersion of the cast in warm water (not hot) also has the advantage of speeding up the impression material's setting time. Where matrix location relies on the soft tissues because there are insufficient teeth, we prefer an impression matrix rather than a more flexible vacuum-formed matrix. However, vacuum-formed matrices do have their uses.

Vacuum-formed matrices can be made of clear vinyl sheet produced on a stone duplicate of the waxed-up cast. A stone duplicate is necessary to avoid melting the wax when the hot thermoplastic material is drawn down. Not everyone is enthusiastic about using vacuum-formed vinyl matrices because they are flexible and can distort when seated. However, vacuum matrices are indispensable for moulding light-cured resins. If more rigidity is required, specify the material normally used to make orthodontic Essix retainers (Fig. 23.11c). Another option is to make the matrix using clear silicone jaw registration material (e.g. Memosil™ 2, Heraeus Kulzer). If you have adjacent preparations and want to keep the provisional restorations separate, consider incorporating pieces of stainless steel matrix strip (Fig. 23.12). However, tight proximal contacts (e.g. with multiple veneers) may prevent such a matrix being seated.

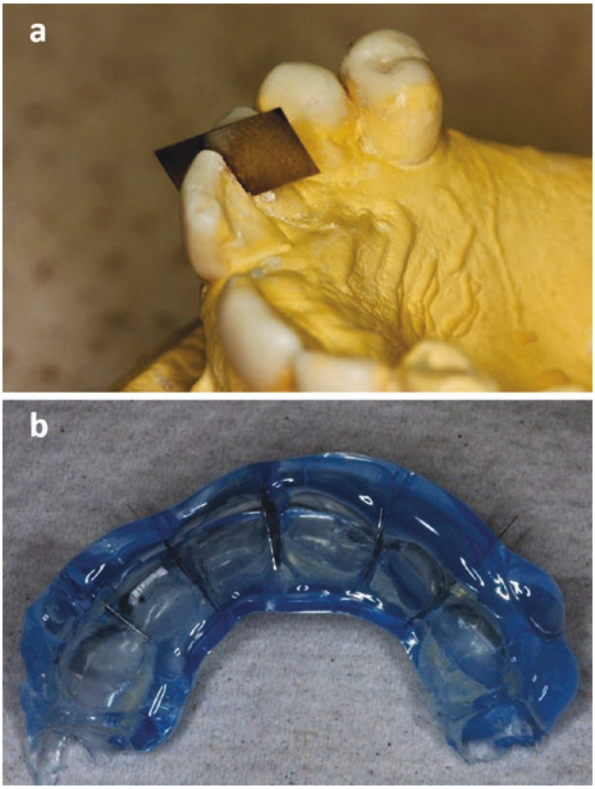

Fig. 23.12 Separating provisional restorations using strips of stainless-steel matrix band. Each strip is positioned interproximally on the wax-up (**a**). A clear silicone jaw registration material is syringed around the stone teeth to be prepared and adjacent locating teeth. The underside of the set silicone matrix shows the stainless-steel separators in situ (**b**)

Whatever matrix is chosen, it must be used carefully. After tooth preparation, a thin smear of petroleum jelly is placed over the prepared tooth and adjacent teeth. The matrix is blown dry and the mixed resin syringed into the deepest part of the mould, taking care not to trap air, especially at the incisal angles. After reseating, the matrix is held in place until the resin reaches a rubbery stage. It is then removed and interproximal excess detached in the same way as for a proprietary shell. Setting can be monitored to some extent by testing the consistency of a small portion of material syringed onto the front of the seated impression. Following removal, the provisional restorations are trimmed, polished and cemented.

23.3.2.4 Direct Syringing

When no shell temporary can be found to fit, and, for whatever reason, no matrix is available, it can be useful to syringe material directly around a preparation. The polyethyl methacrylate materials are best as they can be mixed to sufficient viscosity not to slump but are still capable of being syringed. This property whereby a material undergoes an apparent decrease in viscosity at high rates of shear, as when passed through a syringe nozzle, is called "shear thinning". It is also seen with the polyether material, Impregum™, 3M ESPE.

When syringing, start at the finish line and spiral the material up the axial walls. Overbuild the contours slightly as it is easier to trim away excess than to have to add later.

23.3.2.5 Malleable Composites

As mentioned previously, individual preformed crowns are available in malleable tooth-coloured composite (Protemp™ Crown Temporization Material, 3M ESPE) [19]. These crowns can be burnished intra-orally to improve marginal adaptation, and proximal and occlusal contacts can also be fashioned before curing. However, a convenient indirect method, avoiding any exotherm problem, is to record a localised impression and then cast a working die at the chairside. Currently, Protemp™ malleable provisional crowns are available only for the posterior teeth, but the range may be extended to include the anterior teeth at a later stage.

As these preformed composite crowns become more mechanically robust, there is likely to be a growing interest in using them to make cost-effective medium- to long-term restorations.

23.3.3 Indirect Provisional Restorations

Many dentists will not have used indirect provisional restorations and may find it hard to justify laboratory costs. However, indirect provisionals offer certain advantages with complex cases needing long-term temporisation for multiple preparations. Firstly, materials can be used which are stronger and more durable, e.g. heat-cured acrylic, self-cured acrylic or composite resin. Secondly, if aesthetic or occlusal changes are to be made, these can be developed on an articulator. Indirect

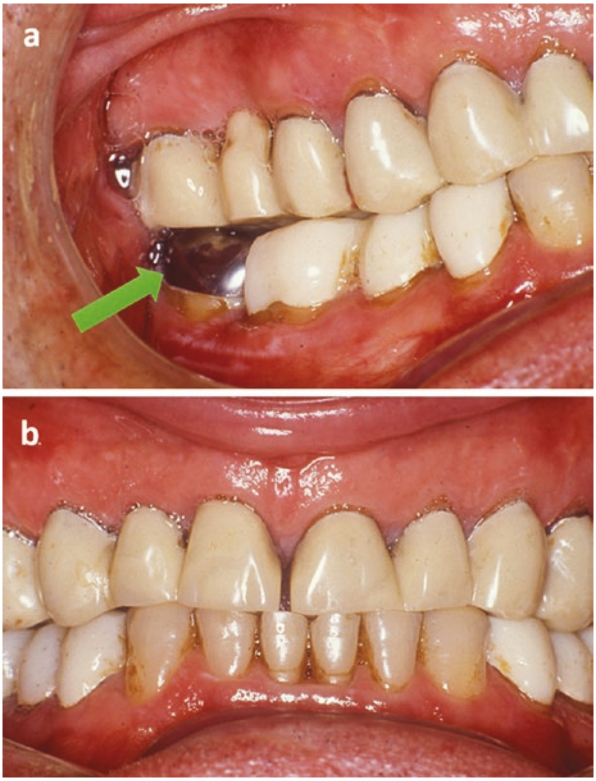

Fig. 23.13 Metal and acrylic provisionals used in the occlusal reconstruction of a bruxist. A relined NiCr shell at tooth 37 (green arrow) where a previous acrylic provisional crown had fractured repeatedly (**a**). The upper arch has provisionals made of metal copings veneered with heat-cured acrylic. A good bond between metal and acrylic is essential to improve fracture resistance (**b**)

provisionals can save clinical time, particularly where there is to be an increase in vertical dimension, e.g. when restoring a bruxist (Fig. 23.13).

Where major work is being undertaken, it is best to decide on the type of provisional restoration during treatment planning (see Chap. 18). If indirect provisional restorations are chosen, sufficient time can be scheduled either to make them whist the patient waits or an additional appointment can be made to fit those made in the laboratory.

23.4 Provisional Restoration of Adhesive Preparations

Provisional restorations for conventional tooth preparations (e.g. crowns, 3/4 crowns and onlays) are retained in a similar way to the definitive restorations, i.e. via a cement lute on preparations with minimally tapered axial walls (see Chaps. 15 and 20). However, the lack of conventional retention provided by most adhesive preparations often results in temporary cements being ineffective. Several strategies can be used to deal with this problem, but some are more appropriate for certain situations than others:

- No temporary coverage may be necessary (e.g. with veneer preparations involving minimal dentine exposure and not removing intercuspal or proximal contacts; where space has been created with a removable Dahl appliance—see Chap. 13—the appliance can be used in the interim to retain the teeth in position)
- A simple coat of zinc phosphate cement to protect exposed dentine (e.g. in tooth preparations which are not aesthetically critical and where the occlusion is either not involved or the restoration can be returned rapidly from the laboratory and fitted before significant tooth movement occurs)
- Composite resin bonded to the opposing tooth to maintain occlusal contact and prevent overeruption (e.g. shims or veneers where some additional occlusal reduction is required). After the definitive restoration is placed, the opposing composite is ground away
- Composite resin bonded to a spot etched on the preparation (e.g. veneer preparations which are aesthetically critical or occlusally critical or have fresh cut dentine). The provisional restoration can be formed using directly placed composite onto the unbonded tooth surface, but this is time consuming for multiple restorations. Alternatively, a clear vacuum-formed matrix can be used with bis-acryl or heated restorative composite [16] to make it flow more easily. For longer-lasting provisionals, acrylic veneers may be made in the laboratory. A spot etch limits the area of bonding and facilitates composite removal, but the bonded area must be ground back to the tooth substance when the definitive restoration is fitted. If the composite is cut without water spray, it is easy to distinguish between the powdery surface of the ground composite and the glassy appearance of the underlying tooth. However, a spot-etched provisional restoration will be vulnerable to microleakage in all but the bonded area, so patients should be advised to avoid food and drinks likely to cause staining (beetroot, red wine, tumeric etc.)
- Conventional provisional restorations cemented with either a non-eugenol temporary cement or a hard cement such as zinc carboxylate. This approach may be used for adhesive restorations having some mechanical retention (e.g. an inlay or resin-bonded crown). The choice of cement will depend on how retentive the preparation is. For example, veneer preparations on multiple teeth will often provide some mechanical retention for linked provisional restorations (e.g. via the embrasures) and can also be luted with temporary cement, whereas preparations for one or two veneers will be more difficult to make retentive and are more reliably held by the spot-etch technique (see above)
- If the immediate dentine-sealing (IDS) technique has been used (e.g. where exposed dentine is likely to be sensitive), great care is needed to ensure the composite resin provisional material is not bonded to the sealed dentine surface. Effective isolation is therefore required with a thick layer of petroleum jelly or PTFE tape before making the provisional restoration. To avoid contaminating the sealed surface with provisional cement, mechanical retention (e.g. with clear resin into the embrasure spaces) is preferred, but is not particularly reliable. Consequently, the definitive restoration must be returned from the lab and fitted within 2 weeks [20]

- Fabrication of an Essix-type removable retainer which will provide some protection to the prepared tooth surfaces and maintain even occlusal contact. Tooth-coloured veneers can be incorporated within the labial aspect of the retainer if preparations are significant or ugly. This approach could also be used with the IDS technique.

Provisionals for adhesive preparations are only effective in the short term. Certainly, their diagnostic usefulness for testing changes in aesthetics and occlusion is much more limited than with provisional restorations for conventional preparations.

23.5 Problem-Solving

Several problems may be encountered when making provisional restorations. Some of these are discussed below:

23.5.1 Insufficient Bulk of Material, Air Blows, Voids and Marginal Discrepancies

The axial walls of resin provisionals are often thin making them prone to damage during removal from the mouth. This is particularly the case when minimal amounts of the tooth are removed, e.g. the lingual aspect of preparations for gold crowns. To prevent damage, the provisional should be made temporarily wider by relieving the appropriate part of the impression with a large excavator (Fig. 23.14). The excess resin can be recontoured after it has completely set. Alternatively, the non-occluding aspects of a tooth can be bulked out with soft red carding wax prior to recording the impression to be used as the matrix for making the provisional restoration. The carding wax can be made to stick by first painting the tooth with varnish (e.g. glass-ionomer cement varnish).

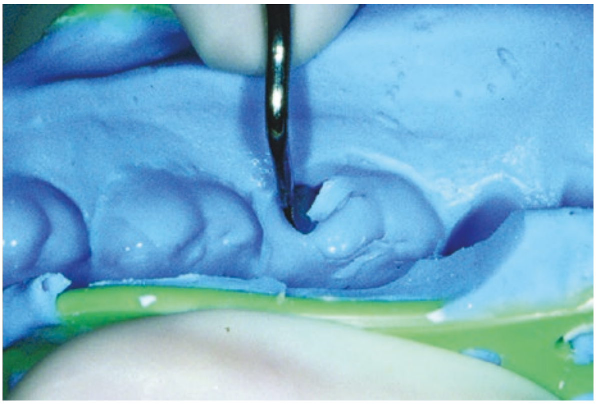

Fig. 23.14 Where the resulting provisional restoration would be too thin, the inside of the alginate matrix can be trimmed to give a greater bulk of resin

The best way to avoid voids in provisional restorations is to ensure the syringe tip remains in the resin when syringing material into a matrix. Tooth preps that have an inlay component can also have material syringed into the tooth preparation which helps prevent trapping the air.

If after removing the matrix a provisional crown has major defects (e.g. too thin, cracks, large voids or grossly defective margins), it is best remade. However, less severe defects can often be repaired with a flowable, light-cured composite. Remember freshly cured bis-acryl composite has a greasy surface layer which must be wiped away with ethyl or propyl alcohol before applying and curing a resin bond and then the flowable composite [14].

If there are marginal discrepancies, a good technique is to reline the provisional restoration with bonded flowable composite or with the bonded provisional material. A handy tip is to flare the inside of the crown margin with a bur which provides for a greater bulk of reline material and more area for it to bond. To facilitate seating, it is best not to fill the whole crown with resin but to confine the reline material to the inner aspect of the crown margin, thus reducing hydrostatic pressure.

23.5.2 Gross Occlusal Errors

An impression matrix not being seated fully often causes gross occlusal errors. These errors may occur for two reasons:

- Fins of interproximal impression material being displaced and sandwiched between the impression and the occlusal surface. To prevent this error, trim away any suspect areas from the inside of the impression with a scalpel or scissors before reseating
- Hydrostatic pressure built up within the unset resin during seating of the impression matrix. To prevent this error, consider cutting escape vents between the crown margin and the periphery of the impression with a large excavator.

23.5.3 Locking in of Provisional Restorations

Provisional restorations are often locked in making removal difficult or impossible without destroying them. If the preparation is free from undercuts, a common cause is material extruded into the undercuts formed by the proximal surfaces of the adjacent teeth. The technique of cutting out a triangular wedge of material from the gingival embrasure space with a half Hollenback instrument has already been mentioned. This must be done whilst the material is still soft and before any attempt is made to remove the provisional restoration from the preparation. If insufficient material is removed from the embrasure, the partly polymerised material may well deform or break on removal.

Alternatively, block out large proximal undercuts beforehand with carding wax secured to the affected tooth surface with dried varnish.

Once successfully removed, trim any thin flash with a pair of scissors but resist the temptation to try the provisional back in until fully set. The seating is usually straightforward after grinding away any excess from the proximal surfaces. Occasionally, slight adjustment of the intaglio surface is needed to facilitate seating.

23.5.4 Multiple Crowns

When using a matrix to make provisional restorations for several adjacent preparations, they invariably end up linked together interproximally. If the preps have a similar path of insertion, the linked provisional can be cemented and splint the teeth together. Splinting the teeth together in this way has an advantage of preventing drift due to poor interproximal and occlusal contacts. However, it is extremely important to ensure the gingival embrasures are opened sufficiently to give good access to toothbrushing (Fig. 23.15a–c). This is best accomplished with a flame-shaped bur (Fig. 23.15d).

Where adjacent provisional crowns need to be separated (e.g. because of conflicting paths of insertion), one way is to use the technique already shown in Fig. 23.12. Another way is to insert small pieces of Mylar™ strip into, about 1 cm long, between the teeth to be prepared. Of course, tight proximal contacts may first need to be relieved with an abrasive strip. The Mylar™ strips should already have holes punched in their buccal and lingual portions with a rubber dam punch to aid retention in the overimpression. Once in place, a small amount of alginate is smeared over the Mylar™

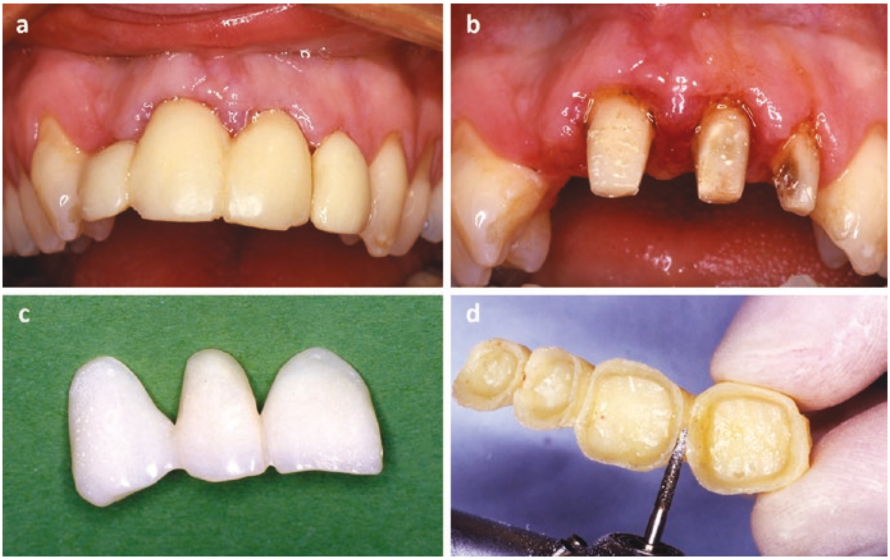

Fig. 23.15 Provisional restorations and gingival embrasures: no gingival embrasure space had been provided between the maxillary incisors (**a**). Bleeding from the inflamed gingivae prevented impressions being recorded (**b**). Patients maintain gingival health best where there are open gingival embrasures (as shown in this provisional bridge) to allow toothbrush penetration interproximally (**c**). Gingival embrasures under linked provisionals can be opened out with a flame-shaped bur (**d**)

strip's retentive holes before seating the tray. When the impression is removed, the strips should stay embedded in the alginate and can then separate the resin/composite crowns whilst they are made. More simply, make one section of the provisional first, trim away excess, apply petroleum jelly, reseat and then form the second section up against the first. If necessary, the two sections can be glued together with bonding resin and flowable composite following cementation. You will of course need to section the join before removal if there are conflicting paths of insertion.

23.5.5 Partial Denture Abutments

A provisional crown used as a partial denture abutment is made best from an acrylic resin (e.g. Trim II™) as additions are easy to make. The following technique is recommended: The provisional crown should initially be kept clear from where rest seats and guide planes are to contact. Fresh resin is then placed in these areas over which is placed a layer of PTFE tape then the partial denture reseated. After the resin has set, the denture is removed, the PTFE tape peeled away, and the provisional crown is finished.

23.5.6 Eugenol-Containing Temporary Cements and Adhesion

As discussed previously, eugenol-containing cements should be avoided where it is intended to cement the definitive restoration to an underlying composite core or a resin-bonded dentine surface.

23.5.7 Removing Temporary Crowns

Although it is desirable for provisional restorations to remain in place, they should be easily removed at the next appointment when the definitive restorations need cementing. Sometimes finishing a prep or recording the impression is delayed, so there are advantages if the provisional remains intact and can be reused until a further appointment.

When preparations are of optimal height and taper, the use of even comparatively weak temporary cements may make removal difficult and particularly so when definitive crowns are cemented on a temporary basis.

To make removal easier, the cement should be applied in a ring around the inner aspect of the provisional restoration's margin. Alternatively, the manufacturer's modifier should be added to the cement (Fig. 23.6). Equal lengths of base and catalyst with a third of a length of modifier will soften the cement appreciably. Therefore, the proportion of modifier needs to be gauged for each case.

The simplest way to remove a provisional restoration is to dry it with an air syringe and then use gloved fingers to gently rock and twist and pull the restoration from the preparation. Other methods of removing provisional restorations without risking damage to the margin of the preparation or restoration are considered in Chap. 24.

23.5.8 Removal of Excess Cement

Temporary cement removal is facilitated by applying petroleum jelly to the outside of the restorations and placing floss under each connector of linked crowns before seating. Once set, the excess cement is easily removed with the strategically positioned floss (Fig. 23.16).

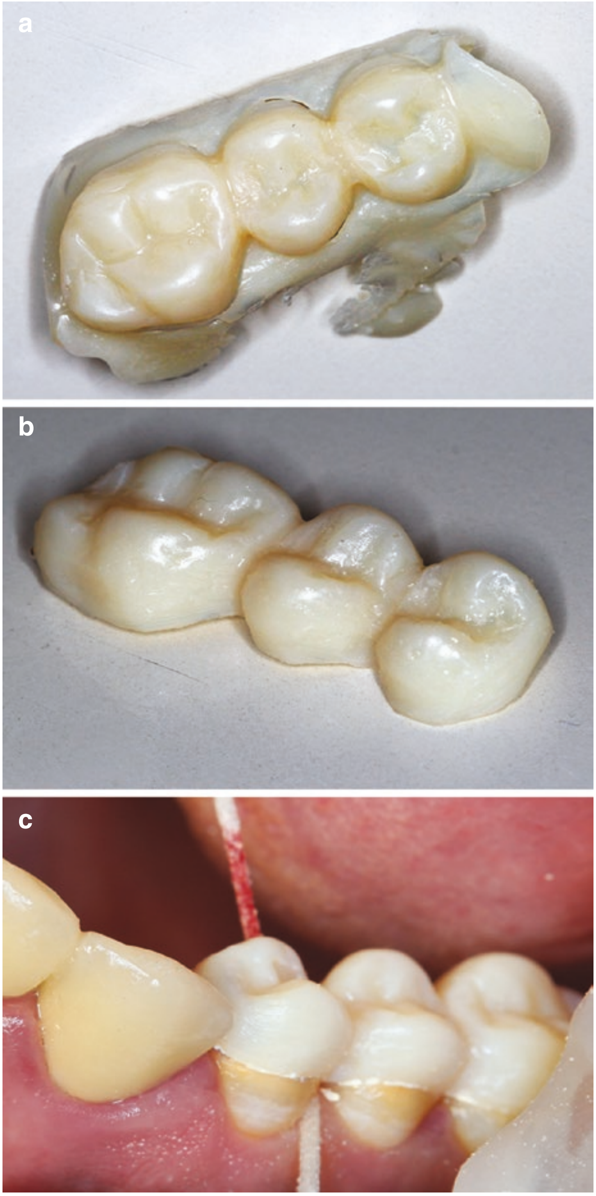

Fig. 23.16 Linked provisionals for onlay preparations after removal from matrix (**a**). The flash and embrasures are then trimmed (**b**). Superfloss™ (Oral-B) is used to remove excess temporary cement interproximally (**c**)

23.5.9 Premature Failure

A surprising number of provisional restorations fail before the definitive restoration can be fitted. One study in a dental school found 19% of provisionals failed, generally due to loss of cementation or fracture. The risk of failure was higher with molars and with inexperienced students [21].

Loss of cementation can be largely avoided by ensuring harmony with the occlusion. A few seconds spent marking up and adjusting occlusal contacts will save time overall. Occasionally, it is necessary to use a stronger cement, such as zinc polycarboxylate, especially where retention is limited.

Provisional restorations may break in service or when removing and replacing them for a multistage treatment. Either way a decision may be needed to repair or remake. A repair is usually the weaker option but may be sufficient to tide the patient over a short period. Again, a resin bonding agent can be used with a flowable composite, but it is important first to grind away the contaminated surface layer and, if available, use airborne-particle abrasion to tribochemically silicate the roughened surface [14] (see Chap. 15).

Conclusion

Quality restorative dentistry needs quality provisional restorations for predictable results. Dentists therefore need to be familiar with the range of materials and techniques for short-term, medium-term and long-term temporisation. Forethought and planning are also needed to ensure the most appropriate provisional restoration is used, especially when multiple teeth are to be prepared or where occlusal or aesthetic changes are envisaged. Such changes are best tried out with provisional restorations so that modifications can easily be made intraorally and when satisfactory copied into the definitive restorations. In this respect, an initial diagnostic wax-up is invaluable to facilitate the construction of laboratory-formed provisional restorations or matrices.

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Fitting and Cementation

24

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24.1 Learning Points

This chapter will emphasise the need to:

- Try in restorations using a logical sequence to locate issues preventing seating, and adjust for optimum fit, aesthetics, and occlusion
- Be aware of materials needing specific surface treatments prior to resin bonding
- Collaborate with your nurse and use scrupulous moisture control while adhesive bonding and when using multistage adhesives
- Select a conventional cement (e.g. zinc phosphate) for retentive preps with subgingival margins where resin bonding and removal of extruded cement would be difficult
- Appreciate the different approaches needed for luting veneers and securing implant crowns (screw-retained and cemented)
- Arrange follow-up and appropriate supportive periodontal care where this is indicated.

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The try-in and cementation of any extra-coronal restoration are critical to a successful and durable outcome. "The strength of a chain is in its weakest link", and nowhere in dentistry is this truer as for these final operative stages. The considerable time and effort spent during preceding stages may easily be undone by a cursory try-in, a poor choice of cement, or sloppy luting technique. Once cemented there is little scope for modification, and if a patient declares a restoration unacceptable, it is usually destroyed in the process of cutting it from the underlying preparation—a situation most dentists and patients would want to avoid.

24.2 Preoperative Procedure

Before the patient arrives, it is always reassuring to check the fit of a restoration on its die and inspect opposing stone teeth. The casts and dies of conventional dentistry are not only tangible but also allow areas of concern to be identified prior to trying-in restorations intraorally.

Examine the restoration using a good light and under magnification (2.5–5× is usually sufficient), ensuring the intaglio (fitting) surface of the restoration and the die are clear of defects and the margin does not appear overextended.

Look for rubbed die surfaces (i.e. where die spacer has been abraded and the stone shows through) and damaged stone margins. The former may indicate an area on the restoration's intaglio surface which will bind against the preparation and prevent it seating fully. The latter may indicate the die was poorly handled by the technician prior to waxing (or scanning). Alternatively, the die margin may have been damaged while seating a restoration with an overextended margin.

With multiple adjacent restorations, it is well worth asking your lab to pour a solid working cast in addition to the one sectioned for individual dies. The need for the solid cast arises because the relocation of sectioned dies in a working cast is not always reliable [1–3]. Without a solid cast, the potential for interproximal inaccuracy and the time taken to adjust can be significant.

Before the patient arrives, check the restoration's occlusion on either handheld or articulated casts. An overbuilt restoration and the risk of occlusal prematurity may arise from one or more issues which may have slipped past the lab's quality control:

- Abraded or damaged stone teeth
- Occlusal blebs and drags on the working casts and opposing casts
- Incorrect mounting of the intercuspal position (IP).

In addition, if the casts are mounted on an articulator, assess the shape and smoothness of guidance surfaces and if a restoration is likely to interfere in excursions.

Increasingly, these checks will not be possible with digital dentistry unless a hybrid approach is used with scanned casts, but restorations can still be inspected prior to try-in, e.g. for overextended margins.

24.3 Try-in Procedure

24.3.1 Explain Procedure and Remove Provisional Restoration

Explain to the patient that if the restoration can be tried in without local anaesthetic, they can help by giving feedback on the tightness of the contacts against adjacent teeth and the comfort of the “bite”. Of course, if a tooth is particularly sensitive, local anaesthetic may be necessary, and a few patients will insist on local anaesthetic for any operative procedure. An anaesthetised tooth requires an extra careful check of interproximal and occlusal contacts. Even so, it is best to anticipate the need for further adjustment and instruct the patient to return to the surgery if a restoration feels high when the numbness wears off. Bear in mind some patients can tolerate the fitting of a restoration but may need some local anaesthetic for cementation when water sprays and air jets prove uncomfortable.

Remove the provisional restoration taking care not to damage the preparation margin. If possible keep the provisional restoration intact in case it needs to be used again should there be a problem preventing the definitive restoration from being fitted. Dry the restoration and try first to remove it with gloved fingers. If that fails a good instrument for removing provisional restorations is one which allows them to be grasped just below the contour line (e.g. a towel clip or an old-fashioned pair of needle hub forceps). Some dentists use an excavator but this may cause marginal damage. A particularly useful method which avoids levering the restoration off at the margin is to apply a circumferential matrix band (e.g. Tofflemire or Siqveland). The band grips the restoration, while a gentle rocking action is applied to unseat it using the instrument’s handle.

Clean all temporary cement carefully from the preparation, particularly in grooves and in boxes. If any is left, the definitive restoration will be prevented from seating.

24.3.2 Seating the Definitive Restoration

Place the restoration on its preparation and try and seat it without undue force. If it fails to seat properly, the causative factors must be systematically identified and eliminated:

- Ensure there is no retained temporary cement or gingival tissue trapped under the restoration
- Recheck the restoration for other laboratory errors, e.g. casting blebs, overextended margins, and damaged die. Casting blebs can be carefully removed with a bur. Sharp features in stone dies are prone to damage during laboratory stages, so focus on corners of preparations and the corresponding fitting surfaces of the restoration

- Check and adjust tight proximal contacts which may be preventing the restoration from seating. Ultra-thin occlusal marking foil can be useful to mark tight proximal contacts. Hold the foil against the proximal aspect of the adjacent tooth using Miller's forceps and then seat the restoration, so the foil is sandwiched between restoration and tooth
- If there is a significant proximal discrepancy, recheck the working cast for damage to the proximal surface of the stone teeth and how well the die reseats
- Adjust overextended margins from the axial surface (see Fig. 24.1) and polish. If excess material is trimmed from below, it often results in a dismal outcome (see Fig. 24.2)

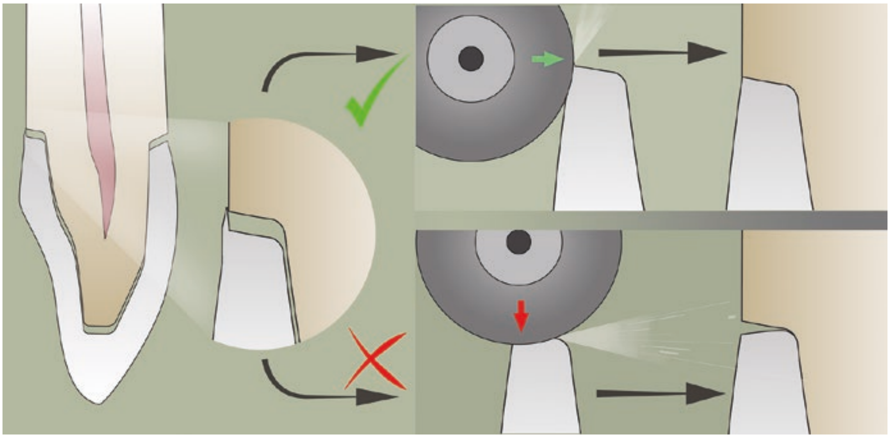

Fig. 24.1 Adjusting a marginal discrepancy caused by an overextended lingual margin. The right way is to reduce the overextension from the axial surface until the restoration seats. The wrong way is to reduce it from underneath which results in a deficient margin

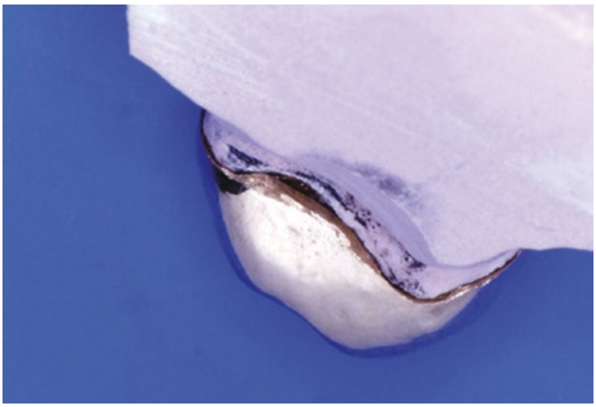

Fig. 24.2 A poorly trimmed margin ignoring the advice in Fig. 24.1. The resulting gap meant this restoration had to be remade

- If the restoration is still not seating, burnish marks on the matt intaglio surface of a metallic restoration may indicate where it is binding against the preparation, but this does not work for ceramic restorations. Aerosol sprays (e.g. Occlude Spray™, Pascal International) may help identify such areas but can be messy and are prone to build-up with repeated applications, particularly if it gets wet. Another, very precise, way of identifying binding areas on restorations is to use a fast-setting, light-bodied addition silicone. The impression material is injected into the restoration which is then seated. Once set, the restoration is removed from the mouth following which the shell of set impression material is peeled out using a pair of College forceps. By holding the shell up to the light, any holes in the impression will reveal where the restoration is binding. The corresponding areas on the restoration's intaglio surface can then be carefully adjusted with a bur before retrying fit.

24.3.3 Assessment of the Seated Restoration

Once the restoration is seated fully, you can then assess other factors in more detail:

24.3.3.1 Proximal Contacts

Use dental floss to ensure proximal contacts are not too tight or non-existent. The floss should pass through the contact without too much difficulty, but there should be some resistance. If the contacts are too tight, articulating paper can be used as described above to mark the contact's exact location, before lightly adjusting and polishing. If this is difficult to do intraorally, the contact may also be marked up with the restoration seated on the working cast. Take care not to open a contact accidentally when adjusting. An open proximal contact will predispose to food packing and may require the restoration to be returned to the laboratory for either modification (ceramic or solder addition) or remake. Occasionally, replacement of a defective proximal restoration in an adjacent tooth provides a simple expedient to establish proximal contact.

24.3.3.2 Marginal Fit

A restoration with good marginal fit reduces the risk of cement dissolution, recurrent caries, and plaque retention, thereby promoting tooth and gingival health [4]. Poor marginal fit may compromise a restoration's longevity and can present variously:

- Open margin—a visible gap or one which can be probed
- Positive ledge—a restoration margin which overhangs the preparation finishing line
- Negative ledge—an underextended restoration margin which leaves a step at the preparation finishing line.

Positive ledges can sometimes be corrected by adjusting the restoration from the axial surface (look again at Fig. 24.1), but a negative ledge or an open margin may require a restoration to be remade. Whatever type of marginal defect, it is worth discussing the cause of the problem with your laboratory, bearing in mind that the fault may lie with the impression.

24.3.3.3 Aesthetics

An aesthetic definitive restoration is likely to result if the planning, procedures, and concepts discussed in Chap. 17 are followed. However, it may still be necessary to make minor adjustments to the shade and shape of ceramic restorations at the time of fit. Ceramic can be recontoured using diamond burs and polishing instruments. The shade of ceramic restorations can also be altered, for example, by creating a darker shade with stains and refiring or changing the shade of translucent restorations by using a tinted cement lute. A water-soluble trial cement can be used to test a variety of tints before selecting a matching resin cement. This is described later for veneers.

When prescribing ceramo-metal restorations, these can be tried in at the 'biscuit bake'. This allows adjustments to be made to you and your patient's satisfaction before the final glaze. Some dentists do this routinely, but others reserve the biscuit bake for when they anticipate difficulty with getting the required shape and shade.

If a patient is unhappy with the appearance of a new restoration and any modifications are likely to be substantial, then it is better not to cement it, but instead temporise and get a new one made from scratch. To avoid further disappointment with the second restoration, the reasons for dissatisfaction with the first one must be determined.

Alternatively, if a patient is simply unsure about the aesthetics, a trial period with the restoration temporarily cemented can be helpful. This is discussed later, but before any restoration is luted into place, the occlusion must be checked and if necessary adjusted.

24.3.3.4 Occlusion

During planning the clinician should have determined the intended occlusal scheme (conformative or reorganised) and pattern of occlusal contacts for individual restorations. For example, a posterior restoration may only require holding contacts in IP and disclude during excursions, while an anterior restoration may have holding contacts and provide an excursive contact which helps guide mandibular movement (anterior guidance—see Chap. 12). Only by knowing what you want to achieve will you be able to achieve it.

Before you assess and adjust the occlusion, a restoration must be fully seated. In addition, its proximal contacts, marginal fit, and aesthetics should all be acceptable. Some restorations intended for adhesive retention are almost impossible to assess accurately in relation to occlusion until they have been cemented. However, a calcium hydroxide liner (e.g. Dycal™, Dentsply) may sometimes hold a restoration sufficiently to make assessments and adjustments before definitive cementation. Clearly, the advantage in completing occlusal adjustment before cementation is that adjusted areas can be easily polished, particularly if the lab is close by.

A systematic approach to adjusting the restoration's occlusion will provide the best results.

Firstly, with the restoration removed from the mouth, identify a pair of adjacent occluding teeth. These are known as "index teeth" (see Fig. 24.3). Reseat the restoration and use the separation between these index teeth to gauge visually how much (if any) adjustment is needed. In addition, use shim stock and articulating foil to check the occlusal contacts between the index teeth and between the restoration and its opposing teeth. Shim stock is an 8 μm Mylar™ film which can be held in forceps and used between occluding teeth to assess the firmness of contact. GHM Hanel™ (Prestige UK) articulating foil is available in double sided or single sided (which only marks one arch). We prefer double-sided foil which is only 12 μm thick and is less likely than thick articulating paper to give false marks. It is also below most patients' level of oral perception, so unlikely to influence jaw position. It is best used in Millers forceps (see Fig. 24.4) to prevent it from buckling and folding when inserted intraorally. Often, glazed ceramic and polished metal are initially difficult to mark. Metal can be made matt with airborne-particle abrasion, but this is unsuitable for ceramic. A top tip is to apply a thin layer of varnish (as might be used to seal newly placed glass ionomer cement) and allow to dry. This makes the first ink mark easier to see.

There are other highly sophisticated means of evaluating occlusal contact which are worth knowing about but are not in common use (see Box 24.1).

Assess occlusal contacts in the intercuspal position (IP) first. The aim with posterior restorations is to have firm shim stock contacts which are simultaneous with those of the adjacent teeth. However, with anterior restorations light shim stock contacts are needed, particularly if the other anterior teeth have light contacts.

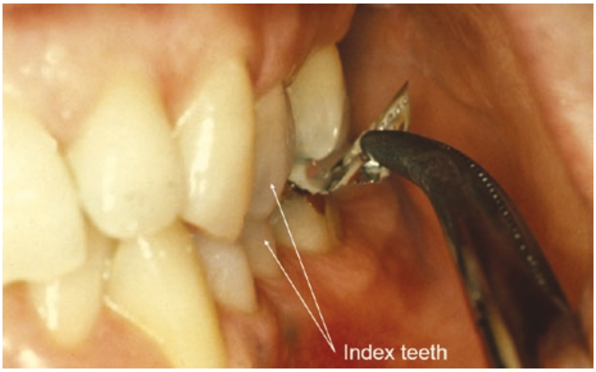

Fig. 24.3 Before fitting a restoration, identify a pair of occluding "index teeth" using shim stock. The separation of these teeth will help determine how much adjustment is needed when the restoration is fitted

Fig. 24.4 Coloured GHM articulating foil set-up in Millers forceps for checking the occlusion. Black GHM is used for intercuspal contacts and red for excursions. Note the gold onlay has *no* red marks because it has been adjusted to provide disclusion

Box 24.1: Sophisticated Occlusal Contact Analysis

Electronic devices have been developed such as T-scan™ (Tekscan Inc.) to evaluate occlusal contact. A digital display of forces generated between individual teeth is obtained via thin film pressure sensing technology. This technology has been used in a broad range of applications including medical, automotive, aerospace, agricultural, and civil engineering. The latest version of the dental T-scan™ gives highly reproducible results; however these may not represent the occlusal forces in IP as the teeth are separated by the pressure sensing film which is 0.1 mm thick [5]. Furthermore, the T-scan™ was found to be unsuitable for evaluating the occlusion of patients with severe skeletal discrepancies and occlusal problems [6]. From a practical perspective, articulating foil is still required as the T-scan™ does not mark occlusal contacts on the teeth.

Close examination of the occlusal contacts marked with GHM foil can give an indication of teeth subject to higher occlusal forces. These markings have the ink displaced from their Centre giving a 'bull's-eye' appearance [7]. Dentists who desire a more precise method of using articulating foils to evaluate biting force on individual teeth may wish to explore the dental Prescale system™ (Fuji Film) which uses a pressure sensitive film that marks with different coloured inks depending on the interocclusal force. The markings are then scanned electronically for occlusal force analysis.

Fig. 24.5 Guidance marked up on the anterior crowns. Metal backs have been used because of limited occlusal clearance and to reduce the risk of ceramic abrading the lower incisors. The metal has been airborne-particle abraded to show the occlusal markings. Note that lateral excursions are guided by the canines and protrusion by the central incisors. The lateral incisors are kept free of excursive contact to avoid overloading the relatively fragile tooth preparations

Most patients will readily detect an occlusal discrepancy, unless their teeth are numb. If local anaesthetic has been used, ask them to tap their teeth together and palpate the restored tooth for fremitus which is felt digitally as a vibration. In addition, a high restoration sounds different to when all the teeth are tapped together in IP. So, listen for a difference with the restoration in and with it out. The important message here is not to rely entirely on the articulating foil.

Once IP has been re-established, lateral excursions can be assessed. Again, this should involve marking up the contacts with GHM foil. Use a different colour from that which was used for assessing IP. We normally use black for IP contacts and red for excursions. Where you plan to have guiding contact ensure, this provides a smooth, harmonious excursive movement without displacing the restoration. With multiple anterior crowns, try and keep weaker lateral incisors free from guiding contacts (see Fig. 24.5).

Adjust new restorations occlusally with a large flame-shaped diamond bur and use an Iwanson gauge (a thickness gauge) to help prevent perforation of the restoration. Occasionally, you may need to make minor adjustments to an opposing tooth to prevent perforation of a new restoration or exposure of rough opaque ceramic. If this is anticipated, consent the patient appropriately in advance. The adjusted tooth should of course be smoothed and polished as should the restoration (see below).

As well as checking IP and lateral excursive contacts, we advise manipulating the mandible back into the retruded arc of closure to ensure a deflective contact has not been introduced by the new restoration.

Rarely, a new restoration may be short of occlusion. Few patients having a single extra-coronal restoration will be aware of the lack of occlusal contact, but eventually overeruption can cause occlusal instability and destructive interferences as teeth regain contact. It is better to ensure occlusal stability when restorations are fitted by taking care previously with appropriate tooth preparation/temporary restorations and accurate impressions/jaw registration. Interocclusal space is easily lost when multiple preparations extend along the full length of a posterior sextant. Often the loss of space occurs while mounting casts and can be avoided by using an accurate jaw registration. If you encounter new restorations which lack occlusal contact, decide on an individual basis whether to:

1. Monitor and possibly adjust the occlusion as it re-establishes
2. Add ceramic or solder, as appropriate, to correct the occlusal deficiency
3. Remake the restorations.

Options 2 or 3 may be preferable when patients are unhappy with the sensation of their newly restored teeth not meeting evenly.

24.3.3.5 Finishing and Polishing

Following adjustment, ceramic will be rough and needs to be smoothed and polished with a sequence of progressively finer abrasives. Polished ceramic is less abrasive and less likely to wear opposing natural teeth [8, 9]. Suitable rotary polishing instruments are available from several manufacturers. Occasionally, where a large adjustment is made, a restoration may need to be returned to the lab for reglazing. However, for monolithic zirconia, a polished surface is less abrasive than a glazed surface (see Chap. 14).

Metal surfaces can be polished with finishing burs and abrasive rubber points.

The bright reflectivity of metallic restorations (jewellery effect) may sometimes benefit from being dulled by airborne-particle abrasion of the surface using fine alumina particles or glass beads.

24.4 Luting the Restoration

Once the fit, aesthetics, and occlusion of a restoration are satisfactory, it can be luted (cemented) using a temporary, conventional, or adhesive cement. The variety of available cements and their applications are described further in Chap. 15.

Dentists may wish to consider using the immediate dentine sealing (IDS) technique for indirect composite and ceramic restorations involving areas of freshly cut dentine [10]. After tooth preparation the freshly cut dentine is sealed with dentine-bonding agent before recording the impression. As mentioned in Chaps. 9 and 15, the short-term advantages of IDS include improving bond strength and decreasing bacterial leakage, micro-gap formation, and dentine sensitivity. A recent review considers that although there is little long-term research in this field, there are currently no studies highlighting any major disadvantages [11]. Nevertheless, the approach requires a meticulous technique, particularly, as mentioned in Chap. 23, to avoid inadvertently bonding the provisional restoration to the sealed dentine surface. In addition, the sealed dentine surface must be effectively cleaned (e.g. polishing with fluoride free pumice [12]) prior to bonding the definitive restoration.

24.4.1 Temporary Cementation of a Definitive Restoration

Sometimes you may want to cement a definitive restoration temporarily to help a patient decide on aesthetics or to check the occlusion, phonetics, and access for appropriate hygiene. On other occasions, a patient may attend for crown fitting with pulpal symptoms from the prepared tooth. Here, it may be helpful to cement the crown with a soft cement allowing time to evaluate a potential endodontic problem that may require treatment. Realistically, this approach can only be used with crowns which have sufficient retention to allow a soft temporary cement such as Temp-Bond™ (Kerr Dental) to be used. If you intend to use a resin cement for the definitive lute, remember to use a non-eugenol version of Temp-Bond™. As discussed in Chap. 15, studies are equivocal as to the plasticising effects of eugenol on resin, but it is better not to take the risk.

With more retentive preparations, the cement can be softened further by adding one third modifier to equal measures of base and catalyst. This facilitates restoration removal at a later appointment. Another tip is not to fill a crown with cement but apply it only as a ring around the inner crown margin. Even so, a soft-cemented definitive crown can be more difficult to remove than a temporary crown which flexes more while being dislodged helping break the lute. Fortunately, if you are unsuccessful at removing a soft-cemented restoration with a matrix band, there are other options.

A wonderful invention, based on the principle of the sticky toffee, is the Richwil Crown and Bridge Remover™ (Almore International). The Remover is simply a small block of material which softens when placed in hot water. Once softened, the block is positioned over the crown needing to be removed, and the patient bites into it. To help position the block, insert a wooden interdental stick beforehand which acts as a handle. As it cools the block hardens and sticks to the occlusal surfaces of the restoration and opposing tooth. The patient is then instructed to snap his or her mouth open which invariably dislodges the temporarily cemented crown. Usually, the crown remains stuck to the block which in turn remains stuck to the opposing tooth. While the block can easily be peeled from the tooth, it often sticks tenaciously to the crown; if so, put it back into hot water before trying again.

24.4.2 Controlling Cement Thickness

As reviewed in Chap. 15, there are several methods which can be used to control cement film thickness. Die spacing is the most commonly used method [13], whereby the laboratory technician paints several layers of die relief agent over the whole die, but avoiding the preparation margin. Alternatively, with a CAD/CAM restoration, a lute space can be programmed in. Typically, a space of 30–40 μm is provided. This produces a crown which is a slightly loose fit on its preparation but with no rock. The luting cement fills the space during cementation. Controlling the volume of cement placed in the restoration prior to seating is also important. Too much and you risk not being able to seat the restoration; too little and voids will be left in the cement which may adversely affect retention. It is best to think of painting the cement over the whole intaglio surface rather than part-filling a crown with a flat plastic instrument.

External venting is a less commonly used method to reduce cement film thickness. This involves purposefully creating a perforation in the restoration's occlusal surface and restoring this separately following cementation. Internal venting is where an escape channel is made in the axial wall of the preparation or the intaglio surface of the restoration to help excess cement escape.

24.4.3 Deciding on the Type of Cement Lute

The luting technique will depend on the type of restoration and the choice of cement. In the past when only conventional cements (i.e. zinc phosphate, glass ionomer, and zinc polycarboxylate) were available, it was very simple. Nowadays, there are several adhesive resin alternatives and surface preparations (see Chap. 15) which can be used instead of conventional cements. In the main these resin cements are dual-cured to allow cementation of restorations where a curing light cannot penetrate effectively. They can provide excellent bond strengths but are all technique sensitive particularly in respect of moisture control and clean-up of extruded cement. So, conventional cements still have their place, particularly for restorations with retentive preparations and subgingival margins.

In the following two sections, we will firstly consider techniques for luting with conventional cements (including dual-cured adhesive resin alternatives) and secondly veneer cementation. Adhesive resin cements are essential for luting veneers. Veneers are often sufficiently translucent for a light-cured lute which offers better long-term colour stability than dual-cured lutes [14].

24.4.4 Luting Technique for Conventional Cements and Adhesive Resin Alternatives

The cementation of restorations using conventional or adhesive resin cements will share certain stages which are outlined in Box 24.2. With adhesive cements, the protocol will vary significantly between materials. Consequently, manufacturer's instructions should be followed closely for effective conditioning and priming. This advice applies to all resin luting materials including those for luting posts (see Chap. 19).

Conventional cements must be allowed to set before the excess is removed. However, with adhesive resin cements, the excess is best removed soon after seating. If left to set, any excess resin adheres to the tooth and restoration. Rotary instruments are then required to remove it which can be particularly difficult proximally. The excess resin may therefore remain as "iatrogenic calculus". This problem is

Box 24.2: Luting Techniques for Conventional and Self-Cured Adhesive Cements

- Isolate the preparation and ensure good moisture control. This is particularly important for adhesive cements. Isolation with rubber dam can be beneficial, but there are two caveats: Firstly, the applied dam must not creep onto the preparation and get trapped under the margin of a luted restoration. Secondly, don't risk gingival recession from a dam clamp damaging delicate periodontium.
- Clean the preparation and restoration with water spray.
- Air-dry but do not desiccate the preparation.
- Apply conditioner and/or primer to the tooth, and apply silane treatment or metal primer to the intaglio surface—As necessary (*if adhesive* cement).
- Mix the cement according to manufacturer's instructions.
- Lightly coat the fitting surface of the restoration—Some operators use a brush.
- Seat the restoration quickly with firm finger pressure—Excess cement will be expressed from the margins.
- Maintain pressure on the restoration for about 1 min.
- Remove excess cement soon after seating and before cement sets (*if adhesive cement*)—See Fig. 24.6.
- Use a visible light activation unit to fully cure or apply an oxygen barrier gel around the margin (*if adhesive cement*)—See Fig. 24.6.
- Remove excess cement once cement sets (*if conventional* cement)—See Fig. 24.7.
- Clean and thoroughly check interproximal areas using floss or tape—See Fig. 24.7.
- Final evaluation of the restoration in situ includes a further check of the occlusion.

exacerbated with subgingival margins where difficulties of access and moisture control make adhesive resin cements an increasingly unsuitable choice the more subgingival the margin.

24.4.5 Luting Technique for Veneers

As mentioned previously, light-cured resin cements are best for luting veneers unless they are too opaque for the curing light to penetrate. Several products are available specifically for luting veneers, and these come with water-soluble try-in pastes colour matched to the corresponding luting composites. However, some dentists prefer to use preheated restorative composite. Preheating makes the viscous composite flow more easily, and it is claimed that the lute will have superior physical properties [15].

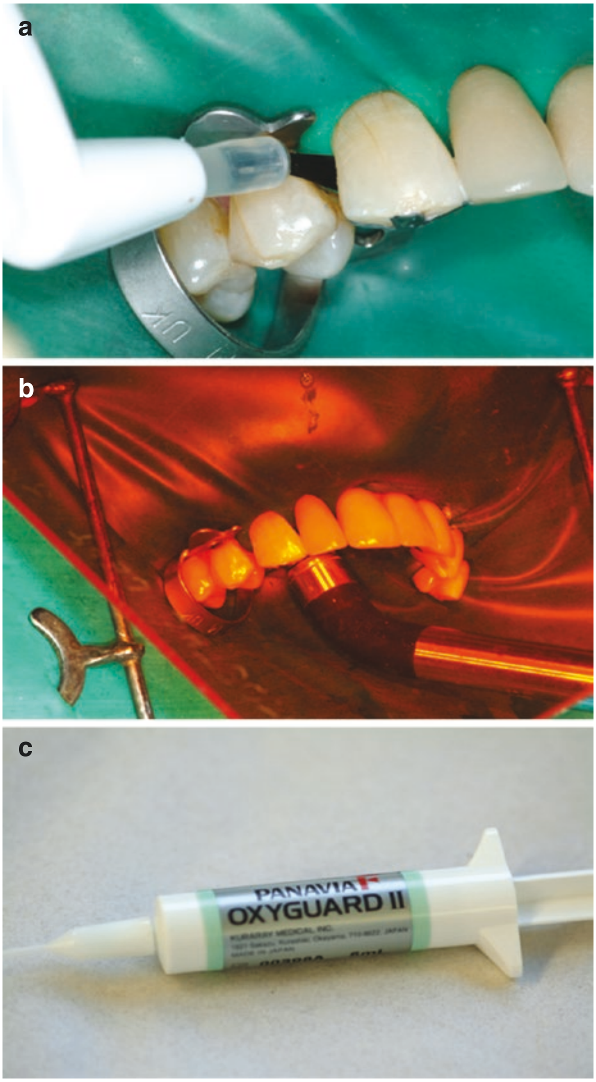

Fig. 24.6 A dual-cured resin cement used to lute a palatal onlay at 13. Remove excess resin cement before setting with a dry brush (**a**). After each sweep clean the brush with a tissue. Then follow with Superfloss™ interproximally. To prevent oxygen inhibition of the resin exposed at the margins, the area can either be light-cured (**b**) or covered with a layer of air-excluding paste (**c**)

It may indeed be a good idea but needs some evidence to support it as a mainstream option. Moreover, if a different shade is needed, the unset composite is removed from the veneer with a solvent which may have a detrimental effect on bond strength.

Outlined below are the main steps for veneer luting. Again, manufacturer's instructions should be carefully consulted as there will be minor but potentially important variations between products. It is best to think of there being two distinct processes: firstly, the preparation of the veneer and tooth for bonding and, secondly, dentine bonding and veneer luting. Veneers and other small restorations are easily dropped if handled directly with gloved hands. Better to use an adhesive tipped instrument, e.g. OptraStick™, Ivoclar Vivadent.

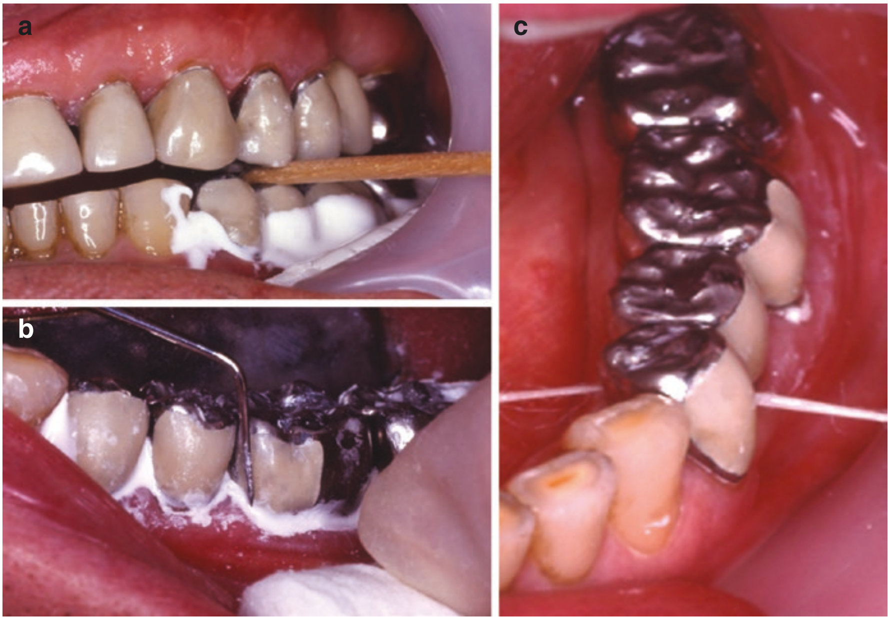

Fig. 24.7 Conventional cementation with zinc phosphate or glass ionomer cement: After trying in the restorations, load the crowns with a thin layer of cement and seat. The patient can bite on orange stick to maximise seating of the ceramo-metal crowns (**a**)—but this may risk fracture of ceramic restorations. The *cement must set before excess is removed* with a sharp probe (**b**) The proximal excess is removed from each restoration using floss (**c**)

24.4.5.1 Preparation of the Veneer and Tooth

1. For ceramic veneers, etch the intaglio surface using hydrofluoric acid (HF). The dental laboratory usually does this, but remember HF concentration and etching time are ceramic specific. For composite veneers roughen the intaglio surface by airborne-particle abrasion. In the laboratory Rocatec™ can be used and in the surgery Cojet™, 3M—ESPE (see Chap. 15).
2. Clean tooth with pumice; rinse thoroughly and lightly air-dry.
3. Check the fit and aesthetics of the restoration. The initial try-in can be made using water which gives a similar effect to a translucent try-in paste and allows the underlying tooth colour to influence the veneer shade.
4. If the colour needs to be adjusted, select an appropriate shade of try-in paste, and apply to the veneer's intaglio surface. Gently seat the veneer onto its tooth preparation. With multiple veneers, start at the midline and seat veneers sequentially working back.
5. Having confirmed fit and aesthetics, remove the veneers, and with a water spray, thoroughly rinse away the try-in paste from the tooth and restoration and then dry. Do not place the etched veneers onto the stone working cast as the stone residue can significantly reduce resin bond strength [16].

6. Clean the veneer's intaglio surface thoroughly with 35% phosphoric acid prior to applying the silane (for ceramic veneers) or adhesive (for composite veneers). Apply the acid with a Microbrush X™, Microbrush, for 15 s followed by rinsing and drying. Then either:
   (a) Brush a layer of the manufacturer's silane onto the intaglio surface of the *ceramic veneer*, and lightly air-dry to evaporate the solvent.
   (b) Or apply resin adhesive to the intaglio surface of the *composite veneer*. Evaporate the solvent with a gentle stream of air over the adhesive for about 5 s until it no longer moves. Do not light-cure at this stage.
7. Reclean the prepared teeth using flour of pumice slurry. Rinse and lightly dry. Isolate the area to prevent contamination. Place Mylar™ matrix strips through the proximal contacts between teeth to prevent unwanted bonding to adjacent teeth.

24.4.5.2 Dentine Bonding (Total-Etch Technique) and Veneer Luting

1. Etch the tooth preparation with 34–35% phosphoric acid. Apply etchant to both dentin and enamel for 15 s. Rinse for 10 s. Blot excess water leaving the tooth moist, but if it is accidentally dried, rewet the bonding surface with water for 15 s and re-blot to leave moist.
2. The application of dentine-bonding agents to the moist tooth surface will either be two-stage or one-stage depending on whether there is a separate primer and bond or if they are combined. Check the number of applications required, and remember to evaporate the solvent from the primer using a gentle stream of air. Remember also to apply the bond to the intaglio surface of the silanated ceramic veneer. Don't light-cure just yet or the fit of the veneer will be jeopardised.
3. Syringe a thin layer of the selected shade of the veneer cement onto the veneer's bonding surface. Keep the applied cement under cover away from strong lighting.
4. Seat the veneer using gentle pressure allowing excess cement to extrude from the margins. Secure the veneer into place by spot curing on the facial surface away from the margins using a small diameter light guide for 20 s.
5. Remove excess unset cement from the margins using a blunt instrument (see Fig. 24.8) or a dry brush. Alternatively, the excess cement can be 'tack-cured' for 3 s with a standard halogen light causing the excess to gel and allow for easier clean-up.
6. Light-cure the labial, lingual, proximal, and occlusal surfaces for 30 s each. A longer exposure of at least 40 s for each surface is required for opaque or dark cement shades. Ensure the light-curing unit has a minimum light output of 400 mW/cm^2 [17].
7. Remove the interproximal matrix strips. Then remove any gross excess of cement using flame-shaped composite finishing burs (Fig. 24.8). Check and adjust the occlusion taking care that contact against the veneer does not inadvertently lift

the adjacent teeth out of contact in protrusion. With multiple upper incisor veneers, spread the edge-to-edge contact across two or more veneers.

8. We recommend making a separate appointment for fine finishing and polishing of the margins. This also allows the occlusion to be rechecked. Although various strips and discs are available, careful use of finishing burs under magnification is often the only way to reach otherwise inaccessible margins. An excellent final finish can be achieved with diamond polishing pastes applied with a rubber cup (see Fig. 24.8).

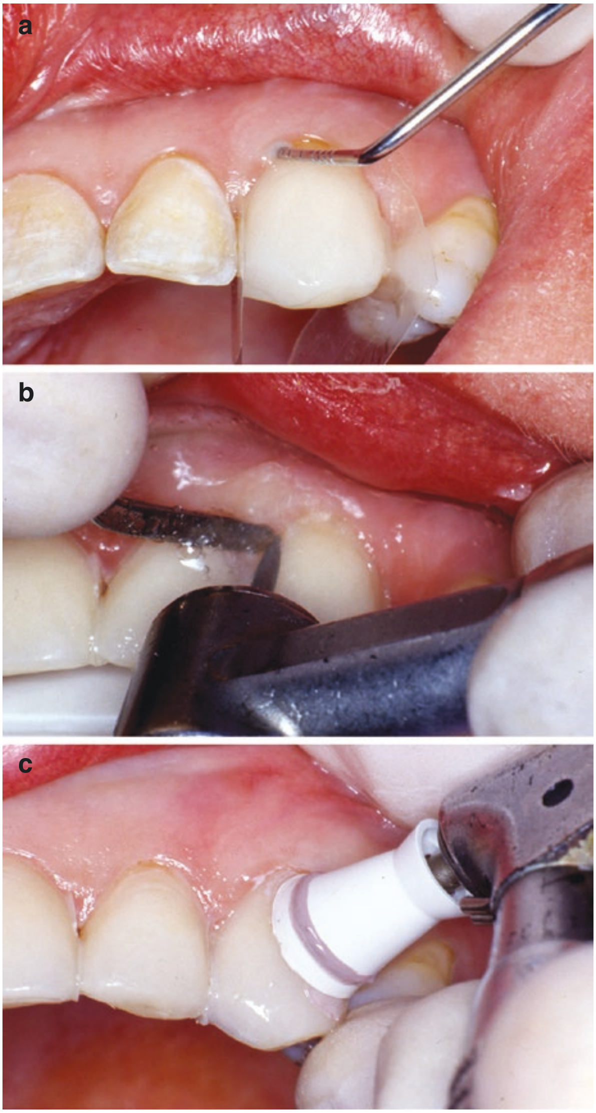

Fig. 24.8 Luting of a ceramic veneer at 13. Use interproximal Mylar™ matrices to stop adjacent teeth and veneers from being bonded together (**a**) and a periodontal probe, and dry brush to remove excess unset cement. Protect the gingivae (e.g. with a flat plastic instrument or similar) while removing any remaining excess with a flame-shaped finishing bur (**b**) After using a sequence of finishing strips and discs, polish the margins and other adjusted areas with diamond paste (**c**)

24.4.6 Bonding Substrates

Instruction cards from several manufacturers detail a slightly different cementation process for “posterior” or “anterior” restorations. With closer scrutiny, the “posterior” systems often employ self-etching primers for dentine bonding—and the “anterior” systems employ a total-etch technique for enamel and dentine bonding. Most of the time, this may be entirely appropriate, but what if you are intending to bond to enamel posteriorly—for example, with adhesively retained onlays when increasing vertical dimension or a resin-bonded bridge wing? The bonding could be compromised by employing a self-etching system rather than total etch. This is where selective etching of the enamel can be employed—but it is, by definition, rather technique sensitive. Dentists may opt to accept the slightly inferior bond strengths of self-etching and self-adhesive products in clinical cases where it would be tricky to carry out the multiple stages of a total-etch technique.

Where teeth are already heavily restored with composite or glass ionomer restorations, a decision must be made whether an underlying restoration is sound and can be bonded to or if it needs to be replaced. If in doubt, it should be replaced. It may even be possible to incorporate a smaller restoration after the new veneer has been cemented. Alternatively, replace the composite before the tooth is prepped, and then prior to cementation, maximise the bond, e.g. by airborne-particle abrasion with Cojet™ (3M—ESPE), to silicate the composite’s surface followed by application of a silane coupling agent. Rubber dam application is recommended to protect the airway from abrasive particles.

Airborne-particle abrasion with 50 μm alumina may also be required to clean and microscopically roughen sclerosed dentine prior to bonding. Sclerosed dentine may be a feature in some presentations of tooth surface loss, but as mentioned in Chap. 15, further research is needed to establish the optimum bonding regime for these cases.

24.5 Implant Crown Try-in and Cementation

As discussed in Chap. 2, implant restorations are becomingly progressively mainstream with a growing interest from patients and general dental practitioners. Practitioners wishing to provide implant dentistry including the provision of implant crowns and other implant-retained restorations should of course be suitably trained (see Chap. 16, Box 24.1). Nevertheless, dentists without formal implant training may be asked by a patient to recement a crown to an implant abutment. So, there are practical as well as professional benefits in knowing how implant crowns are tried in and then either screw-retained or cemented.

With either a screw-retained or cement-retained implant crown, the try-in process follows similar principles as discussed earlier in this chapter for crowns for natural teeth. Careful assessment of the crown and die (or abutment) prior to try-in is essential, followed by thorough clinical assessment of the fit, proximal contacts, aesthetics, and occlusion.

The occlusal management of implant crowns differs from that on natural teeth because implants lack a periodontal ligament. Consequently, natural teeth can move

Fig. 24.9 Use three layers of shim stock to assess firm occlusal contact of an implant-retained crown (here at tooth 15). The adjacent occluding teeth should hold one layer of shim, but the implant-retained crown should hold three layers and just allow two layers to pull through

axially by 25–100 μm compared to only 3–5 μm for dental implants [18]. Therefore, when fitting implant restorations in dentitions still having multiple opposing occlusal contacts, use a triple layer of GHM articulating foil to gauge adequate clearance (Fig. 24.9). An implant crown with a localised 20 μm interocclusal clearance allows adjacent teeth to be naturally intruded in their periodontal ligaments without leaving it occlusally overloaded.

24.5.1 Screw-Retained Restorations

Where possible, we provide screw-retained restorations for implants because:

- There are no problems with the clean-up of excess cement
- They are retrievable allowing for straightforward maintenance
- They don't rely on having long, retentive abutments needed for a cement lute.

The restoration should be tried-in like a cement-retained crown on a natural tooth with attention to the proximal contact points and occlusion. It is worth mentioning that even the smallest error on the master cast can lead to significant defects at fitting. This is because any errors on the cast are magnified by the length of the restoration and highlights the need for accurate impressions (see Chap. 22) and excellent technical support. An unhurried approach is helpful as repeated and frenetic trying in of a restoration while carrying out adjustments can be uncomfortable for the patient. Additionally, the interproximal and occlusal contacts can be difficult to assess fully until the restoration is tightened to its final torque.

Once the restoration has been adjusted, secure it by tightening the abutment screw to the required value (usually 35 Ncm). Next close the screw access. A good way of doing this is first to plug the base of the cavity with sterile PTFE tape leaving sufficient space for a resin composite restoration above (Fig. 24.7). The PTFE tape

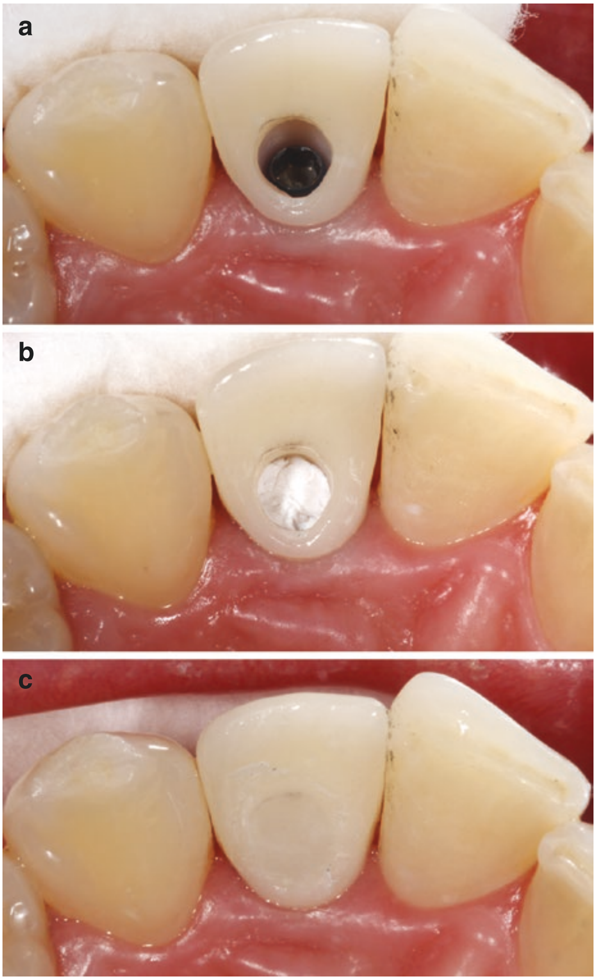

Fig. 24.10 Restoring the screw access hole in a screw-retained implant crown: empty screw access hole showing the head of the abutment screw (**a**) PTFE tape packed into the hole to protect the head of the abutment screw (**b**) Resin composite restoration (**c**)

serves to protect the head of the abutment screw should it need to be accessed later for maintenance. The tape remains much cleaner than the traditional cotton wool plug and is also delightfully easy to remove. Remember that composites covering screw access holes often fail (see Chap. 2). This may be because they are bitten into the access hole, so like an endodontic access cavity, ensure the cavity walls have a slight outward taper or incorporate a suitable step to resist displacement (Fig. 24.10).

24.5.2 Cement-Retained Restorations

Despite their inherent problems, cement-retained restorations remain popular with many dentists. This is largely because in comparison with screw-retained restorations, the abutment for a cement-retained restoration can more easily accommodate re-angulation from implant to restoration trajectory to achieve optimal aesthetics.

Although the try-in process of a cement-retained restoration is like that of teeth, the cementation process can be rather more challenging, particularly where crown margins are deeply subgingival. Hence, the biggest potential complication with cement-retained implant restorations is extrusion of excess cement into the delicate soft tissues of the peri-implant area. If the extruded cement is not effectively removed, inflammation inevitably results (peri-implant mucositis, peri-implantitis) which can lead to bone loss and implant failure. Bear in mind the soft tissue attachment around implants is much more delicate than that around teeth.

The peri-implant tissues are particularly vulnerable after an abutment is fitted as time is needed for soft tissue attachment. Consequently, if a crown is cemented soon after abutment placement, there will be little resistance to excess cement flowing deep into the gingival sulcus. Even a mature tissue attachment to an abutment will be much weaker than that formed to a healthy tooth: The cuff of tissue surrounding an implant abutment has no Sharpey fibre insertions, and the collagen fibre structures and fibre orientations are weaker. Again to avoid disrupting the peri-implant tissues, when recording impressions for a cement-retained implant crown (see Chap. 21), retraction cord should be used with care and some dentists try to avoid using it at all [19], in fear of causing a defect into which excess cement can flow [20].

Traditionally, crown margins on natural teeth are made supragingival or 0.5–1 mm subgingival. By contrast, margins on implant crowns may extend much further subgingivally to hide the abutment-crown junction, accommodate any future gingival recession or because stock abutments fail to allow for adequate customisation of the finish line. Consequently, it may be difficult or impossible to remove all excess cement extruded subgingivally. Furthermore, dental radiographs are often inadequate in detecting excess cement. Linkevicius et al. have recommended implant crowns are made with supragingival margins [21], but how acceptable this would be to most patients is debatable.

The amount of cement used for luting implant crowns is critical, much more so than for natural teeth where a more robust soft tissue attachment limits subgingival cement extrusion. In a study of 401 dentists, each was asked to load a crown with cement as if it were to be cemented clinically onto an implant abutment [22]. It was observed that 35% of them placed over 17 times more cement than was required. On average, this resulted in 94% of the cement being extruded which would clearly be a concern with deeply subgingival margins.

The choice of cement is important for teeth but also for implant abutments. For implant crowns the two main considerations are avoiding problems with excess cement after placement and securing sufficient retention. Perhaps surprisingly, zinc phosphate remains a good choice as extruded cement doesn't adhere strongly to the restoration and can be removed relatively easily. If the abutment is unretentive, an adhesive resin may be considered where there the margin is sufficiently accessible for cement clear-up. However, bear in mind that combining adhesive cements with abutments or restorations made from zirconia may not offer a good long-term solution (see Chap. 14).

Novel techniques have been suggested to manage the menace of excess cement. For example, a rubber dam can be placed around the abutment during crown cementation to channel the flow of excess externally and aid removal [23]. Alternatively, the cement flow may be channelled internally into a recess within the abutment formed by leaving open the access hole for the abutment screw. This approach requires vents within the abutment and is only practicable with titanium abutments [24]. Wadhwani and Pineyro [25] recommend pre-extruding the cement by seating the cement-filled crown on an abutment replica before seating it on the abutment intraorally. A spacer made of PTFE tape, adapted over the replica, is used to prevent the cement sticking prematurely. They claim this results in an optimum layer of cement with little excess. These techniques are ingenious, but so far unproven.

24.6 Follow-Up

Most dentists appreciate the need for effective home care to maintain healthy tooth-retained and implant-retained restorations. It is not enough just to advise patients—they need to be shown to develop the necessary skills. This is all part of "supportive periodontal care" (see Chaps. 4 and 10) which is often best carried out in the general practice setting where patients attend regularly. Implant patients may be under an illusion that their restorations are "fit and forget", so they may need education and gentle encouragement to avoid future problems. Once peri-implantitis becomes established, its management may require specialist skills or advice, so prevention is the better option.

A range of homecare products and techniques are available to suit different clinical situations and dexterities. These should include brushing (either manual or electric/sonic) and interproximal cleaning (flossing, interproximal brushes). With implant-retained restorations, home care and professional cleaning must not damage the implant surface. For example, interdental brushes should have plastic-coated wires. Scaling instruments should be constructed of materials that are effective in removing calculus but do not cause damage to the implant surface, e.g. titanium, gold plated, or plastic.

A short-term review (1 month) is useful to check plaque control and provide motivation. Thereafter, a suitable recall can be decided to suit a patient's disease susceptibility.

Sufficient time needs to be set aside for supportive periodontal care, and some specialists may allow up to an hour; however much less time is needed for patients with only one or two implants in an otherwise healthy mouth. The four essential phases at these appointments are:

1. Examination (see Chaps. 10 and 18), re-evaluation, and diagnosis
2. Motivation and reinforcement of oral hygiene instructions
3. Debridement (prophylaxis and instrumentation) and treatment of infected sites (which may require specialist input)
4. Polishing and reviewing the recall interval [26].

Clearly, general health and other factors which may influence periodontal breakdown and peri-implantitis (e.g. smoking, occlusal overload, etc.) as described in Chap. 4 also need to be considered and managed, including appropriate referral if medical or specialist advice/input is required.

Conclusion

Fitting a restoration has always required skill to get a good result. Nowadays, dentists also need an appreciation of the wide range of luting materials available and when and how to use them. In addition, there are now many surface treatments available for enhancing the bond to different materials. For predictable results, the correct sequence of materials must be applied to the tooth and restoration whilst maintaining scrupulous moisture control. With multi-stage adhesive luting, close team work between the dentist and dental nurse is essential. Once set, excess cement must be removed, and nowhere is this more important than with cemented implant crowns where conventional zinc phosphate still has a role to play. An appropriate follow-up regime should be arranged for supportive periodontal care where this is indicated.

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25 Adapting Crowns to Existing Prostheses

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25.1 Learning Points

This chapter will consider:

- Retrofitting a new crown to an existing partial denture
- Techniques that avoid sending a patient's denture to the laboratory
- Techniques based on whether the new crown needs to:
  - Fit only against an alloy denture connector
  - Fit also against existing clasps and rests
- Techniques for retrofitting crowns made with modern materials and CAD/CAM production.

25.2 Introduction

The length and quality of service provided by a partial denture depend on the maintenance of both the denture itself and the patient's supporting dentition. As tooth units are lost, it may be possible simply to augment an existing prosthesis by adding denture teeth and pink acrylic. However, if supporting teeth require either a new or replacement extra-coronal restoration, the adaptation of the new restoration to the denture may be problematic, particularly for an existing alloy denture and if dentists are not aware of all the options. If the existing denture is replaced, it is expensive.

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A reasonable short-term solution is simply to cut off clasps and rests, but loss of support, retention, and fit, may eventually have unwanted consequences.

A better option is to create a new extra-coronal restoration which conforms accurately to the existing alloy denture and to the occlusion. This is not an over-challenging task and allows a satisfactory denture to remain in service. Therefore, this chapter provides an outline of techniques for how to do this. When carried out successfully, they can save time for the dentist and expenditure for the patient. In addition to the various impression techniques for the new restoration, will invariably be required an accurate opposing impression and an appropriate interocclusal record.

Since Killebrew first published on this topic in 1965 [1], many revised techniques have been described [2]; some of them are so complex and technique-sensitive that they can be tricky to execute precisely. Conversely, some are simple but may require extensive adjustment of the final extra-coronal restoration prior to cementation [3]. Others, whilst working effectively, have been superseded by more user-friendly techniques, with the introduction of new materials and new crown production methods. Many earlier reported techniques involve recording information about the original form of the tooth in question [4], but little or no information was gathered about the denture itself. Nowadays, much greater efforts are made to record the features of the existing denture.

A range of techniques illustrative of the many available will be described including two preferred methods currently used at several UK dental schools.

25.3 Simple Method

The simplest technique is to record an impression for the new crown with the denture in place. In this way, the denture is picked up within the impression and sent to the laboratory. Before pouring-up and to allow the denture to be easily removed from the cast, any undercuts are carefully blocked out. The denture can later be seated on and off the cast and a closely adapted wax-up made for the new crown [5]. A major disadvantage with this method is that patients are left without the denture between appointments. However, most of the other techniques described below allow patients to keep the denture.

Where only the fit surface of the denture needs to be accommodated against a new crown, we recommend the following technique: A working impression of the preparation is recorded with the denture in situ. However, instead of sending the denture to the laboratory, it is removed from the impression and returned to the patient. The technical process [6] is outlined in Fig. 25.1 and involves the lab making an acrylic matrix representing the denture's fitting surface in the region of the crown preparation. To do this, the technician flows acrylic pattern resin into the impression space previously occupied by the denture. To aid subsequent location of the matrix, acrylic is also flowed into the lingual aspects of the impression spaces of adjacent teeth. Once set, the acrylic matrix is removed and relocated on the stone cast allowing adaptation of the restoration pattern to the matrix and full access to the preparation margins.

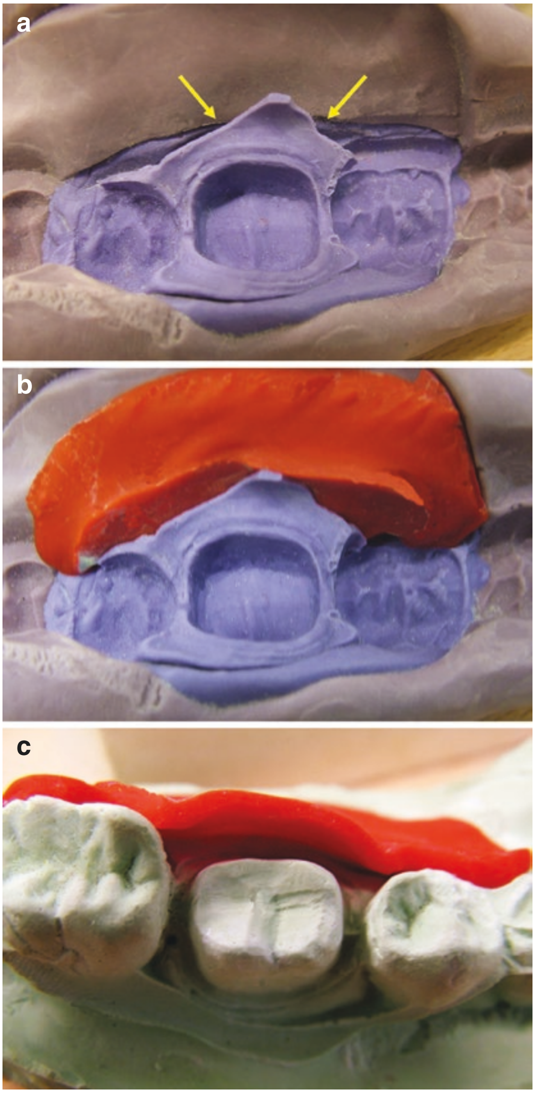

Fig. 25.1 Creation of a localised replica of a denture connector. The impression is recorded with the denture in situ. On removing the denture, it leaves a recess—see arrows (**a**). Red pattern resin (Duralay™, Reliance Dental Manufacturing) has been poured into the recess—note the impression has been trimmed back afterwards to show how the pattern resin replicates the fit surface of the denture (**b**). To make a working cast, die stone is then poured against the acrylic replica. This gives a denture replica (matrix) which can be removed and re-seated reliably on the cast (**c**)

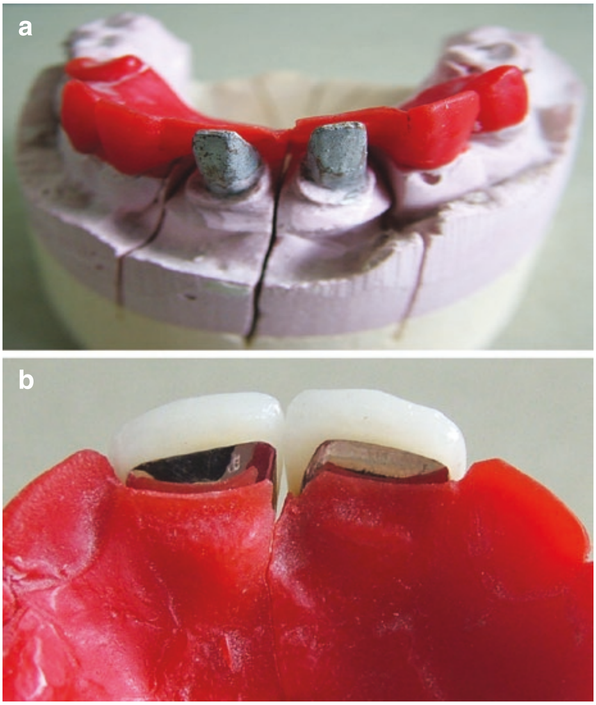

Fig. 25.2 Another localised replica of a denture: Here teeth adjacent to the preparations have been included in the matrix to improve its location on the sectioned working cast (**a**). The lingual and proximal surfaces of the two ceramo-metal crowns have been formed against the matrix (**b**)

An alternative which works well when adapting new anterior crowns to an existing partial denture is to incorporate the adjacent teeth in the acrylic denture replica. This approach gives very positive reseating of the acrylic matrix against the underlying stone cast (Fig. 25.2) and avoids having fragile stone teeth anteriorly which may fracture easily.

25.4 Accommodating Clasps and Rests

Whilst the previously described methods are useful, they are not a good solution for rests and clasps. The relationship of these more intricate elements to the preparation is best recorded *directly*. A convenient way of doing this is with a silicone matrix. This is made by syringing a silicone mousse material, normally used for occlusal registration, around the preparation with the denture in place (see Fig. 25.3). Importantly, the denture is *not* picked up within the working impression for the new crown. Instead, the working impression is recorded as normal without the denture in place. This impression along with the separate silicone index is sent to the laboratory. A provisional restoration for the preparation is made in the usual way (see Chap. 23), but to prevent it being dislodged, take care to ease it where it fits tightly against the partial denture.

In the lab, a removable replica of the clasps and occlusal rests is made by flowing acrylic pattern resin into the silicone index located on the stone die. Once set, this

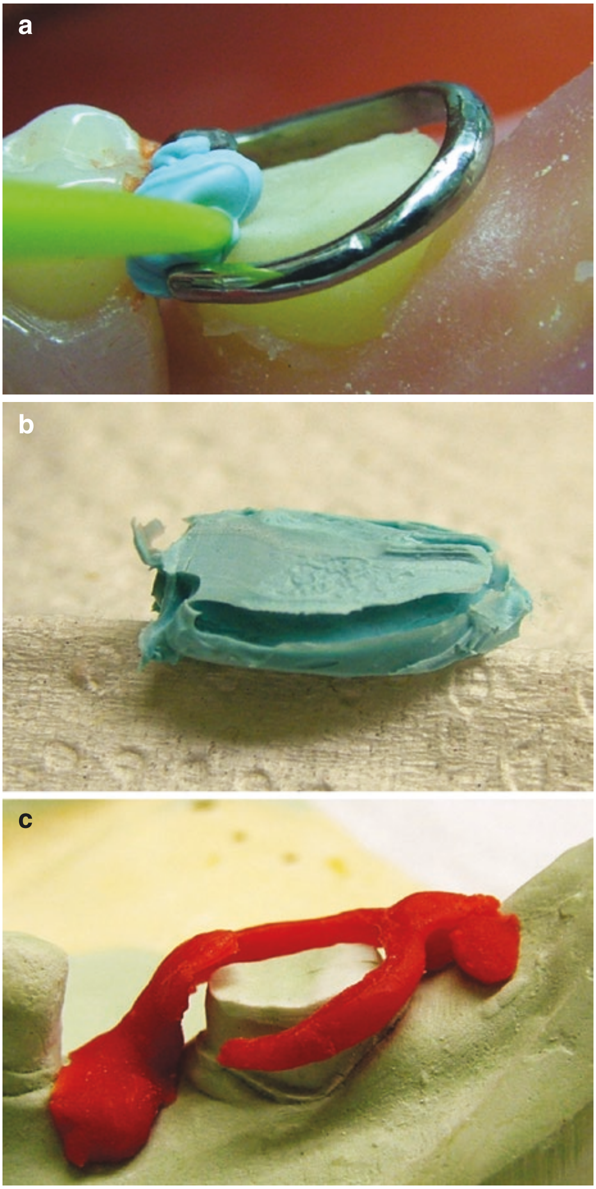

Fig. 25.3 Capturing the position of a clasp and occlusal rest for a new extra-coronal restoration. The silicone mousse is syringed under the rest and the clasp with the denture fully seated (**a**). The outline of these features must be captured clearly in the set mousse (**b**). The mousse impression is placed on the preparation die and an acrylic replica of the rest and clasp is formed. The "feet" mesially and distally are to locate it on the working cast (**c**)

replica forms an index which is used to shape the wax pattern for the crown. The replica must be reliably relocated on the cast to ensure clasps and rests are correctly orientated. One way of creating a stable location for the replica is to extend the resin into two or more holes strategically drilled into the working cast [7]. Another way, which we prefer, is simply to extend the resin mesially and distally onto suitable features already present on the stone surface.

Box 25.1: Other Ways of Adapting a New Crown to Existing Clasps and Rests

- Livaditis et al. [10] advocate syringing silicone mousse over the preparation *and then* seating the denture over the top. This is a good approach providing the silicone mousse does not prevent the denture seating fully as may occur if it is partly set.
- Thurgood et al. [11] and Lumley and Rollins [12] describe the process of creating a full resin matrix entirely in the patient's mouth. This is a time-consuming and technique-sensitive approach. Clearly, the pattern resin must not be allowed to envelope the clasps and rests or the matrix will be locked in once set.
- Welsh [13] advocates the manipulation of self-cure resin into a non-tacky consistency chair-side which is then pushed down over the prepared tooth and the denture then seated. Notwithstanding the potential inaccuracies described above, this approach also provides a relatively poor adaptation of the resin matrix to the underlying tooth preparation and denture.
- Lubovich and Petersen [14] describe forming the pattern for the new restoration entirely in the mouth. This is done using an occlusal pre-preparation wax matrix. After the tooth is prepared, the wax matrix filled with pattern resin is seated onto the prep. As the resin begins to set, the wax matrix is removed and the denture seated into place allowing the claps and rest assemblies to imprint onto the surface of the resin. The resin pattern is then processed in the usual way.
- A modification to the preceding technique relies on the initial production of a metal coping. The coping is then augmented with pattern resin with the denture in situ. The augmented coping is processed in the usual way and incorporated into the restoration [15].

There are several similar techniques for dealing with clasps and rests (see Box 25.1).

25.5 Accommodating Precision Attachments

Although this presentation is comparatively rare, it may occasionally be necessary to consider retrofitting a new extra-coronal restoration to a denture precision attachment. This is described most recently by Uludag [8]—although the precision attachment described in the paper is probably only available in and around Turkey. Nonetheless, the method may be adapted for retrofitting crowns having an extra-coronal attachment (patrix) which engages with a resilient matrix within a free-end partial denture. This sort of resilient matrix allows a small amount of hinge movement of the denture under occlusal loading. Essentially, the denture is picked up within the crown impression and a master cast poured up. The denture is then removed from the cast and a proprietary patrix pattern inserted in the resilient matrix within the denture. With the patrix pattern correctly located, it can then be waxed into the coping for the new crown and then cast. A disadvantage of the technique is that patients need to be without their denture between appointments, but this may be a small price to pay compared with having a sophisticated partial denture remade.

25.6 CAD/CAM

Marchack [9] describes a method of creating a durable zirconia coping designed to contact the denture components, whilst the aesthetic parts of the crown are built in weaker sintered ceramic (see Chap. 14). The clinic and laboratory procedures are as follows:

In the clinic, the denture is seated and provisional crown composite syringed over the tooth preparation and under the denture components. Once set, the resulting composite coping captures the denture's guide planes. It also captures the fit surfaces of the rest seats and clasp assemblies. The composite coping is removed and an impression recorded of the tooth preparation without the denture in place. Both the impression and coping are sent to the laboratory.

In the laboratory, the cast is poured. The die is then trimmed and scanned. Before placing the coping on the die, it is cut back to accommodate the aesthetic sintered ceramic. A further scan is then made with the composite coping in situ. The coping is then finalised on screen and machined using CAD/CAM. Finally, it is veneered with ceramic, avoiding layering over the active elements which will engage with the denture.

This technique could easily be adapted for use with crowns made from monolithic zirconia which would avoid the need for the coping to be cut back.

The advantage of building zirconia features to accommodate clasps and rests is that it should reduce the risk of ceramic chipping or fracture. For the same reason, where ceramo-metal crowns are being made, it is best to accommodate the rest seats and guide planes in metal. Nevertheless, aesthetic considerations may sometimes preclude areas of clasp engagement on crowns being made in metal.

Conclusion

Instead of replacing an existing but satisfactory alloy partial denture, it is always worth considering retrofitting a new restoration. There are many techniques available, and we have highlighted two uncomplicated methods which appear to work well within UK dental schools. Critical to any of the methods is good communication between clinician and technician, ensuring from the outset that both parties are clear about the process.

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