Esthetic Oral Rehabilitation with Veneers

A Guide to Treatment Preparation and Clinical Concepts

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Update to Preparation Design and Clinical Concepts Using the LeSage Veneer Classification System

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Brian P. LeSage

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1.1 Introduction

Porcelain veneers had long been considered to be only an esthetic solution. However, their range of indications has been steadily increasing, making ceramic veneers a highly viable alternative to classic, far more invasive forms of restorative treatment. Today, veneers can be used to handle esthetics (discolored teeth, fractured and worn teeth, diastemas, dental defects, etc.) and to restore the biomechanics of the dentition, as well as many other indications.

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Historically, preparations for ceramic veneers have varied from extremely aggressive to a minimal reduction or a lack of preparation. The concept of no-preparation or minimal-preparation veneers is nearly 40 years old, but for decades there was no classification system categorizing the extent of preparation for different veneer treatments [1]. This lack of clear-cut guidelines for technical procedures and for case selection led to confusion and misunderstandings. The author proposed such a classification system in 2013, and in this chapter, the LeSage veneer classification system is expanded on and explained, and examples for implementing the system are presented. The author's veneer classification system published in 2013 is based on an assessment of the amount of enamel available and the amount of dentin exposed. This system benefits dentists, lab technicians, and patients, by assisting in diagnosis of various clinical scenarios and guiding conservative veneer preparation and placement [1].

Today, we are moving toward minimally invasive dentistry with the philosophy that less is more. Treating esthetic demands with noninvasive or minimally invasive techniques can preserve the natural tissues [2]. Less tooth reduction means better adhesion and clinical longevity. It is no longer acceptable to over-prepare teeth for convenience or lack of understanding of alternative treatments. In recent years, laboratory techniques have evolved to produce ultrathin ceramic veneers, which has increased the popularity of "no-prep" veneers [3]. This so-called "no-prep" approach has been described for more than 10 years in the literature [4–6] and ideologically reiterates the methodologies of when veneers were first introduced as conservative, additive restorative procedures for which slight or no preparations were required [7, 8]. When properly selected and managed, "no-prep" veneers can have biologically healthy and optically beautiful margins and emergence profiles, all supporting the biomimetic dental philosophy of tooth preservation and less amputation of tooth structure [9] (Figs. 1.1 and 1.2).

However, these days, it is no longer acceptable to limit veneer descriptions to no-prep or conventional all-ceramic designs. Explained in this chapter are two additional, distinct classifications that should aid dentists, lab technicians, and patients in their ability to provide better communication, consent, diagnosis, treatment planning, material selection, education, and tooth structure preservation.

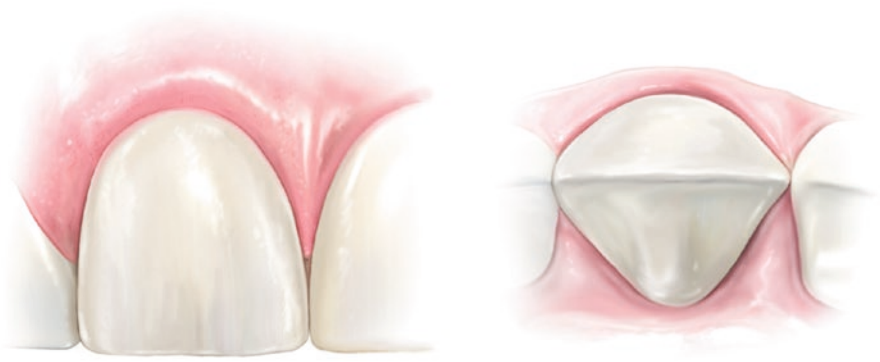

Fig. 1.1 Normal tooth contours from facial and occlusal views

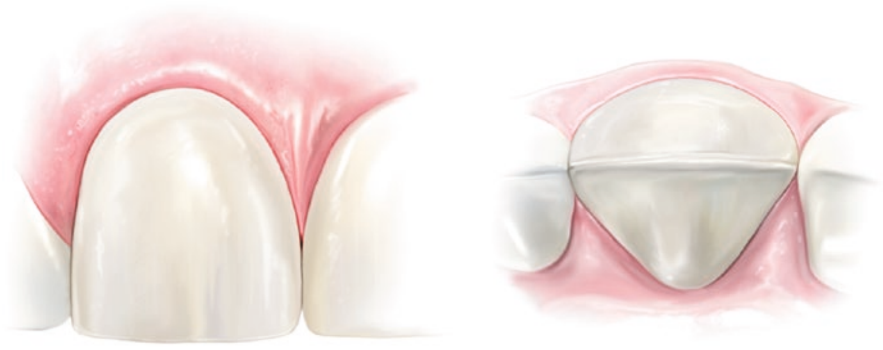

Fig. 1.2 "No-prep" veneer shown when indicated. In many clinical scenarios, adding volume will move line angles to the interproximal zone and make the tooth appear wider

It is important to consider veneers as part of the multidisciplinary field of restorative dentistry. In addition to the LeSage veneer classification system, this chapter also includes tips for ensuring the long-term success of veneers and patient satisfaction. These include the usage of prototypes, digital smile design, a try in one veneer technique, as well as proper preparation and adhesion protocol. Ultimately, clinician experience is the most important tool for determining appropriate treatment plans to address clinical concerns and patients' esthetic demands [1, 10].

1.2 Orthodontics as an Interdisciplinary Approach

There are a variety of treatments and solutions that can be applied to move, straighten, and ultimately align your teeth. One of our goals is to limit the amount of tooth structure removal when placing veneers. Often, we can employ a minimally invasive interdisciplinary ortho-restorative treatment plan. Frequently, far less tooth structure is lost if orthodontic treatments are used to fix tooth alignment prior to placing veneers. Orthodontic treatment is a noninvasive modality for achieving desired results and/or ensuring teeth are properly positioned for long-term predictable function and esthetics.

For example, prominent gaps may require orthodontic treatment before the placement of veneers. Without orthodontic treatment, closing the gaps with veneers will result in creating the look of abnormally large teeth. Moderate to severe crowding may also require orthodontic treatment to align the teeth. If veneer treatment is carried out without orthodontic treatment, the rotated teeth will need to be heavily ground down to accommodate the veneers, weakening the teeth in the process and in some cases exposing the nerve. Similarly, a patient who presents with a narrow arch form may require orthodontics before the placement of veneers. The author uses Invisalign® approximately 50% of the time as a pre-prosthetic modality to prevent preparing beyond the dentinoenamel junction in the teeth. Providing esthetics, while accommodating for anterior guidance and eliminating working and nonworking interferences, is a key component of long-term orthodontic occlusal stability.

Interdisciplinary modalities may also include the following: perio-plastics, tooth bleaching, direct composite restorations, and porcelain veneers, which are options providing predictability and longevity in carefully selected esthetic cases [1, 11].

1.3 Prototypes, Digital Smile Design, and a Try in One Veneer Technique

Veneers have to be esthetically pleasing. There are multiple opportunities within the veneer placement process that we affirm, and reaffirm, the veneers are pleasing to the patient before solidifying the final treatment outcome. The patient likely has specific expectations, and there should be a test drive with provisional restorations to ensure proper esthetics and function prior to fabrication of the final veneers [12].

It is common to create mock-ups, or temporary trial veneers, by taking impressions or by using CAD/CAM technology to make a mock-up digitally. The author prefers to make prototypes, which can be used for a significant amount of time, simulating the final outcome, allowing the patient to test esthetics, phonetics, and function. Bis-acryl resin temporary materials have become the material of choice for *esthetically driven* veneer prototypes due to excellent mechanical and optical properties, marginal adaptation, polishability, and favorable add-on properties [13].

Similarly, a digital smile design (DSD) can be used to increase the emotional commitment and consequently the rate of acceptance of your dental treatments through an emotional mock-up [14]. The DSD is a digital planning tool for esthetic dentistry, in which the evaluation of the esthetic relationship among the teeth, gingiva, smile, and face is obtained through lines and digital drawings that are inserted on the facial and intraoral photographs of the patient [15–18]. A bis-acryl temporary material is dispensed into the putty matrix to fill the facial surface. The filled matrix is inserted into the patient's mouth, the matrix is removed, and excess material is removed. It is common to then take photos or a short video of the patient for them to see the transformation. This full-face picture of them will increase satisfaction and emotional commitment to the final treatment plan.

While DSD presents some advantages, the author regards prototypes as an objective and efficient tool in treatment planning communication. They can be used to confirm the treatment plan before and/or after the final preparation, thereby evaluating the final restorations within the limitations of biological and functional considerations [5, 19].

The author now introduces into the literature the practice of the "try in one" (TIO) veneer technique. At the delivery appointment, one central incisor prototype is cut out and the definitive veneer is tried in. This single veneer should fit to place confirming the midline and the length of the definitive restorations (Fig. 1.3). Thus, the author's TIO technique confirms fit, length, contacts, and color. Trying in one veneer provides a reference point to prove that the length, shape, and shade are appropriate prior to cementing all the final restorations. This TIO technique is a useful process for reassuring the patient that all their esthetic parameters and expectations have been met and holding the dentist and ceramist accountable.

Fig. 1.3 (**a**, **b**) "TIO technique" (**a**) Close-up of patient's approved esthetically driven bis-acrylic prototypes demonstrating uniformity with variety (**b**) Definitive veneer #8 placed within existing prototypes to confirm length, width, and midline and hold all team members accountable

All of these processes build trust between the patient and dentist. They allow the patient to request changes throughout the process, so that they feel in control and satisfied with the final outcome.

1.4 Veneer Preparation

Expected veneer longevity depends on tooth preparation, which should ideally be confined to enamel and minimally involve proximal contact areas and functional considerations, such as occlusion [20]. It is also necessary to maintain the cervical enamel margin and incorporate the incisal edge to increase fracture resistance and enable proper placement [20]. To increase functional and esthetic properties of these restorations, proximal extensions should be created just beyond contact areas [20]. The clinical success of porcelain veneers depends upon many factors. Although dental and gingival structures play important roles in optical response and withstanding masticatory forces, dentists must consider and recreate many anatomical components while providing functional integrity [20].

One critical step in the preparation technique is the achievement of sufficient ceramic thickness [13]. While conducting their studies, researchers Shillingburg and Grace found that as patients age, the enamel thickness on the facial surfaces of anterior teeth decreases [21–23]. On the cervicofacial surface of the central incisor, 1 mm above the cementoenamel junction, enamel thickness ranges from 0.17 mm to 0.52 mm, with a mean thickness of 0.31 mm [21–23]. The thickness on the midfacial surface, 5 mm from the cementoenamel junction, ranges from 0.45 mm to 0.93 mm, with a mean thickness of 0.75 mm [21–23]. The author used these tooth structure parameters as a framework for the LeSage veneer classification system and the author's preferred Class I or Class II veneer preparation techniques. The guidance provided in the LeSage classification system, informed by enamel thickness, allows for conservation of tooth structure and predictable minimally invasive veneer preparations.

The typical veneer preparation model is technique-sensitive and incorporates guidelines for achieving functional and esthetic results. When reducing the labial and proximal surfaces, there must be no less than 0.3–0.5 mm of room, and it should be uniform whenever possible [21, 24–29]. When going from thick to thin—as in a large Class IV incisal fracture or large Class III composite removal—a smooth transition must be incorporated. Extending the preparation interproximally to the midpoint of the papilla, parallel to the crown's original form, is necessary to improve adhesion, conceal the margin, allow an accurate impression, and increase the overall veneer strength [21, 26, 29]. The decision to reduce the incisal edge should be based on whether there is a need to increase the tooth length and the labiolingual width of the incisal edge [21, 26, 29]. Since line angles are involved, rounded corners and edges must be established.

Veneers with an incisal butt margin usually demonstrate fracture loads similar to those of unprepared teeth [21, 30]. In these cases, the incisal edge may be reduced by up to 2 mm [21, 28, 31]. However, the preparation's facial margin should ideally be chamfered and in enamel [21, 26, 28, 29, 32]. The interproximal and gingival margins of porcelain veneer restorations also must end in enamel at or above the free gingival margin or barely within the gingival sulcus when possible [21, 26, 29].

Techniques exist that allow for consistent tooth surface reduction while minimizing it [12, 33, 34]. Because traditional veneering approaches can lead to significant dentin exposure, strategies should be taken to limit preparations to the enamel [12, 13, 34]. Using an additive diagnostic procedure and silicone indexes avoids unnecessary dentin exposure, improves biomechanics and esthetics, and allows more predictable bonding [13].

Gürel et al. recently showed a 98.7% success rate of porcelain laminate veneers when the preparation depth is kept within the limits of enamel [35]. For misaligned teeth, a transparent silicon index can be used to prepare esthetic pre-evaluative temporaries to be used as a guideline to prepare the tooth structure. They resemble the exact final contours of the final outcome, such as the incisal edge position and the facial contours of the teeth; we can start by preparing the teeth 0.5 mm through the mock-up as if we were dealing with a simple case in which the teeth are aligned properly [36]. Once teeth are prepped according to their limitations, adhesion protocols can commence.

1.5 Proper Adhesion

The enamel bond is beyond reproach and is the strongest, least invasive, most conservative, and most predictable bond available. Enamel bonding mimics the dento-enamel junction or the natural bond between enamel and dentin [37]. The same cannot be said about bonding to the dentin. However, even bonding to dentin is favored over nonadhesive approaches [38]. The "gold standard" remains total-etch three-step systems or three-step etch and rinse [38–40].

There remain many issues to consider before bonding to dentin [21]. For example, adhesion more often fails at the dentin–cement interface [21, 41]. Also, microleakage typically occurs between the dentin and cement, leaving underlying dentin unprotected [21, 41]. Studies show that the bond strength of resin cements to dentin is much lower than bonds to enamel, which is why maintaining an enamel periphery is essential [21, 41–45].

The ideal scenario is to keep the bond completely in enamel. Of utmost importance and when properly prepared, enamel substrates provide the most predictable surface to bond porcelain [1, 46–49]. The micro-retentive adhesion of porcelain to enamel has been well-documented for more than 20 years [1, 30, 46]. In a longitudinal study with a 12-year follow-up, ceramic veneers cemented on enamel showed significantly higher clinical longevity than those cemented on dentin, with success rates of 98.7% and 68.1%, respectively [50].

Unaffected by lingual preparation design, porcelain veneers adhesively bonded to enamel demonstrate the greatest long-term success rates, making no-preparation veneers the treatment of choice when indicated [1, 46–49]. When dentin is involved, an enamel periphery is preferable for predictability [1, 30, 46]. When less than 50% of enamel periphery and less than 50% enamel remain, discussion with the patient about limitations and predictability of the outcome is necessary [1, 10, 46]. Given these conditions—50% or more enamel on the tooth is required and 50% or more of the bonded substrate is on the enamel—70% or more of the margin must be enamel. The condition or integrity of the substrate to which veneers will be bonded is also important for success [51–53].

Veneer cementation is fundamental; it should be done with extreme care. It is important to remember that, unlike conventional crowns, which use dual-cured resin cements, ceramic laminates should use a purely light-cured luting agent to prevent the color shifts that can occur due to chemical changes in the curing process [54]. Absolute isolation during cementation procedures is essential for bond maintenance, which ultimately protects the internal surface of the restoration and is necessary for longevity [52, 53].

1.6 Classifications of Veneer Preparations

Referred to as no, minimal, or conventional preparation, veneer classifications—or lack thereof—create a large gray zone of misunderstanding and miscommunication with patients and within the dental profession. Left unanswered, questions regarding tooth structure removal, finish lines and margins, and other aspects can cause confusion in practice.

Flaws and inaccuracies in previously proposed preparation guidelines make those guidelines irrelevant [55]. To dissolve uncertainty, this veneer classification system was proposed to aid with diagnosis, treatment planning, patient education, consent and understanding, and communication among dental team members, and to provide viable solutions to public requests for elective procedures.

Defined as the way something is categorized, labeled, organized, distinguished, arranged, or sorted, classification adds clarity. Dentistry has distinguished Class I through Class V classifications in operative dentistry; there are inlays, onlays (3/4 and 7/8), and full-coverage crowns in prosthodontics. Classifications exist for furcations in periodontics; lip lines; bone quality; LeForte's CL-I, CL-II, and CL-III in orthodontics; removable prosthesis cantilevers; and bone/crest levels. In 1974, Talim and Gohil classified tooth cracks and fractures in endodontics, and Misch classified implant prostheses for patients; in 2009, McLaren classified ceramics [52]. Since classification systems have infiltrated so many aspects of life, veneers should be no different.

In the absence of widely advocated porcelain veneer tooth preparation guidelines, Tables 1.1 and 1.2 show the basis for the LeSage veneer classification system. The system was introduced to clarify the aforementioned gray zone between classic conventional veneer preparation and no- or minimal-preparation veneers. This metric provides an accurate measurement system for quantifying tooth structure removal on a case-by-case basis [56]. Studies show that when a conservative approach is taken and significant tooth structure remains, dentists can provide patients with a better prognosis for the restored teeth [56].

The LeSage veneer classification system divides preparation and veneering into reduction (referred to as space requirement, working thickness, or material room), volume of enamel remaining, and percentage of dentin exposed. Notably, classifications I, II—both of which incorporate addition veneers—and III require 70% to 100% enamel periphery.

Table 1.1 Basis for the LeSage veneer classification system (dentin exposed)

Reduction	Facial	Dentin exposed
CL-I No-prep or practically prep-less	Detectable with magnification, with or without gingival finish lines	0[a]
CL-II Modified prep-less or minimally invasive	Up to 0.5 mm	10–20%[a]
CL-III Conservative design	0.5–1 mm	20–50%[a]
CL-IV Conventional all-ceramic design	1+ mm	50%

[a]Enamel periphery of at least 70%

Table 1.2 Basis for the LeSage veneer classification system (enamel remaining)

Reduction	Facial	Enamel remaining
CL-I No-prep or practically prep-less	Detectable with magnification, with or without gingival finish lines	95–100%
CL-II Modified prep-less or minimally invasive	Up to 0.5 mm	80–95%
CL-III Conservative design	0.5–1 mm	50–80%
CL-IV Conventional all-ceramic design	1+ mm	<50%

1.6.1 CL-I

CL-I is the purest form of *no-preparation* or *practically prep-less* veneers but can include a discreet finish line or only a loupe-detectable margin (Fig. 1.4). The term *addition veneers* frequently describes this preparation design today. In this classification, 95–100% of enamel volume remains after preparation, and no dentin is exposed. Ideal whenever possible, preparation must be completely and only in enamel.

This preparation type can be easily achieved using a bis-acrylic preparation guide created from a putty or silicone matrix of the diagnostic wax-up, which can be applied to the teeth [55]. Depth cuts of 0.5 mm for CL-I are placed into the incisal and facial aspects of the bis-acrylic preparation guide, which should result in the depth-cutting bur not touching the tooth, and the clinician should consider removing the aprismatic enamel and placing a practically undetectable finish line to aid ceramists in determining margin placement. These depth-cutting grooves minimize potential for over-preparation.

Many times considered the best option because of their tooth structure preservation qualities, prep-less veneers have limitations, including esthetic outcomes. Calamia found that veneers placed with no preparation resulted in periodontal problems as a result of over-contoured teeth that changed the emergence profile [1, 46, 57]. It was concluded, however, that the veneer treatment modality would function long term [1, 46, 49]. To correct the emergence issue, a 0.5-mm reduction restored by 0.5 mm of porcelain provided nearly the original tooth profile with the veneer in place [1, 46]. Additionally, it was discovered that wrapping the incisal edge enhances strength and that preparations limited to the facial surface only were not as strong as those with a wrapped incisal edge [1, 31, 46]. This latter veneer preparation type is described below as CL-II.

Some indications for no-prep veneers include peg laterals, genetic anomalies producing smaller teeth, short and worn teeth, orthodontics leading to a narrow arch, and patients with larger lips. Disadvantages may include limited shade alteration capability, difficulty developing the correct axial inclination, proportional errors, and trouble forming the proper gingival symmetry [1, 46, 58].

Fig. 1.4 Illustration demonstrating LeSage Class I veneer preparations requiring little to no tooth structure removal. Facial reduction allowing for 95–100% of the enamel remaining and no dentin should be exposed

1.6.2 CL-II

CL-II deals with *minimally invasive* or *modified prep-less* veneers (Fig. 1.5). Addition veneers also may fall in this classification. This category should exhibit 80–95% volume of remaining enamel, 10–20% exposed dentin, and up to 0.5 mm of reduction. Ideally, CL-II veneers would have complete enamel periphery but may involve a small zone on the gingival margin consisting of dentin to clearly establish the restoration margins [59]. Additionally, 5–15% of dentin may be exposed on any facial surface (i.e., mesial, distal, or gingival), depending on veneer rotation. To complete a CL-II preparation, a bis-acrylic preparation guide, as previously described, can be used. An example of a CL-II prep will be discussed in the following section.

1.6.3 CL-III

CL-III is a *conservative preparation* classification (Fig. 1.6) and described as 60–80% enamel volume remaining, 20–40% dentin exposed, and 0.5–1 mm of

Fig. 1.5 Illustration demonstrating LeSage Class II veneer preparations requiring a modified design. Facial reduction should be less than 0.5 mm, 80–95% of the enamel should remain, and 10–20% of the dentin can be exposed. (Brown in illustration is exposed dentin)

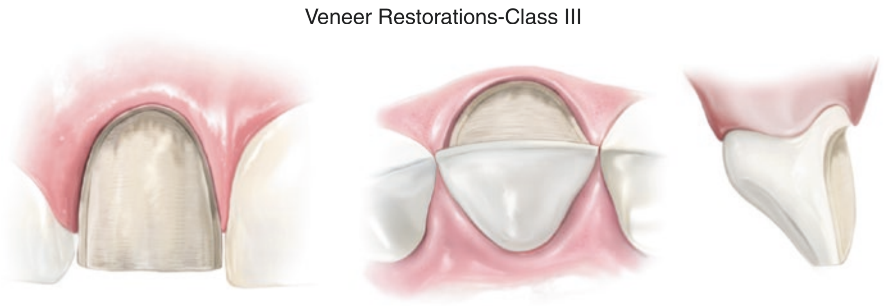

Fig. 1.6 Illustration demonstrating LeSage Class III veneer preparation design requiring some “conservative” reduction. Facial reduction is 0.5–1 mm, the enamel remaining should be 50–80%, and dentin exposure is maximized at 50%

reduction. With more room for restorative material, the gingival margin will typically involve more dentin [59]. However, greater than 70–80% of the finish line must still be in enamel.

1.6.4 CL-IV

CL-IV is a *full veneer* or *conventional all-ceramic* design (Fig. 1.7) and is best described as approximately 50% of enamel volume remaining, greater than 40% of exposed dentin, and 1 mm or more of reduction. The peripheral margin may consist of only 50–70% enamel. Although this veneer preparation type has become an almost universally accepted technique for placing full veneers, functional and esthetic limitations remain—including lower fracture loads and decreased marginal integrity that ultimately lead to restorative failure [60, 61]. Preparation design and fatigue influence the marginal accuracy of veneers bonded to maxillary central incisors, with significantly higher marginal gap formations developing in complete veneer preparations [60, 61]. Therefore, all limits of restorative options should be considered before undertaking this procedure. A case study of a CL-IV prep will be discussed in the following section.

Any given patient could exhibit any combination of classifications due to acidic erosion, genetics, restorative material requirements, occlusion, or tooth- and arch-size discrepancies. As in periodontics, one tooth can be a CL-I furcation and a CL-III in the same dentition, and each has differing treatment approaches, prognosis, and varying care. Again, this veneer classification system was designed to help clarify professional communication and allow patients to better understand how much tooth structure will need to be removed. Such information will enable better informed consent, with patients making the choices they see fit.

When preparations fall outside these parameters, a crown should be *considered* for predictability and longevity.

It is well established that when a tooth has greater than 50% of enamel missing, moderate sclerotic dentin, and greater than 3 mm of unsupported porcelain, a crown must be considered. Magne found that 65% of a tooth's integrity comes from the

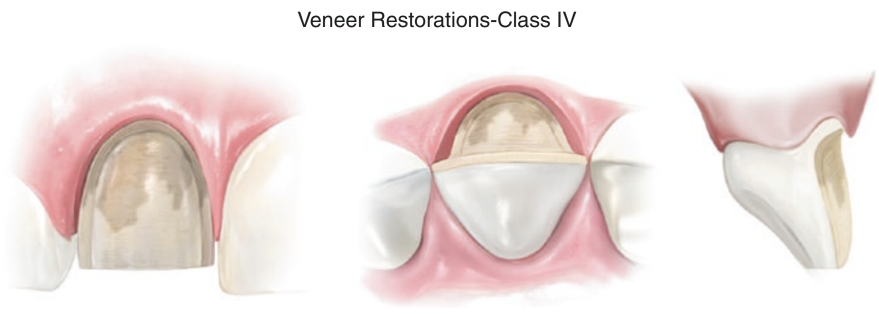

Fig. 1.7 Illustrations demonstrating LeSage Class IV veneer preparations, considering conventional preparations. Facial reduction is typically greater than 1 mm, with less than 50% of enamel remaining and greater than 50% of dentin exposed

cingulum and approximately 27% from lingual marginal ridges [62, 63]. These anatomical landmarks must be preserved at all costs [64]. No significant differences in crown flexure were found between natural and veneered incisors when the cingulum is presevered [64].

However, clinical decisions must be based on the dentist's clinical experience, scientific data, evidence-based literature, the clinical scenario, the patient's desires (i.e., time and money considerations), and full consent based on knowledge of advantages, disadvantages, risks, benefits, and prognosis. These factors are significant in treatment selection. CL-I veneer preparation with its 100% enamel substrate is more predictable than CL-IV with its significant dentin exposure.

1.7 Case Studies

1.7.1 Case I Demonstrating the LeSage CL-II Veneer Preparation Design

Patient is a 62-year-old male who wanted a better color to his teeth and to show more teeth by adding length and width to his smile. The pre-op images show the dark color, deficient vestibular reveal, chipped incisal edges, and damage to his dentition due to parafunctional habits (Figs. 1.8 and 1.9). The goal was to create a pleasing smile with minimal tooth reduction, while maintaining good health.

A full mouth series of X-rays showed minor tooth decay indicating replacement of an existing crown and several simple composites prior to analyzing his dentition for

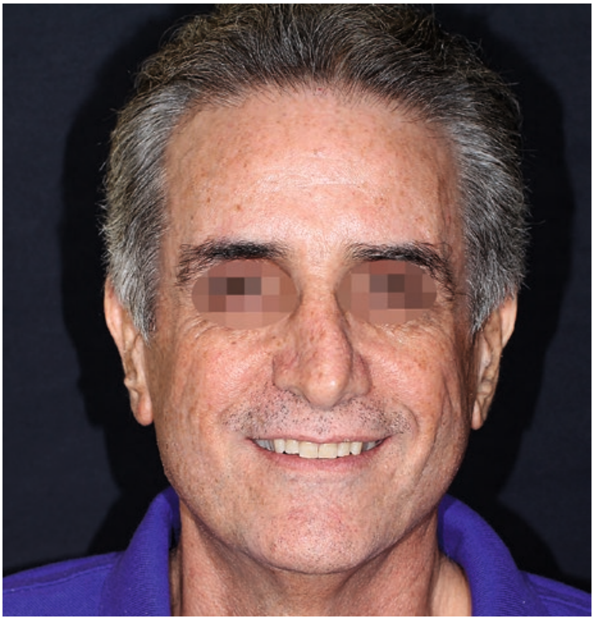

Fig. 1.8 Full-face pre-op of patient before orthodontic care and all-ceramic restorations on maxillary and mandibular teeth in the esthetic zone

Fig. 1.9 Smile view pre-op showing patient's chief complaint, "I would like a better color to my teeth and want to show more teeth when I smile"

Fig. 1.10 Retracted view pre-op showing damage to lower teeth with exposed dentin and dark, aged color to dentition

veneers. A diagnostic workup was performed with facebow transfer and centric relation mounted study models on a semi-adjustable articulator (SAM-3, Great Lakes, Tonawanda, NY) and diagnostic photographs. It revealed the need for orthodontic treatment to widen the arch and reposition the maxillary and mandibular teeth into more ideal anterior relationship to create a more protective occlusal scheme and not prepare past the dento-enamel junction. The incisal edges in both arches had exposed dentin which needed to be covered for long-term stability (Fig. 1.10).

After approximately a 1-year course of Invisalign (Figs. 1.11 and 1.12), a new series of diagnostic models were mounted on the SAM-3 articulator, diagnostic photos retaken, and a diagnostic wax-up completed (Fig. 1.13). Minor occlusal equilibration to eliminate any CO-MIP slide and gain immediate anterior disclusion was performed prior to starting the smile makeover.

Luxatemp (DMG, Ridgefield Park, NJ) bis-acryl, using the preparation guide introduced by Drs. Magne and Gürel, was applied to the teeth using a putty matrix fabricated from the diagnostic mock-up (Fig. 1.14) [13, 36]. Depth-cutting grooves of 0.5 mm were placed in the bis-acrylic material minimizing the depth and thus also minimizing the amount of enamel removal on each tooth (Figs. 1.15 and 1.16).

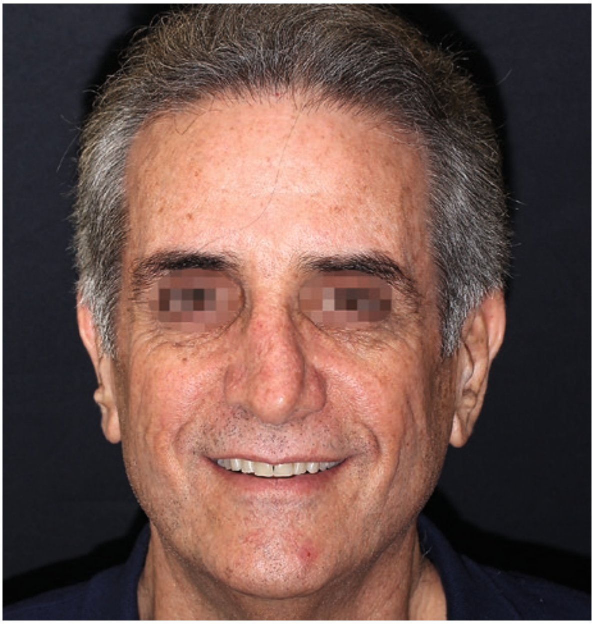

Fig. 1.11 Full face of patient after Invisalign treatment. Notice fuller buccal corridor

Fig. 1.12 Retracted frontal view showing wider arch and better alignment of teeth after Invisalign

Fig. 1.13 Wax-up of maxillary teeth #4–13 on articulator working out esthetics and function

Fig. 1.14 Custom preparatory guide placing bis-acrylic on teeth to be restored

Fig. 1.15 0.5 mm grooves placed into bis-acrylic. On patient's right the bis-acrylic has been removed, and visible is the less than 0.5 mm groove remaining to guide a minimal preparation of the final restorations. Note the incisal edges of the teeth #6–8 and the facial of tooth #7 were not even touched with the depth-cutting bur guides

Fig. 1.16 Preparation of teeth #4–8 showing minimal dentin exposure—LeSage Class II veneer preparation design. Minor troughing visible after electrosurgery unit as a means for retraction

This modified prep-less veneer preparation technique will almost guarantee the authors preferred LeSage veneer CL-II preparation design: maintaining the preparation in 95% enamel and a 0.1 mm interproximal separation of the prepared teeth at its narrowest point (Fig. 1.17). To aid with shade communication including the ceramist, properly exposed images with the appropriate shade tabs are taken (Fig. 1.18).

An easy and effective way for patient visualization of their new smile design and final outcome is in fabricating prototypes, also known as temporaries or provisionals. These prototypes are created to the specifications of the anticipated definitive restorations, used to test and verify that the desired esthetic and functional outcomes are met.

Fig. 1.17 Minimal preparation to teeth #4–13, confined primarily in enamel

Fig. 1.18 Shade tab photo taken prior to dehydration of dentition. This is one of the multiple images taken to communicate chroma and value of the teeth and final restorations to the ceramist

Fig. 1.19 Prototypes immediately finished and polished in the mouth

Prototypes were fabricated using the “shrink wrap” technique; bis-acrylic was placed in the putty matrix and allowed to self-cure set in the mouth. This allows the prototypes to shrink and lock between the teeth and onto the teeth (Fig. 1.19). Prototypes are worn until the patient expresses complete satisfaction with their smile makeover (Figs. 1.20 and 1.21). Patient’s approval of the prototypes is essential prior to the ceramist fabricating the veneers.

The Geller model poured from a PVS impression shows the removable dies and the stone papilla form and gingival tissues (Fig. 1.22). An incisal putty matrix from the model of the approved prototype aids the ceramist in fabricating predictable definitive restorations. Shown are the definitive feldspathic restorations on the Geller model (Fig. 1.23) and a mirror (Fig. 1.24).

The first step at the delivery appointment is the TIO technique; one central incisor prototype is cut out and the definitive veneer is tried in. This single

Fig. 1.20 Smile view showing prototypes/temporaries to trial esthetics and function

Fig. 1.21 Full face with prototypes trialing midline, smile line, incisal edge position, arrangement, and composition

Fig. 1.22 Geller models showing removable dyes and stone papilla. Putty matrix from approved prototype to aid ceramist with length, midline, and incisal edge effects

Fig. 1.23 Definitive restorations on Geller model

Fig. 1.24 Minimal thickness veneers showing polychromicity

veneer should fit to place confirming the midline and the length of the definitive restorations. Once fit and esthetics are confirmed by the clinician and approved by the patient in the authors' TIO technique, the remaining prototypes are removed. The tooth preparations were cleaned and all final veneers were tried in for approval by the patient. Once approved, the cementation process began.

Following the proper adhesion protocol is essential to the long-term success of the restoration. With proper isolation, the preparations were cleaned, etched, rinsed, and partially dried. The strong adhesion of porcelain to enamel is one of the primary reasons that no-prep (LeSage CL-I) and minimally prep veneers (LeSage CL-II) are the treatment option of choice when indicated. The primer was then applied and agitated for 30 s, air-dried, and light cured. Resin adhesive was placed on tooth and light-cured resin cement on the intaglio surface of the veneer. Bonding the definitive feldspathic restorations to an enamel substrate allows for the most predictable bond strengths, which directly correlate to clinical longevity [65]. The veneers were seated, light pressure was applied, and excess cement was wiped from the margins. The shade of the veneer and thickness of the porcelain material help to guide the curing time.

Fig. 1.25 Retracted view of final layered feldspathic restorations showing natural progression of shades, perfect imperfections in size, axial inclination, and arrangement

Fig. 1.26 Close-up view showing lowers also restored to address functional issues

The same technique was used on the mandibular veneers. A dual "E" appliance was fabricated to maintain and protect the patients bite and restorations. The restorations in the retracted view (Fig. 1.25), relaxed lip position (Fig. 1.26), and full face (Fig. 1.27) show the reestablishment of canine guidance, the protection of the exposed dentin, and the patients pleasing smile makeover.

1.7.2 Case II Demonstrating the LeSage CL-IV Veneer Preparation Design

This case involves a 31-year-old patient who wanted a better match in translucency and color in replacing the veneers on teeth numbers 8 and 9, placed approximately 10 years ago. Existing veneers were too opaque and thus appear lifeless in the mouth. The patient wanted to whiten the remaining dentition and create veneers with esthetically pleasing color and translucency.

Visual tension was present (Figs. 1.28 and 1.29). The restored central incisors had a very rectangular shape, long connector, and gingival health issues. In the full-face relaxed lip position view (Fig. 1.30), the facial and dental midline coincides, and nearly 4 mm of tooth reveal was present. The patient had a mild case of bruxism

Fig. 1.27 Full face with minimally preparation all-ceramic restorations

Fig. 1.28 Smile view showing visual tension in her smile. Veneers on teeth #8 and 9

but expressed a commitment to avoiding any unnecessary function or load on the restorations. Using the patient's signs and symptoms, and the patient's preferences, will assist with the new smile design to create the appropriate length, midline, outline form, color, and translucency.

Treatment started in a periodontist's office by performing scaling and root planning of the maxillary sextant. The veneers were then carefully cut off using a coarse diamond (# 6466–020, Brasseler, Savannah, GA). Besides ensuring a definitive margin and removing all cement for maximum bond strength, no additional tooth

Fig. 1.29 Retracted view—preoperative. Notice opacity and lack of translucency to veneers and long connector

Fig. 1.30 Relaxed lip position—preoperative

prep was performed. The preparation was a LeSage CL-IV, the least-predictable bond, as seen many times in replacement veneers, with greater than 50% dentin exposed and at best 50% of margin in enamel. CL-IV is the least-predictable bond. Therefore, patients should be properly informed and given all treatment options. The stump shade, even after internal bleaching with sodium perborate, affects the restorative material selection and porcelain layering technique (Fig. 1.31).

Lab-fabricated prototypes made with acrylic were used to guide the gingival healing and papilla formation. The prototypes' goal is to mimic the natural esthetics of color, translucency, contour, embrasures, composition, and arrangements (Fig. 1.32). These prototypes were worn for 4 months prior to approval by the patient (Fig. 1.33).

The definitive feldspathic veneers were delivered using a total-etch, three-step system adhesive and resin cement. The relaxed lip position smile (Fig. 1.34) shows the translucency, harmony, and balance the patient desired.

Fig. 1.31 Remove veneers on teeth #8 and 9 and refine preparations. Typical LeSage Class IV veneer preparation design as seen in most re-treatment cases

Fig. 1.32 Smile view with prototypes. Notice gingival health, pleasing translucency, and outline form

Fig. 1.33 Retracted view of prototypes. Gingival embrasure properly contoured to allow for gingival ingrowth

Fig. 1.34 Definitive all-ceramic restorations showing natural harmony and balance to patient's smile

1.8 Conclusion

Dentistry has sound, indisputable evidence affirming adhesive dentistry as the most conservative, least invasive, and most predictable way to restore teeth to normal form, function, strength, and optical properties when tooth-colored materials are used. Additionally, adhesive dentistry preserves the greatest amount of tooth structure, while satisfying patients' restorative and esthetic needs [1, 11, 66]. Clinicians must stay abreast of material selection, adhesive protocol, and scientific advances.

Before considering available smile-enhancing options, patients should undergo comprehensive clinical examinations, including an esthetic and functional evaluation [1, 11]. Ultimately, success is measured using the functional and esthetic parameters desired by the patient and required by the dentist.

More clinical evidence is needed to provide the standard of care required to comply with and support nonmaleficence [1, 67]. From Latin *praedicius* or *praedicere*, meaning to know beforehand, the term "predictability" suggests that dentistry should develop models that dentists can follow to provide predictable comprehensive esthetic outcomes. The LeSage veneer classification system enables dentists to improve the quality of their dental treatment and give patients the best in function, longevity, and esthetics.

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Orthodontics for Esthetic Dental Treatment: Symbiotic Efforts for Optimal Results

2

Olivier F. Nicolay and Asma Almaidhan

Contents

2.1 Introduction

The concept of beauty has captivated scholars since ancient times. Many researchers have attempted to analyze human beauty and objectify it by suggesting some underlying foundations such as symmetry and proportions. This beauty notion extends across many disciplines including evolutionary biology, sociology, and developmental psychology [1–5].

Human fascination with beauty and esthetic trends is continuously evolving; moreover, public awareness and desire to improve facial appearances are at the

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R. D. Trushkowsky (ed.), *Esthetic Oral Rehabilitation with Veneers*,
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highest level [6]. This trend of heightened public awareness and expectation is paving a new way of dentistry toward a more comprehensive approach with esthetic principles at its core. The oral health of the patient and his or her dentition are fundamental in dental treatment. However, the final esthetic outcome should be among the first steps in treatment planning [7]. The ideal esthetic approach in dental treatment planning often requires a multidisciplinary approach engaging various dental professionals. This process requires thorough communication among dental practitioners and a basic understanding of what each discipline can provide.

It has become more prevalent to include orthodontic treatment in planning comprehensive multidisciplinary cases. This trend could be attributed to the role of pioneers such as Vincent Kokich [8–14], who brought to the forefront a significant opportunity to improve the outcomes that orthodontics offers to practitioners. Moreover, the advent of digitized clear aligner therapy as a treatment modality has broadened the base of the patients accepting adjunct orthodontics therapy to enhance esthetic treatment results.

The intent for this chapter is to emphasize certain aspects pertinent to diagnosis and treatment planning that are usually overlooked when one considers pre-restorative orthodontic alignment of teeth, which could then avoid patient and practitioner disappointment at completion.

Accordingly, this chapter will cover facial evaluation; optimal anteroposterior, transverse, and vertical positioning of the maxillary incisors; skeletal diagnosis; and space management. Moreover, it will illustrate some of these points using the management of multidisciplinary treatment planning.

2.2 Diagnosis

A majority of dentists nowadays design their dental treatment plan with the objective of maximizing esthetics. As such, many dental practitioners are working collaboratively to achieve higher esthetic outcomes [15]. Historically, esthetic outcomes were opted as less significant than function and emerged in a later stage of dental treatment planning. This approach resulted in a compromised treatment outcome and, possibly, patient frustration.

A case example is an adult male patient seeking a solution to “reduce the too forward-placed prominent front teeth.” Oral and dental examinations revealed that he had severe overjet and overly proclined incisors. The patient was told he would need extraction of the upper premolars to reduce the overjet and incisor proclination. The patient became upset because he had implants to replace the missing maxillary teeth. Thus, the restorative treatment plan for this patient aimed to restore function over esthetic consideration. For that reason, it is recommended that every patient have a comprehensive examination to consider the face and dental esthetics. Treatment options that include addressing facial and dental esthetics should be explained to the patient, even if the patient is not aware of any appearance issue, as this may change with time. The patient can then make an informed decision after discussing his/her expectations and treatment outcome goals.

The primary objectives of treatment should consider biology, function, stability, and esthetics all at the same time when formulating a problem list and treatment outcomes. The dental practitioner ought to formulate treatment objectives after a comprehensive assessment of a patient's face, smile, and dental structure. The objectives should not be solely based on restoring dentition.

The teamwork approach among dental professionals is well established [8, 15–18]. It promotes a higher level of dental care. Moreover, this collaboration should extend not only among dental specialists but also to medical professionals in order to provide the best treatment outcome [19, 20]. An example is excessive gingival display upon smiling. The treatment approach should be chosen based on diagnostic findings and treatment objectives. If the resultant gummy smile is due to hypermobility of the facial muscles even though there are good facial and skeletal proportions, then the treatment objective should aim to reduce the excessive muscle elevation during smiling by injecting *C. botulinum* toxin. However, in cases of excessive gingival display that is associated with a long face and vertical maxillary excess (VME), orthodontic treatment alone or combined with orthognathic surgery should be selected based on the severity [21, 22]. Furthermore, a gummy smile due to short clinical crowns requires treatment with crown lengthening and restoration [23].

There are various treatment options among the disciplines. Selecting the appropriate treatment depends on the evaluation of facial proportions, occlusion, and the patient's desire and expectation. The treatment, therefore, begins with a proper and thorough diagnosis of the patient, not just the dentition.

Evaluation of facial esthetics, profile, lip position, and smile should be part of every patient's examination. This comprehensive approach yields the most successful treatment outcomes.

2.3 Facial Analysis

A systemic approach to evaluate facial proportions and esthetics in dentistry has long been established [24]. In orthodontics, the paradigm has shifted from the twentieth-century Angle paradigm that focused on establishing perfectly aligned teeth with an ideal relationship to their opposing arch, assuming the face will then be harmonious. This is not necessarily true; facial attractiveness is judged by the soft tissue, which is the prime focus of the orthodontic treatment [25].

As discussed earlier, a dental treatment plan should not be solely based on dentition. Dental practitioners ought to provide a comprehensive treatment plan that addresses the esthetic aspects of the entire face, including the smile. The dentist has an obligation to educate the patient about the various treatment modalities and to address his/her desires and expectations from the beginning to avoid disappointment and a compromised outcome.

Facial evaluation is an integral part of patient examination. It starts with evaluating facial symmetry, as symmetric faces are considered more beautiful than those that are not [26, 27]. The facial midline is the reference used to assess facial symmetry (Fig. 2.1). Facial examinations begin with symmetry evaluation and then establish the interpupillary line and determine whether it's normal (perpendicular to the facial midline) or slanted. Both jaws should be assessed in reference to the facial midline to determine any canting. The position of the chin should also be marked for any deviation.

The next step is to evaluate facial proportions; the face is divided into horizontal fifths and vertical thirds (Figs. 2.2 and 2.3). A proportionate face is considered more attractive than those that are disproportionate. However, these proportions may vary among different ethnic groups [9, 28–30]. The shape of the face can be described as mesofacial, which is a face that is proportionate in height and width; dolichofacial, which is a face that is greater in height than in width; or brachyfacial, which is when the face's width exceeds the length proportion. Evaluating the vertical lower facial height determines whether it is normal or if there was an excess or deficit in the lower facial height.

After that, the patient's profile is assessed to determine whether it is straight, convex, or concave by tracing an imaginary line from the forehead to the chin (Fig. 2.4). Note that convex profiles are usually associated with a skeletal class II pattern, while concave profiles are associated with a class III skeletal pattern.

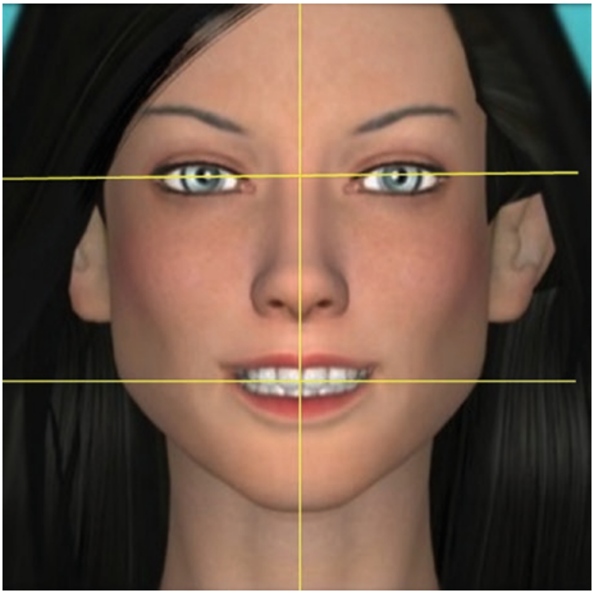

Fig. 2.1 Facial midline, interpupillary line

Fig. 2.2 Proportionate face in widths exhibits equal horizontal fifths

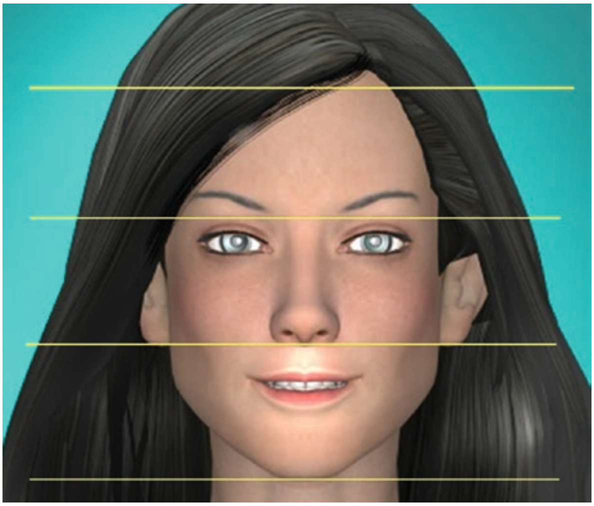

Fig. 2.3 Proportionate face in length exhibits equal vertical thirds

The mandibular plane angle can be observed from the patient's profile and measured in the lateral cephalometric radiograph (discussed under skeletal diagnosis later in the chapter). This will provide the vertical skeletal pattern as to whether it is normal, hyperdivergent (high angle), or hypodivergent (low angle) (Fig. 2.5).

Next is an evaluation of the upper and lower lip position to determine if they are normal, protrusive, or retrusive.

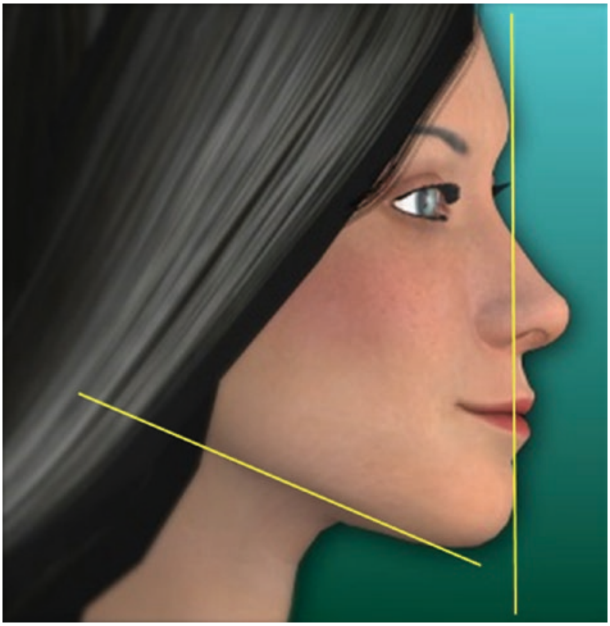

Fig. 2.4 Facial profile and mandibular plane angle. Facial profile can be straight (as in this example), convex, or concave

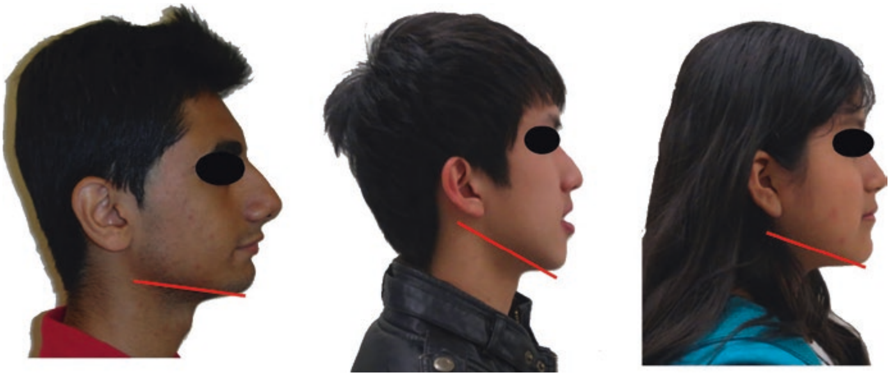

Fig. 2.5 Mandibular plane angles

The principle behind the relationship of the lip position in relation to the nose and chin projection from the profile view is dated to the 1950s and the effort of orthodontist Robert Ricketts in establishing the esthetic plane (E-plane or line), Fig. 2.6. Ricketts' conclusion was based on the sample he studied: for the average Caucasian face, it is more esthetic for the lower lip to be 2 mm behind the E-plane and the upper lip 4 mm behind it. This obviously has variation among different ethnic backgrounds. Moreover, public perception on the ideal lip position and fullness can vary with time as more people nowadays regard fully defined lips as more attractive.

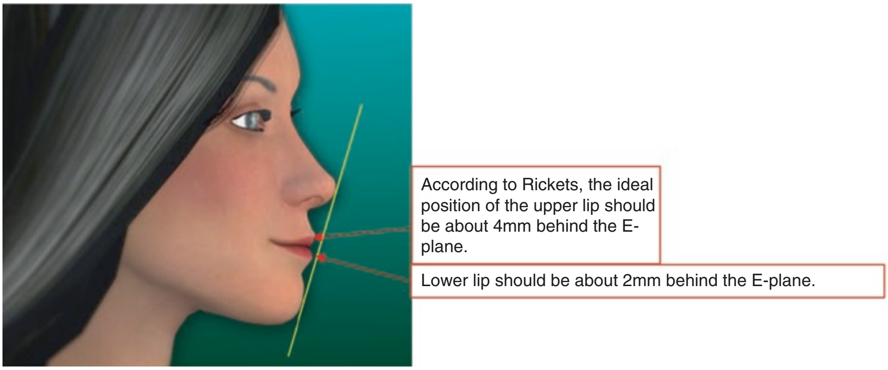

Fig. 2.6 E-plane relationship with the lips. E-plane: virtual line drawn from tip of nose (pronasale) to tip of chin (soft tissue pogonion)

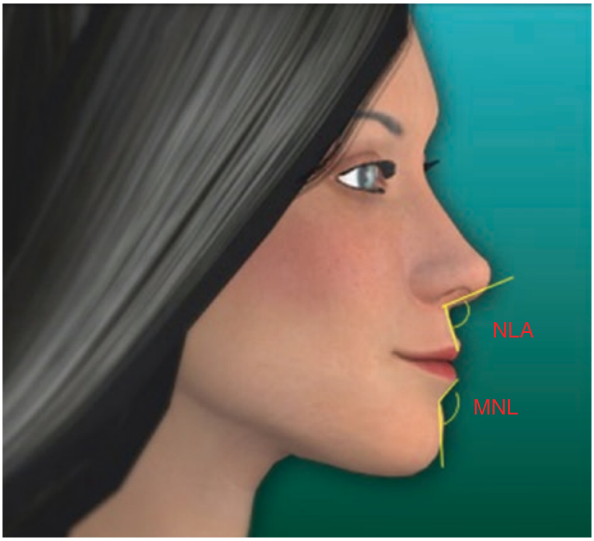

Fig. 2.7 Nasolabial angle (NLA) and mentolabial sulcus (MLS)

The lips receive special attention in facial evaluation; fuller lips are considered more youthful, and the loss of lip volume is regarded as a sign of aging [31]. The position of the lips depends largely on the underlying dental structures. Planning to move the teeth in order to improve the patient's appearance should be vigilantly studied. Excessive proclination of the maxillary incisors results in a compromised look. On the other hand, excessive retraction of the maxillary incisors compromises the projection of the lips and gives more of an aged look.

Next, the nasal–labial angle (Fig. 2.7) is examined to determine whether the angle is normal, acute, or obtuse. This determination is also important when planning the final position of the maxillary incisors. It is not recommended to retract the maxillary incisors when the nasal–labial angle is obtuse as this will increase the angle, while the maxillary incisors should not be brought more anteriorly when the nasal–labial angle is acute.

After that, mentolabial sulcus is examined to decide if it has normal depth, is flat, or is deep (Fig. 2.7). If the mentolabial sulcus is flat, the lips' competence should be evaluated, while if the mentolabial sulcus is deep with an everted lower lip, one should assess whether an excessive overjet is associated with it.

Finally, lip competency should be evaluated to determine if they are competent, competent with muscle strain, or incompetent.

2.4 Function Evaluation

The presence of oral habits like clenching, grinding, and tongue thrusting should be examined. Furthermore, the breathing pattern (nose or mouth) should be assessed. Also, temporomandibular joints, mouth opening, and mastication must be evaluated.

2.5 Dental Analysis

The incisor positions are very critical components in planning the dentofacial esthetics. The incisor spatial orientation—vertical, transverse, and anterior–posterior positions—in interdisciplinary treatment planning with orthodontics will be discussed in detail.

2.5.1 Vertical

2.5.1.1 The Vertical Position of Maxillary Incisors

Smile Line and Incisal Edge Display

The smile line or smile arc is defined as the relationship between the maxillary incisal edge and the superior border of the lower lip. The vertical position of the incisal edge is determined by their parallelism to the lower lip upon smiling [32, 33]. However, in the case of an asymmetric lower lip, the interpupillary line may be used as reference [34].

The smile line can be parallel to the lip curvature, which is known as a consonant or convex smile line. This style is perceived as the most attractive and youthful smile line. A non-consonant smile line or straight smile line is when the maxillary incisal edge is flatter than the lower lip curvature. This gives an older look as teeth tend to naturally wear off through time. A reverse smile line (concave) is the least esthetic [10, 35] (Fig. 2.8).

The presence of canting in the smile should be recorded (Fig. 2.9). Also, the source of canting should be investigated, whether it was skeletal or dental base.

Teeth and Gingival Display

Determining the appropriate amount of incisal and gingival display is age dependent as studies have shown that the amount of incisal and gingival display decreases with aging [11, 12]. These changes are attributed to decreased elasticity and tone of the orofacial muscles.

Fig. 2.8 Incisal edge in relation to smile line. On the right, convex smile line (the incisal line) is parallel to the lip curvature. The middle picture shows straight smile line. The left picture is reverse smile line which is the least attractive smile

Fig. 2.9 The presence of dental and skeletal canting should be noted in the diagnostic stage

This display principle is essential when planning the ideal incisor position in young patients versus the elderly. A 2–3 mm of gingival display in a younger person is considered normal and youthful [13, 14].

It is also worth noting that the lip line is at different levels when the lip is at rest or is smiling. The lip line is also different in a posed social smile versus in a spontaneous smile. The lip line is progressively higher in the latter. The diagnostic smile evaluation should be assessed in various situations. An underestimation of the lip line can result when the practitioner only documents the posed social smile (Fig. 2.10).

The incisal and gingival display can be classified as excessive, average, or deficient (Fig. 2.11).

Excessive gingival display is considered unattractive to both the professional and the public, while an inadequate display is not desired as it is considered a sign of aging [32, 33].

The ideal gingival level is designed based on the appropriate crown width-to-length ratio of the maxillary anterior teeth [36–38], the amount of gingival display upon smiling, [36] and the symmetry of the gingival level between the right and left dentition. Treatment is based on the tooth proportion and the planned final position of the gingival level. If the gingival level is too incisal, a periodontal surgical procedure [39, 40], orthodontic intrusion [8], or orthodontic intrusion and restoration are considered [41–43].

Treatment of inadequate gingival display involves lengthening the maxillary incisal edges. This could be achieved by restorative dentistry [44], orthodontic extrusion [45], or orthognathic surgery [46–48] (Fig. 2.12). The clinical management decision is determined by the patient's facial proportions, muscle tone, crown length, and occlusion.

Fig. 2.10 (**a**) Posed social smile, (**b**) spontaneous smile (note the increased gingival display)

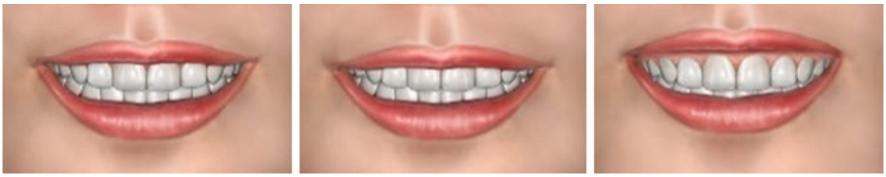

Fig. 2.11 Varying amount of gingival display upon smiling

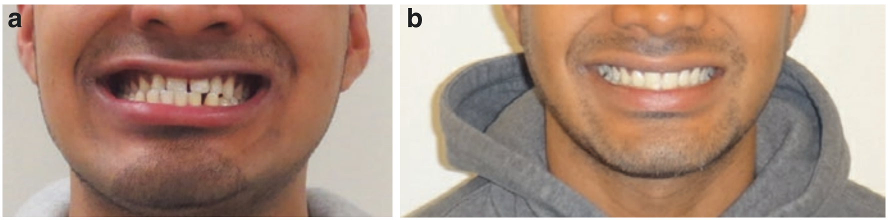

Fig. 2.12 (**a**) Inadequate gingival display due to skeletal discrepancy. (**b**) The patient incisal and gingival display has improved after receiving orthodontic treatment combined with orthognathic surgery

In case of asymmetric gingival level, orthodontic treatment is indicated to level the gingival heights prior to restoration. In Fig. 2.13, one can note the apical and lateral displacement of the maxillary right central incisor as a result of trauma.

2.5.1.2 The Vertical Position of Mandibular Incisors

After planning the final position of the maxillary incisors, the position of the mandibular incisors needs to be designed accordingly.

The vertical position of mandibular anterior teeth should be evaluated. If they were over-erupted, occlusal adjustment, orthodontic intrusion, or both can be used [14]. If they were under-erupted, orthodontic extrusion, or restoration could be planned [49, 50].

Mandibular incisor vertical position should be evaluated in reference to posterior teeth (depth of curve of Spee). Correcting a deep curve of Spee may require intrusion of anterior teeth, extrusion of posterior teeth, restoration, or a combination of all modalities (Fig. 2.14). It is worth noting that leveling the curve of Spee requires additional arch space that should be accounted when planning to move the teeth.

The gingival level would be changed if orthodontic intrusion or extrusion of the anterior teeth is planned [51].

Deep Overbite Correction

Evaluating the vertical position of the maxillary incisors is fundamental in setting treatment objectives and designing a treatment plan for cases of severe overbite. Deep overbite correction can present a challenge. Depending on the diagnosis, the correction may require intrusion of anterior teeth (upper, lower, or both), extrusion of posterior teeth, or relative intrusion by proclination of the anterior teeth. In most instances, it becomes impossible to resolve lower incisor crowding when the patient presents a deep overbite without first correcting the latter.

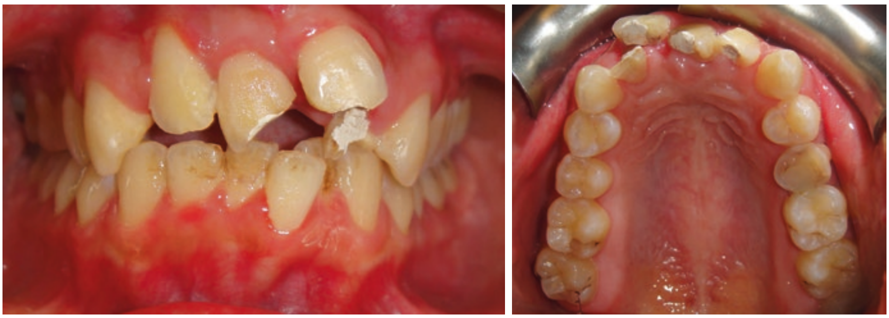

Fig. 2.13 Orthodontic treatment is indicated in this case to align the teeth and level gingival heights prior to restorative treatment

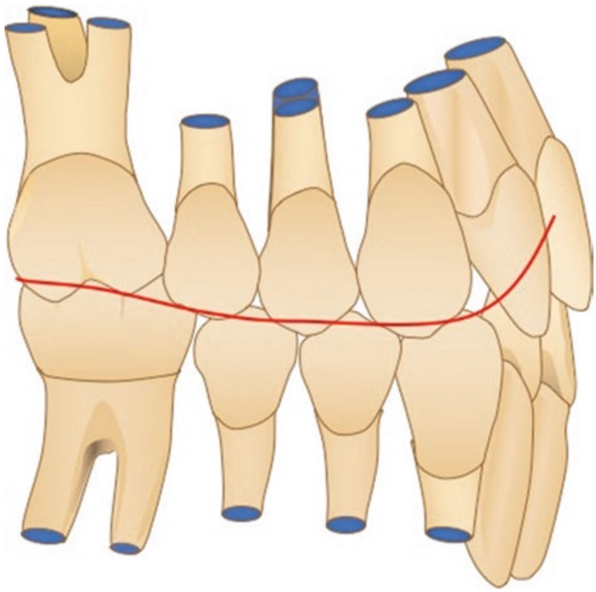

Fig. 2.14 Curve of Spee is more accentuated in cases with increased overbite. Leveling the curve may be done by intruding the incisors or extruding the posterior or a combination of both

The treatment approach for severe overbite cases is dictated by the amount of the incisal display and the smile esthetic. The feasibility of these movements is determined by the mechanical efficacy of the selected appliances and determined by the vertical skeletal pattern.

Planning to intrude the over-erupted maxillary incisors is desired in cases with excessive incisal and gingival display (Fig. 2.15).

However, intrusion of the maxillary incisors should not be attempted in severe overbite cases with inadequate incisal display as it would compromise the esthetic outcome (Fig. 2.16). It is advisable to start by leveling the curve of Spee, to intrude the mandibular incisors, extrude the posterior teeth, or a combination of both methods.

Evaluating the position of the incisors is also critical when planning to restore asymmetric gingival level in anterior teeth (Fig. 2.17a, b). The final position of the incisors and their relation to the opposing arch should be thoroughly studied. Any desired change in the position of the incisors should be addressed before planning the restorative part (Fig. 2.17c, d).

A word of caution is warranted in that instance: resolving lower anterior crowding with IPR in the presence of deep overbite is counterproductive. Orthodontists are very familiar with the concept of Bolton discrepancy. When a patient presents a mandibular deficiency of tooth substance in the lower six anterior teeth compared to the maxillary teeth, there is usually a deep overbite and/or overjet. Intuitively, one should recognize that reducing the width of the six lower anterior teeth will exacerbate the deep overbite. The same should be considered contraindication for extracting a lower incisor. A better strategy is to correct or reduce the overbite before attempting any mandibular tooth mass reduction.

Fig. 2.15 (**a**) The patient is at the beginning of orthodontic treatment; she has increased overbite that was treated with maxillary incisor intrusion. This approach was opted due to the increased incisal and gingival display the patient had initially. (**b**) The patient's smile during the orthodontic treatment. Note the improved gingival display following intrusion of the maxillary incisors. (**c**) The patient's smile at the end of the orthodontic treatment. (**d**) The patient's occlusion before receiving orthodontic treatment. The patient had deep impinging bite in addition to the incisor retroclination. (**e**) The patient's occlusion after receiving orthodontic treatment, the treatment included intrusion of the maxillary incisors, proclination of the incisors (relative intrusion), and leveling the curve of Spee

2.5.2 Transverse

The symmetry of the right and left dentition should be evaluated as part of the patient examination. This includes tooth size, alignment, and position.

2.5.2.1 Relationship of Central Incisors to Facial Midline

Coincident maxillary dental midline with the facial midline is considered as attractive and ideal [52]. It is worth noting that a midline shift of up to 3–4 mm may not be noticeable by laypeople [53, 54]. However, discrepancies in the inclination of the incisors by 2 mm are regarded as unesthetic [20, 55]. Note in Fig. 2.18, a patient seeking orthodontic treatment with a chief complaint of "crooked midline." In agreement with the Kokich study result, the public has lower tolerance toward canted midlines than midline shift without canting. Correcting cants in midline can be done conservatively with orthodontics [56] or with restorative dentistry if the incisors need to be restored [57].

2.5.2.2 Smile Width and Buccal Corridor

A proportionate broad smile is desired. However, care should be taken not to exaggerate the arch layout to produce a wider smile as this will result in an unnatural look. On the other hand, excessive buccal corridors are considered unpleasant to both the orthodontist and laypeople [58, 59] (Fig. 2.19).

Fig. 2.16 (**a**) The patient's smile before receiving orthodontic treatment. (**b**) The patient's smile after receiving orthodontic treatment. (**c**) The patient's occlusion before receiving orthodontic treatment. (**d**) The patient's occlusion after receiving orthodontic treatment. A case with increased overbite and limited display of incisors is contraindicated for maxillary incisor intrusion, as this would compromise the smile appearance. Patient's orthodontic treatment was aimed to level the curve of Spee and to extrude the posterior teeth

2.5.3 Anterior–Posterior Positions

2.5.3.1 Maxillary Incisor Inclination (Proclination/Retroclination)

Evaluating the incisors' labiolingual inclination is critical in esthetic treatment planning. Maxillary incisors can be at a normal inclination, proclined, or retroclined. Lateral cephalometric radiographs provide angular measurements of the incisors' inclination [60].

Another way to examine the inclination of the incisors is to look at the facial surface anterior teeth in relation to the occlusal plane. When the facial surface is perpendicular to the occlusal plane, it allows for higher light reflection, which improves their appearance [61].

Alternately, one can also assess the position of the incisor when observing the profile of a patient when smiling. One of the authors uses a vertical line, parallel to the *true* vertical line and tangent to the soft tissue glabella point, to judge the position of the maxillary incisors and their inclinations (Fig. 2.20). This is a crude application of the Andrews Goal Anterior Limit Line (GALL), whereby the maxillary incisors are tangent to the line; however, more forward can be acceptable for women, while slightly behind might be acceptable for men.

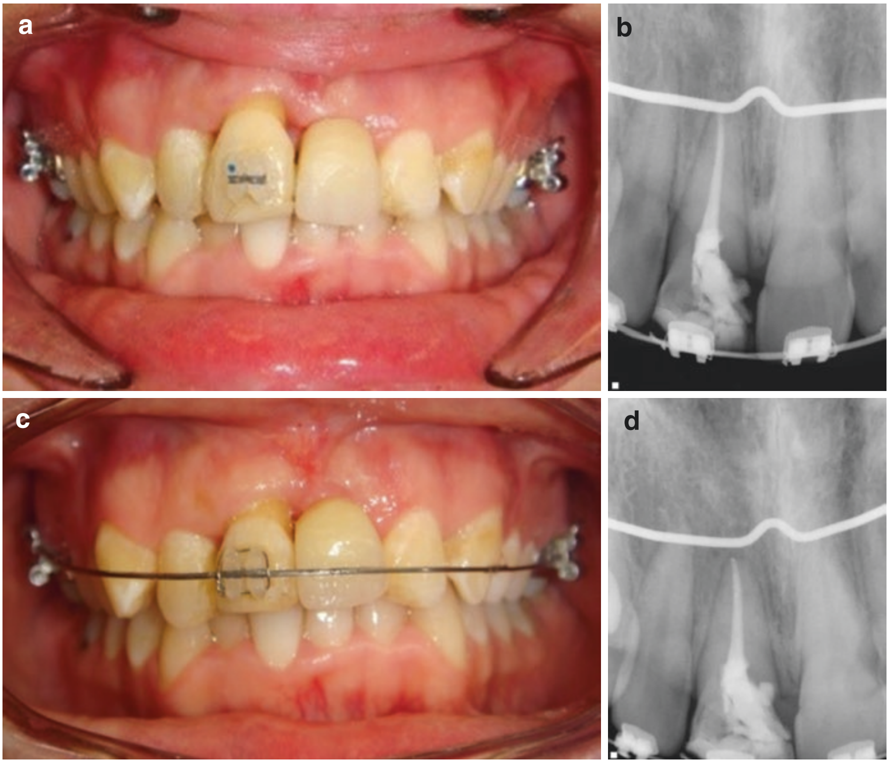

Fig. 2.17 (**a**) Apically positioned upper tight central incisor and uneven bone and gingival level of the upper right central incisor, which compromise the restorative treatment, patient had orthodontic treatment to improve the bone and gingival level prior to tooth restoration. (**b**) Periapical radiograph at earlier stage of treatment. (**c**) The photograph was taken after one month of orthodontic treatment. The treatment included extrusion and lingual root torque. The treatment will continue to extrude the tooth till the gingival level is even. (**d**) Periapical radiograph taken 1 month after the radiograph in (**b**). Note in (**d**) the level of the distal crestal bone and the distance between the root tip and the orthodontic appliance (transpalatal arch)

Correcting the inclination of the proclined or retroclined teeth with orthodontics would save the teeth from extensive preparation for restoration or even endodontic treatment to reach an ideal inclination [23].

2.5.3.2 Mandibular Incisors

Designing the appropriate mandibular incisor position is determined by the maxillary incisor position, the jaws skeletal relationship, the alveolar bone structure, and the lip position. Orthodontic treatment can be used to correct or improve the inclination of the mandibular incisors within the biological range [62].

The ideal inclination should not be taken as absolute angular values. Several factors should be considered in treatment planning for the incisor position and

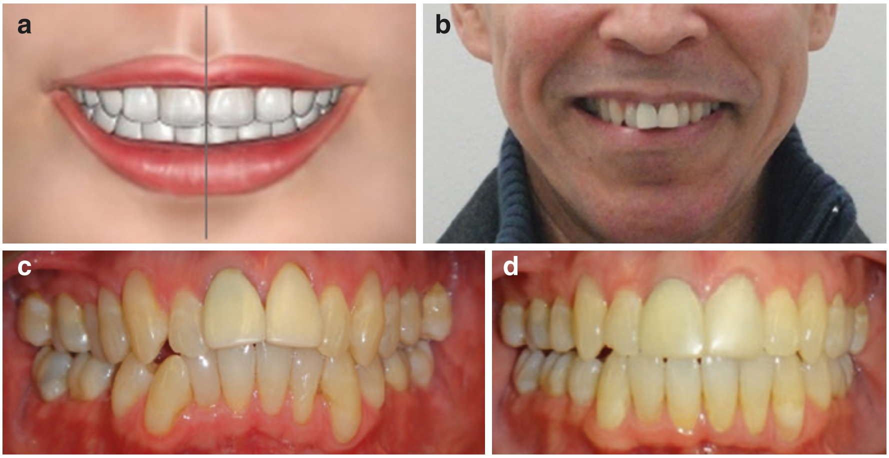

Fig. 2.18 (**a**) Coincident maxillary and mandibular midlines with the facial midlines are considered ideal. (**b**) Patient seeking orthodontic treatment after restorative treatment to fix "crooked midline." This is in agreement with Kokich findings that showed public has lower tolerance to canting in midline than parallel midline shift. (**c**) Closer view of pretreatment. (**d**) Post-orthodontic treatment

Fig. 2.19 Smile width evaluation, broad smile shown on the right, normal smile in the middle, and narrow smile with visible buccal corridor

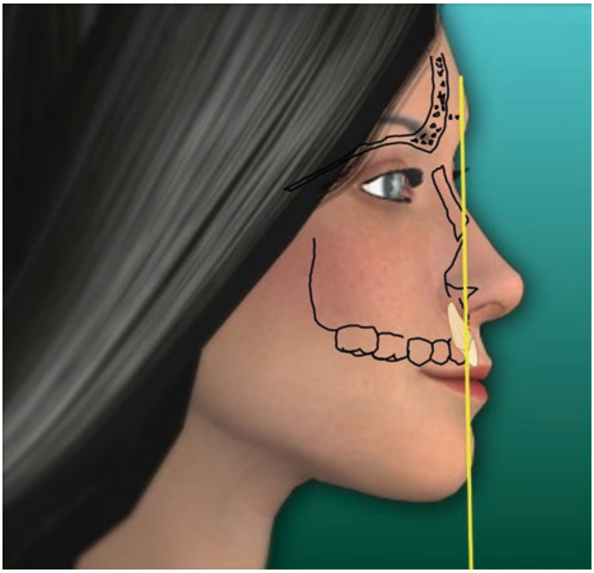

Fig. 2.20 Andrews' Goal Anterior Limit Line (GALL) application to determine the anterior–posterior position of the maxillary incisor

coordination. Cases of increased overjet that result from skeletal discrepancy (skeletal cl II) can be reduced by dentoalveolar compensation, which reduces the inclination of the maxillary incisors (retrocline) and increases the inclination (procline) of the mandibular incisors. The opposite is true for negative overjet. Soft tissue analysis plays an essential role in designing the final position of the maxillary and mandibular incisors. The anterior–posterior position of the lips in relation to the nose (NLA) and to the E-plane (Figs. 2.6 and 2.7) should be considered in planning the position of the incisors. Vigilant planning for cases of prominent protruded lips (acute NLA) should be designed not to increase the inclination or protrusion of the incisors, which may result in compromised facial esthetics. While planning cases with obtuse nasolabial angle and recessive lips, incisors should not be retracted, which is unesthetic and gives an older looking profile.

Note in the Fig. 2.21 case, patient's treatment plan was not based on the cephalometric values of incisor inclination but rather based on the facial appearance. At the end of the treatment, the incisors were more proclined than ideal. This was done in order to improve the patient profile and lip position by giving her a fuller look. This is especially critical in growing patients. Any retraction of the maxillary teeth would result in lips that are further back, which emphasizes the nose and chin prominence and gives an aging appearance to the face that only gets worse with age.

Fig. 2.21 (**a**) Patient present with retrusive lips, deep mentolabial sulcus, and dental crowding. (**b**) Patient received orthodontic treatment that resolved dental crowding by expanding her arch in transverse and A–P. The treatment outcome on patient face showed improved lip support, improved depth of nasolabial folds, and mentolabial sulcus. Despite the increased inclination of the incisors posttreatment, the facial esthetics is improved, which is an important principle to prioritize the facial appearance in treatment planning

Fig. 2.21 (continued)

Correction of Excessive Overjet

Knowing the etiology of an overjet is essential for appropriate treatment. The practitioner will determine whether the root cause of this condition is of skeletal or dental origin and what division of the class II malocclusion (Figs. 2.22, 2.23, and 2.24). A better approach is to consider whether a class II molar relationship exists. In such instance, a patient will present with crowding, cl II molars, and without increased overjet. Failing to recognize the skeletal cl II pattern that underlies the malocclusion in cases without severe overjet is crucial. In such cases, the mere alignment of anterior teeth in a class II division 2 malocclusion will expose a severe overjet (Fig. 2.25).

In any case, the treatment plan should consider the ideal position of the maxillary incisors, determine how complex the required dental movements are, and decide whether they would require comprehensive treatment. Considering that a simple approximation indicates that 2 mm of space must be created to retract the incisal edges by about 1 mm, usually 1 mm per side to maintain midline alignment, an astute practitioner will decide whether a combination of IPR and proclination of the lower incisors would achieve esthetic placement of the teeth and facilitate placement of well-proportioned anterior teeth.

2.6 Skeletal Analysis

2.6.1 Cephalometric Analysis

Orthodontists frequently use cephalometric radiographs to diagnose the skeletal pattern by assessing the position of the maxilla and the mandible in relation to the

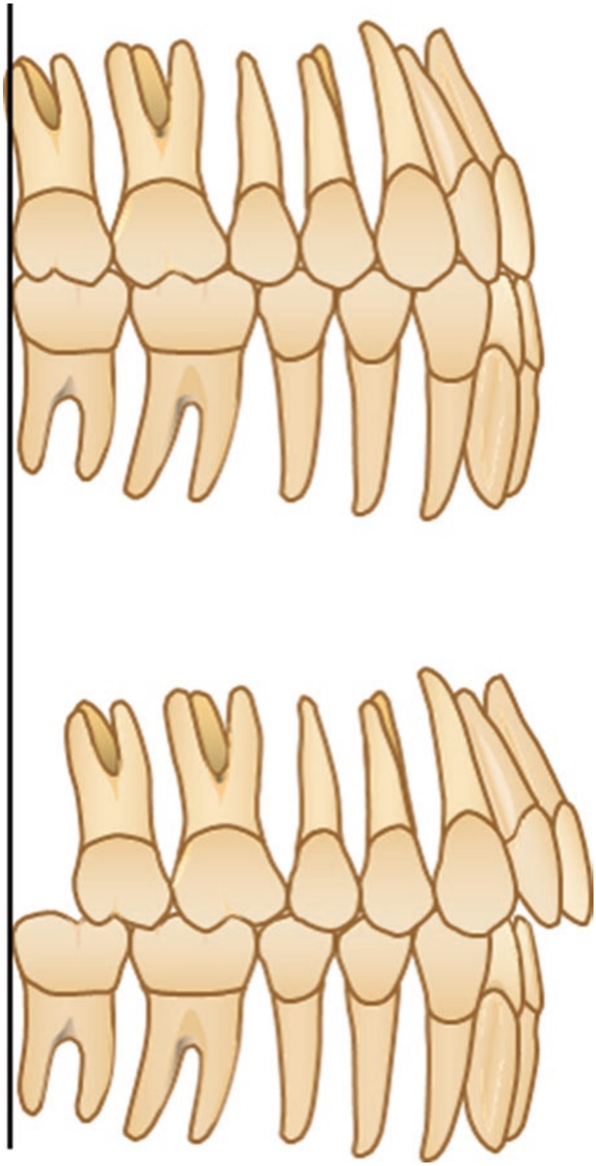

Fig. 2.22 Note the increased overjet resulting from displacing the maxillary arch to a class II relationship

cranial base and in relation to each other. Cephalometric radiographs are also used to evaluate the angular inclination and the position of the incisors. There are many reported analyses that use different references. For example, Steiner's analysis uses the nasion to A point (Na-A) line as a reference to measure the incisal angulation of the maxillary incisors and to determine the anterior–posterior position (Fig. 2.26). The Na-A line forms an angle by intersecting with the maxillary incisor long axis,

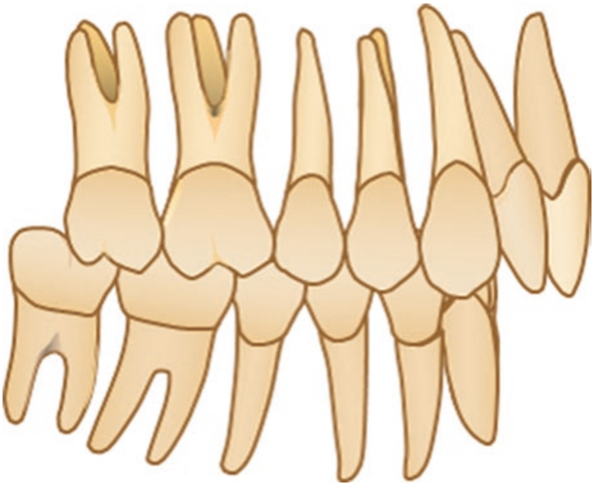

Fig. 2.23 A class II division 1 malocclusion with severe overbite. When deep overbite exists, the mandibular incisors tend to upright and become crowded, except in cases of severe mandibular retrognathism

which will determine the amount of proclination or retroclination of the maxillary incisor. The Na-A line is also used to measure the distance from the incisal edge to the same line to assess the anterior-posterior position, which is how much protrusion or retrusion the maxillary incisors have.

The optimal positioning and angulation of the maxillary incisors as described previously depend upon optimal facial skeletal relationships. Protrusion or retrusion of the maxilla and/or mandible compared to each other leads to different angulations to accommodate the skeletal pattern.

For example, in a so-called class II relationship, the patient will exhibit various degrees of maxillary incisor retroclination and mandibular incisor proclination. The opposite is true for skeletal cl III (Fig. 2.27); the maxillary incisors are proclined, while the mandibular incisors are retroclined. It is not unusual to find this pattern of dental adaptation in skeletal cl II and cl III patterns, which is known as dental compensation for skeletal discrepancy.

2.6.2 Moorrees Mesh Analysis

Cephalometric measurements, however, can be misleading if interpreted in absolute terms. Some have found that proportion analyses, such as the mesh diagram suggested by Moorrees using the "natural head position," better reflect the facial morphology. It is a reproducible orientation of the head in space when an individual is focusing on a distant point at eye level, for example, the horizon line. One then considers a hypothetical plumb line in front of the face as the "true vertical" line and a line perpendicular to it as the "true horizontal." Moorrees elaborated on the work by de Coster to conceive the mesh analysis which is based on proportions and graphically displays the results (Fig. 2.28).

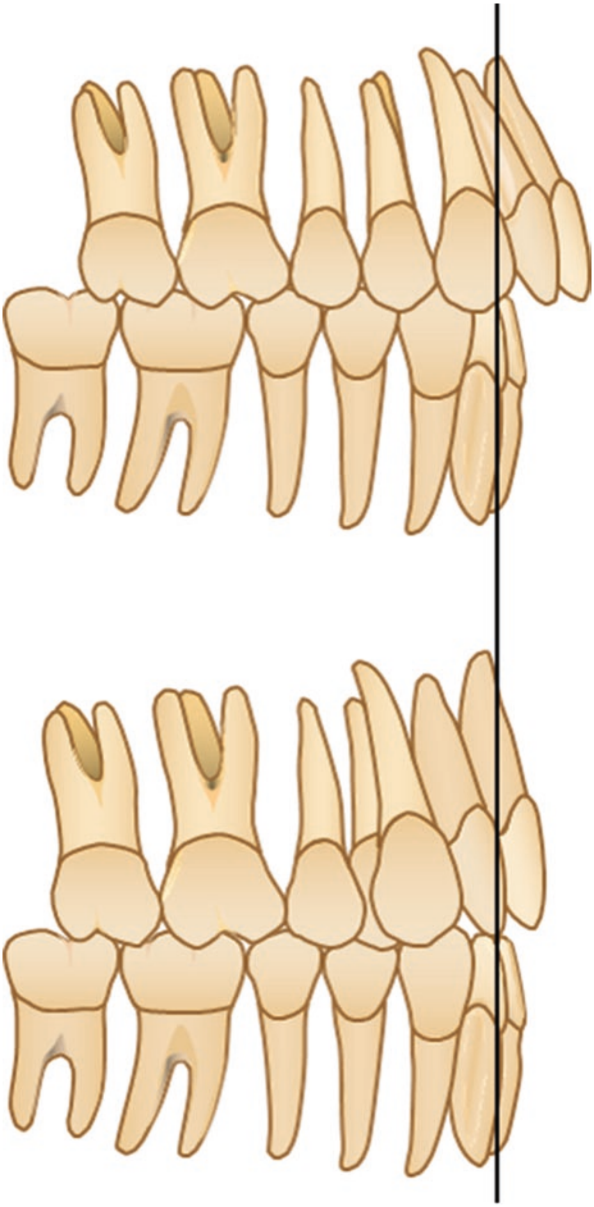

Fig. 2.24 Class II division 1 malocclusion with crowding in the maxillary arch. Note that unraveling the crowding will create a significant overjet or significant tooth substance will have to be removed

2.7 Space Analysis

Space analysis is an integral part of a patient's comprehensive diagnosis. Space analysis provides a numeric estimate of whether the available space is deficient or excessive. Most common teeth alignment problems result from crowding due to

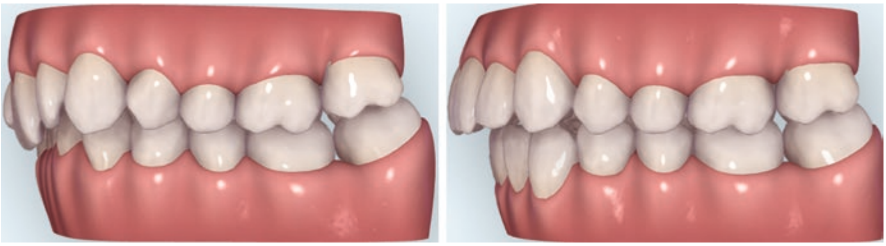

Fig. 2.25 Attempting to align the teeth in cl II div 2, without addressing the skeletal discrepancy or the malocclusion, will unravel severe overjet

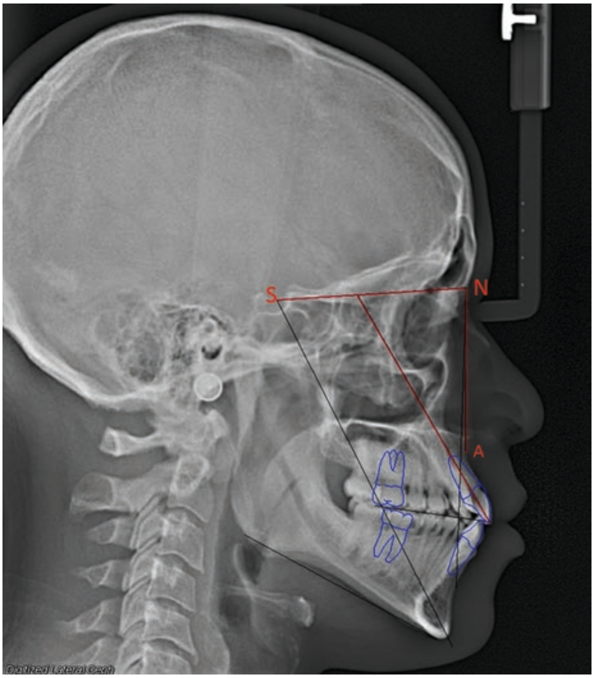

Fig. 2.26 Measuring maxillary incisor inclination using Steiner analysis of the lateral cephalometric radiograph. Incisor inclination is measured by the intersection of the Na-A line with the incisor's long axis (both lines marked in red). Maxillary incisor inclination can also be measured in reference to S–N line

space deficiency. About 29% of White Americans have an ideal alignment scored on the mandibular irregularity index [63]. The rest have varying degree of irregularity from mild to severe.

To align crowded teeth, space analysis is required (Fig. 2.29). Managing the space and aligning the teeth could be complex when there is a skeletal discrepancy, missing teeth, or tooth-size discrepancy [64, 65]. These cases require collaborative work among dental professionals [66]. In cases with space issues without tooth-size discrepancy, orthodontic alignment might be sufficient to resolve the issue [67].

Ever since the dawn of specialty, orthodontic practitioners have usually chosen their therapeutic appliances carefully and focused on their perceived functional

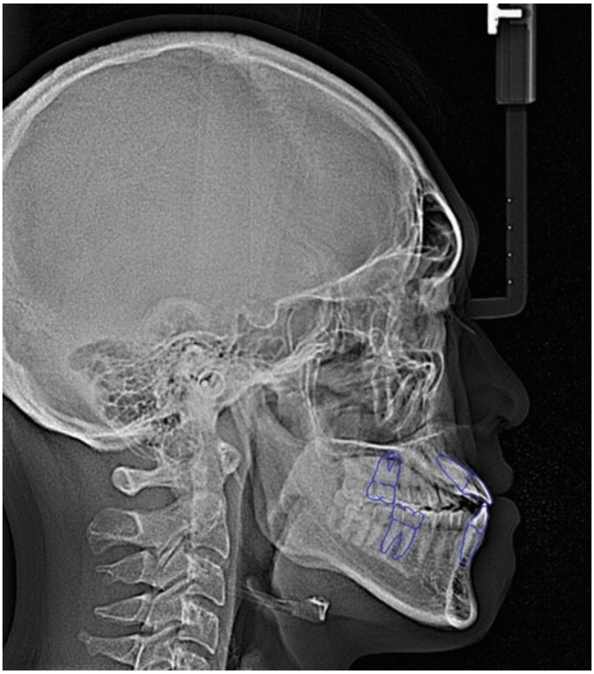

Fig. 2.27 Determining ideal inclination of maxillary and mandibular incisors depends on the skeletal pattern. In this untreated skeletal cl III case, we notice the increased proclination of the maxillary incisors and the retroclination of the mandibular incisors. This phenomenon is known as dental compensation for skeletal discrepancy

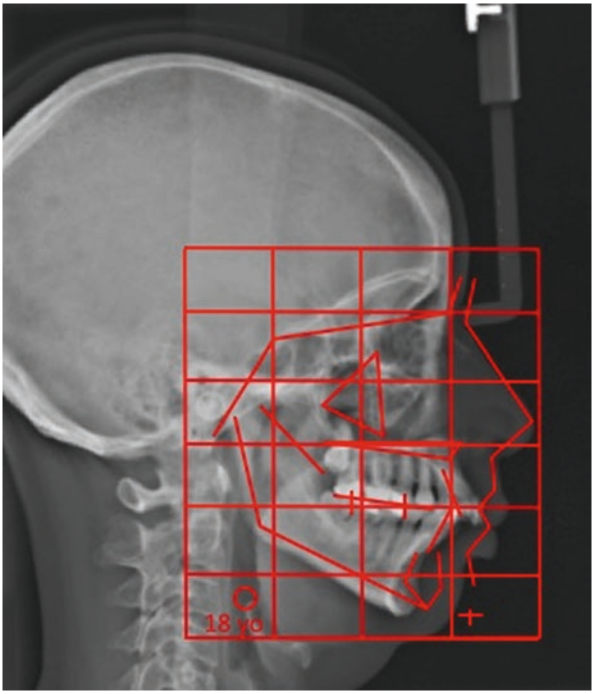

Fig. 2.28 Moorrees mesh analysis that uses the individual's proportions as reference. In this example, the mesh indicates that the patient has protruded maxillary incisors, retrognathic mandible, and protrusive lips

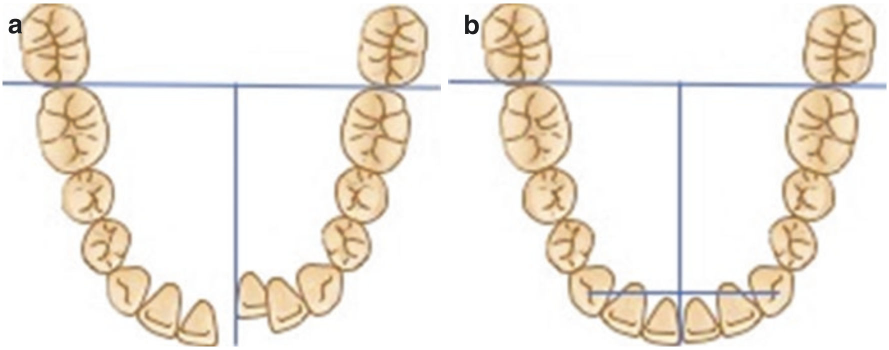

Fig. 2.29 (**a**) Alignment of crowded teeth requires space analysis. (**b**) Based on the analysis and facial appearance, crowding can be resolved by expansion or reducing tooth mass by extraction or interproximal reduction

outcomes and side effects intrinsic within their design to achieve optimal occlusal and esthetic results. Moreover, the therapeutic reliability and predictability of fixed labial orthodontic appliances have evolved to become the standard for assessing the efficacy of treating malocclusions whenever any other treatment modalities might be considered. However, in recent decades, the rapid demand and preference for esthetic, or "minimally visible," orthodontic appliances by the patient may have inadvertently led to alternative treatment plans that ignore previously tested and accepted optimal treatment objectives.

Esthetic orthodontic appliances, most notably lingual appliances and clear aligners, were initially used to treat malocclusions in a limited fashion, i.e., anterior crowding in adult patients. In time, such appliances evolved and improved so that comprehensive management of more involved malocclusion became possible, so much so that esthetic appliances are now being used to treat malocclusions in adolescents as well. The relative newness of these esthetic appliances has created a dearth of literature substantiating their effectiveness and therapeutic outcomes, as much of the claims lack objectivity.

Reports available document that both types of appliances, lingual and aligners, rely heavily on expansion of the dental arches and on the use of interproximal reduction (IPR) of the dental enamel to solve dental crowding.

While these appliances arguably may have esthetic advantages that certainly may enhance patient compliance and, in the case of clear aligners, may actually reduce the hygienic/periodontal risk factors common to fixed appliances, what compromises are accepted in using such appliances? In essence, should therapeutic standards be lowered when patients request specific appliances?

Among most prevalent types of malocclusions, dental practitioner will focus on the treatment of dental crowding, class II malocclusions, and deep overbite. One will assume that proper diagnosis was drawn using comprehensive clinical examination in conjunction with obtaining appropriate records.

2.7.1 Methods of Space Analysis

2.7.1.1 Space Analysis

Space analysis is accomplished by comparing the available space in the arch and the space needed to ideally align the teeth (Fig. 2.30). Space available is calculated by drawing a virtual line where the teeth will be. The space needed is calculated by summing the total width of the teeth. The difference between the available space and the needed space will determine arch space discrepancies. Space deficiency is determined when the available space is less than the total teeth mass, as seen in crowding cases. On the other hand, space excess occurs when the available space is larger than the teeth mass, as seen in spacing cases.

2.7.1.2 Bolton Analysis

Evaluation of size discrepancy between maxillary and mandibular teeth should be routinely conducted to achieve an ideal relationship between maxillary and mandibular teeth. Unaddressed tooth-size discrepancy can prevent achieving an ideal overbite, overjet, and perfect interdigitation. According to Bolton, approximately 30% of the cases overall had tooth-size discrepancy of more than 1.5 mm.

Bolton analysis is performed to predict size discrepancy between maxillary and mandibular teeth [68]. Overall, a Bolton analysis is calculated by comparing the summation mesiodistal widths of all 12 mandibular and 12 maxillary teeth (first molar-first molar) (Fig. 2.31). The anterior Bolton ratio is calculated by measuring the width of anterior teeth (canine–canine).

$$\text{Overall Bolton ratio} = \frac{\text{The sum widths of all 12 mandibular teeth}}{\text{The sum widths of all 12 maxillary teeth}} \times 100$$

$$\text{Anterior Bolton ratio} = \frac{\text{The sum widths of all 6 anterior mandibular teeth}}{\text{The sum widths of all 6 anterior maxillary teeth}} \times 100$$

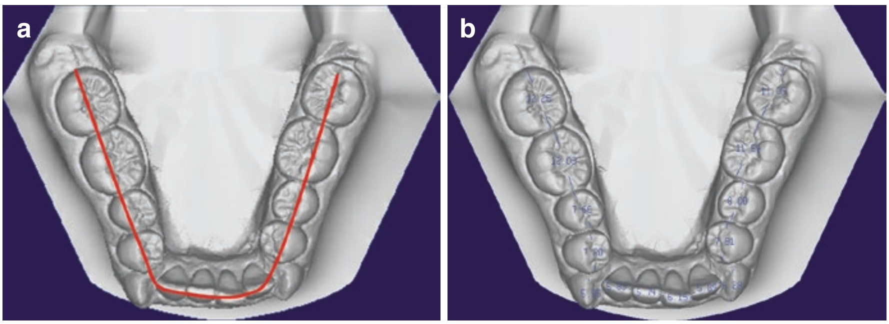

Fig. 2.30 Space analysis is the different between space available (in red) in figure (**a**) and space required; the sum of teeth widths (in blue) (**b**)

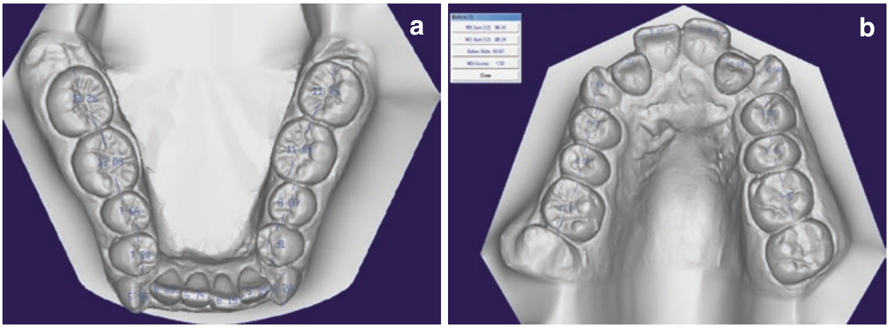

Fig. 2.31 Bolton analysis is calculated by the sum widths of the mandibular teeth (**a**), divided by the sum widths of the maxillary teeth (**b**)

The overall ratio is considered normal when it is 91.3%. An overall ratio that is bigger than 91.3% indicates that there is either an excess in mandibular teeth mass or a deficiency in maxillary teeth mass. An overall ratio that is smaller than 91.3% indicates maxillary teeth excess or mandibular deficiency.

The ideal anterior Bolton ratio is 77.2%. When the ratio is higher, it is expected to have an excess in mandibular anterior teeth or a deficiency in maxillary anterior teeth. The most common example of tooth-size discrepancy occurs in cases with peg laterals. The opposite is also true: when the anterior ratio is lower than 77.2%, it indicates that there is an excess in maxillary anterior teeth or a deficiency in mandibular anterior teeth.

With the technological advancement of the available tools, virtual orthodontic movement simulation enables visualization of space distribution and dental inclination (Fig. 2.32). This is very effective visual tool to be used among the dental professional communications in managing multidisciplinary cases.

Crowding

Two major treatment strategies can be considered to achieve the alignment of teeth in the dental arches:

1. Reduction of dental units, whether by enamel reduction or extraction of dental units when the space requirement is excessive.
2. Expansion of the dental arches (anteroposteriorly and transversely) (Fig. 2.33).

Without entering the extraction–non-extraction debate, it appears that practitioners using clear aligners or lingual appliances tend to avoid prescribing extractions, thereby resorting to using expansion and/or interproximal reduction of teeth, often in combination. This has partially occurred due to the perception that one of the advantages in using these appliances is that they lend themselves readily to the expansion of the dental arches—perhaps as it may be easier to do—than to do otherwise (extract), but where is the evidence? And how stable are the results in performing this expansion? As will be demonstrated later, the practitioner should measure

Fig. 2.32 Virtual treatment planning of space distribution can be done with various options available in the market. This facilitates communications among the dental professional. In this example it was done with ClinCheck software from Align Tech. (**a**) The teeth position at the start. (**b**) The desired teeth position after space redistribution

the amount of crowding in the dental arches before resorting to either enamel reduction, arch expansion, or a combination of both.

Enamel Reduction

Since Sheridan [69] first advocated for systematic proximal enamel reduction as a way of creating space for treating crowding teeth, practitioners have frequently embraced this approach in lieu of prescribing extractions. However, several publications have confirmed that teeth with enamel reductions were not more likely to exhibit caries compared to intact teeth [70–72]. One may question this systematic approach for the patients' dental health in the long run. One major concern with regard to IPR is its irreversibility. Although the first practitioner may perform IPR safely and conservatively to treat crowding, the same patient may seek re-treatment in the future if the initial correction did not lead to stable results. More than likely, astute clinicians will be able to detect evidence of previous IPR; however, the previous enamel thickness will ultimately never be known. Re-treatment using the same protocol may now become iatrogenic if the layer of remaining enamel becomes even more compromised—leading to more sensitivity and further increasing the risk for decay.

Previous investigations (Stroud, English, and Buschang, 1998) [73] (Table 2.1) revealed that the total enamel thickness from the mesial surface of the first mandibular premolar to the distal surface of the second molar is on average less than 9.0 mm (±1 mm) per side if one does not consider the distal surface of the second molar. Therefore, one could conclude that removing 50% of enamel on these surfaces could create about 10 mm of space in the lower arch. However, one should notice that the minimal enamel thickness recorded was substantially less than the mean measurements and patients with thin enamel would thereby be at risk.

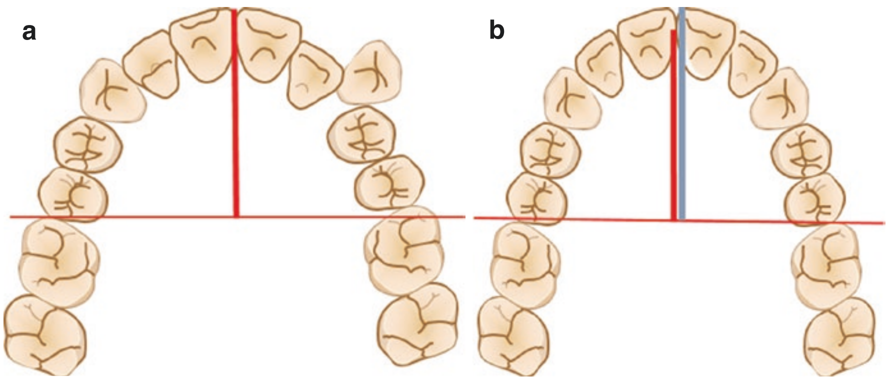

Fig. 2.33 Resolution of crowding through expansion. (**a**) An example of crowded case with space deficiency. (**b**) This can be solved by expansion in anterior-posterior as in this example or transverse dimension (widening the arch)

Table 2.1 Mesial (M) and distal (D) enamel thickness (mm) of the mandibular dentition (sexes combined)

Tooth	Aspect	Mean	SD	Min	Max
First premolar	M	0.99	0.21	0.49	1.65
	D	1.07	0.23	0.54	1.49
Second premolar	M	1.19	0.21	0.61	1.63
	D	1.22	0.22	0.60	1.78
First molar	M	1.28	0.23	0.74	1.87
	D	1.40	0.25	0.70	2.17
Second molar	M	1.29	0.20	0.94	1.84
	D	1.48	0.26	0.95	2.33
Total	M	4.67	0.59	3.64	6.56
	D	5.11	0.70	3.74	6.41

From: Enamel thickness of the posterior dentition: Its implications for nonextraction treatment. JL Stroud, J English, PH Buschang, Angle Orthod 1998. Note the variations in enamel thickness from tooth to tooth

Therefore, one should consider IPR as a strategy only for space creation in true borderline cases and only after having checked enamel thickness of the teeth with intraoral radiographs—preferably bitewings [74]. In such instances where IPR is possible, it should be kept at an absolute minimum [75, 76]. If IPR is not advisable, practitioners should consider extraction of dental unit(s) to resolve crowding without excessive dental arch expansion and should suggest patients use lingual appliances instead of clear aligners for enhanced control of dental movements.

Dental Arch Expansion

A dental arch can be expanded both laterally and anteroposteriorly. The usual target is the maxillary arch, mostly because the mandibular teeth fit within the maxillary teeth and any attempt to expand the mandibular arch is limited by the occlusion with the maxillary teeth to avoid the creation of a crossbite. Stability of the dental expansion should be a consideration when expanding dental arches, and the patient should be advised to use retainers to maintain the corrections.

Lateral expansion in the maxillary arch has gained popularity, mainly for the perceived favorable effect on the width of the buccal corridors.

In the absence of crossbite, dental expansion will create space, but somewhat limited. According to Adkins, Nanda, and Currier (1990), expansion with a fixed rapid palatal expander creates about 0.7 mm of space for every millimeter of net expansion at the premolar area, a little bit more when expanding the canines, but only about 0.25 mm of space for every millimeter of expansion at the level of the molars (Fig. 2.34). One should, therefore, expect a more limited space creation by lateral expansion, although there might still be some benefit in reducing the perceived width of the buccal corridors by exposing more of the premolars.

When considering expansion in the mandibular arch, the practitioner should consider the following principles:

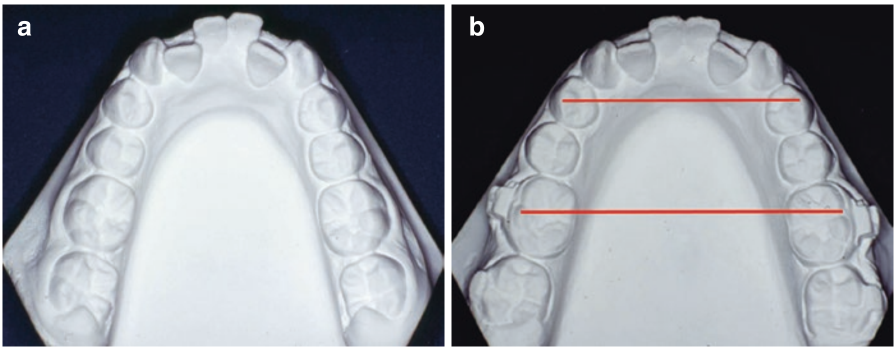

Fig. 2.34 Expansion should be taken with caution as it has limitations. In this case, (**a**) before expansion and (**b**) after expansion, note that inter-canine distance was increased 1.7 mm, inter-premolar distance was increased 4 mm, and intermolar distance was increased 4 mm. Compare the crowding in both arches, you can observe that despite the resultant expansion, the present crowding did not significantly improve

1. More than 2 mm of mandibular canine expansion is considered unstable and prone to relapse.
2. There is less expansion in the molar area, usually leading to very little space gain.

Anterior–posterior expansion can add space gain, e.g., by proclination of the incisors. A reasonable estimation is the creation of about 2 mm of space for each millimeter of incisor proclination. In that instance, esthetic considerations are important. How much proclination of the maxillary incisors is tolerable for smile esthetics? Finally, one could count on some space gain when distalizing maxillary molars, although it might be advisable not to seek full class II correction on adult patients.

Crowding and Gingival Black Triangles

Black triangles compromise the smile appearance. Kokich et al. reported that dentists and laypeople find that black triangles that exceed 3 mm to be unattractive [77].

The formation of black triangles is multifactorial in nature [78, 79]. Some of these factors are related to the dental morphology like the interproximal space, the gap between the interproximal contact point and the alveolar bone, and the crown shape. Some factors are related to the patient age, gingival biotype, and existence of periodontal disease [72].

A study predicts that 15% of patients who had orthodontic treatment for crowding in maxillary incisors could develop black triangles after aligning their teeth [80]. Fig. 2.35 demonstrates a case that started with mild crowding and incisor overlap.

After orthodontic alignment of the teeth, the patient developed black triangles.

This was resolved by recontouring the teeth by interproximal reduction; this creates broader contact area. This is followed by moving the teeth closer. It is worth noting that the alignment of crowded teeth does not cause papilla loss. It is rather that papilla was lost between the overlapped teeth and it is only noticeable after straightening the teeth.

There are various methods to manage gingival black triangles, based on the etiology: can be treated with surgery [81], injecting the gingival tissue with hyaluronic acid (HA) [82], and reshaping the tooth to have broader contact with restoration [83] or orthodontically [74].

Spacing

Occasionally, one must reduce excessive spacing in the dental arches. A differential diagnosis will reveal the etiology of such condition. One should consider tooth size, protrusion of the teeth, and, of course, the presence of an excessive arch perimeter.

Depending on the severity, one may elect to retrocline the anterior teeth and/or distribute spaces to optimize the esthetic outcome regarding tooth size and proportion.

Closing spaces necessitates reversing the thinking applied to space creation. Retroclination of the anterior teeth may be flawed both esthetically—teeth are too upright—and physically when the dental arches are too constricted and interfere with tongue space.

Fig. 2.35 (**a**) Pretreatment, patient presented with mild crowding and incisor overlap. (**b**) Patient developed black triangles after aligning her teeth with orthodontic treatment. It is worth noting that the papilla between the maxillary incisors did not shrink; the papilla preexisting shape was unraveled after eliminating the dental overlap and crowding. (**c**) Black triangles in this case were managed by recontouring the interproximal surfaces to create broader interproximal contact, followed by orthodontic movement that brought the teeth closer. Black triangle development and management

Fig. 2.36 Patient had wide arches with generalized excessive spacing. Due to patient facial appearance and the inclination of her teeth, the case was treated with space consolidation into one space in each quadrant, followed by additional premolar implants

Occasionally, excessive spacing can lead to space consolidation and creation of space for an additional premolar in each quadrant (Fig. 2.36).

Managing the dental spaces should only be attempted after conducting space analysis, Bolton analysis, and skeletal diagnosis (Fig. 2.37). Patient had spacings in maxillary and mandibular arches. Bolton analysis revealed an estimated 4 mm of mandibular excess; this is critical in space management; to completely close the spaces without affecting the occlusion, patient can either get a restorative treatment to increase the width of maxillary incisors or reduce the mandibular space by interproximal reduction, which is what was done in this case.

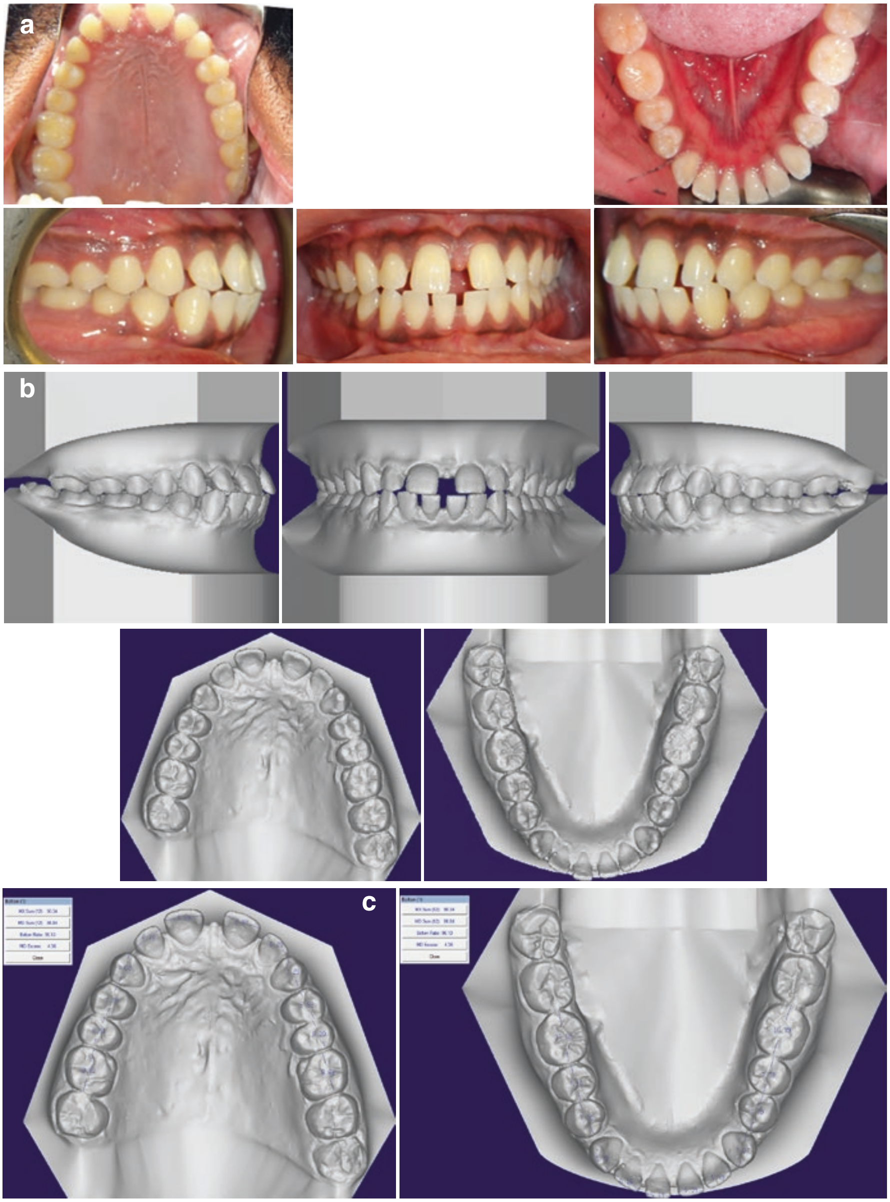

Fig. 2.37 (**a**) Patient present with maxillary and mandibular spacing. (**b**) The digital model of the case. (**c**-i and **c**-ii) Bolton analysis reveals overall mandibular excess that is estimated to be 4 mm. (**d**) Despite having spaces in the mandibular arch, interproximal reduction (IPR) was planned to address the Bolton discrepancy. (**e**) The planned final position of the teeth. (**f**) The patient after space closure and (IPR) performance on the mandibular anterior teeth. Space analysis and dental ratio of upper and lower teeth should be done on every case, even in cases with spacing. This example demonstrates that despite having extra spaces, IPR was planned and performed to address the Bolton discrepancy. Not addressing this discrepancy results in compromised occlusion or incomplete space closure of the upper teeth

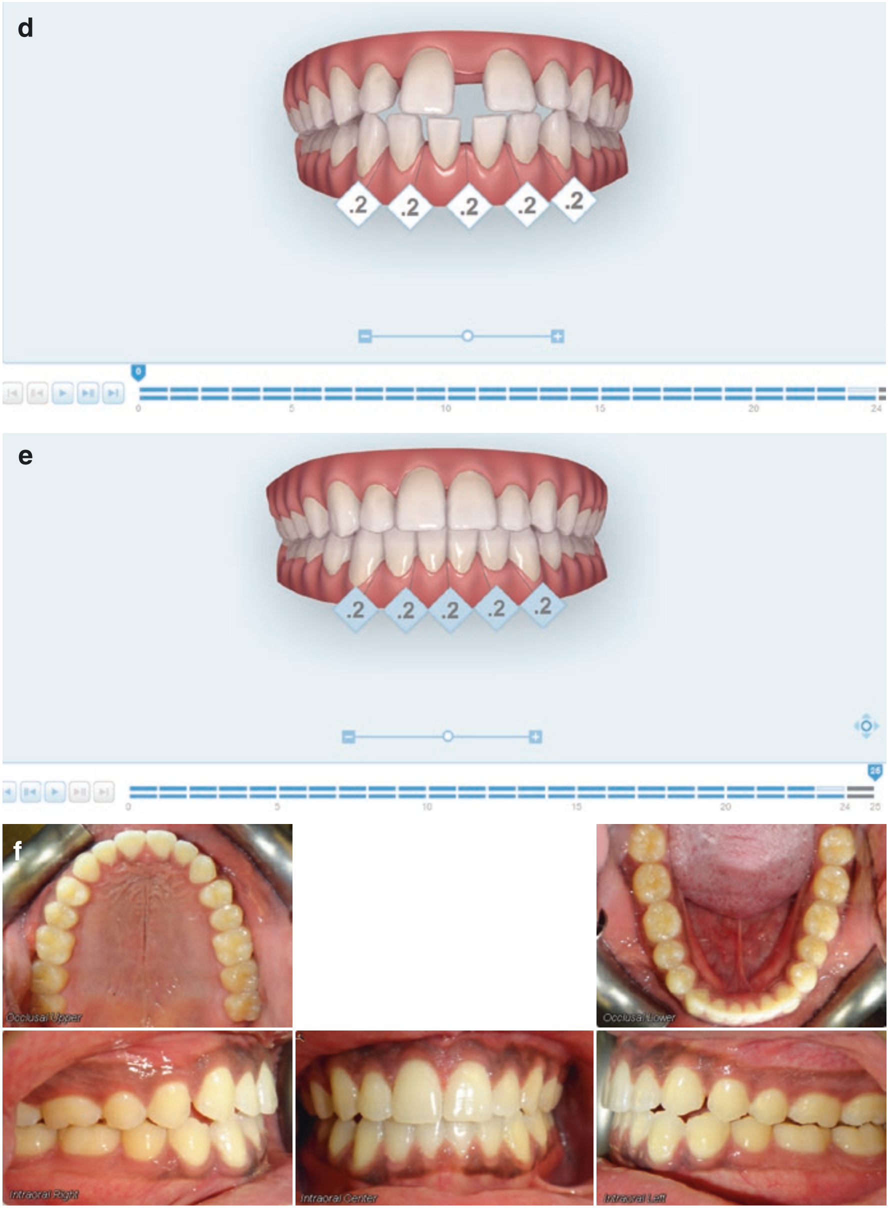

Fig. 2.37 (continued)

Treatment of cases with dental spacing and small or peg maxillary lateral incisors is done collaboratively between the restorative dentist and the orthodontist. The restorative dentist will plan the final position of the teeth for maximum esthetics, while conserving tooth structure. The orthodontist will plan the teeth movement accordingly; Fig. 2.38 is an example of a case that had orthodontic space

Fig. 2.38 (**a**) Case with maxillary spacing and peg lateral incisors. (**b**) The case was orthodontically treated to distribute spaces and with esthetics for veneers

distribution according to the restorative dentist plan and then received veneers at the end of the treatment.

The management of maxillary peg lateral incisors in cases with crowding and skeletal discrepancy should be planned by a team of dental professionals that include restorative dentist, orthodontist, and surgeon. Patient in Fig. 2.39 has skeletal cl III, anterior and posterior crossbite, crowding, missing lower incisor, and peg maxillary lateral incisors. Planning this case was a collective effort from various dental specialists. The restorative dentist planned the appropriate space for the lateral incisor buildup. The final position of both jaws and the teeth and the inclination of the incisors were designed by the orthodontist and the surgeon.

Treatment options for cases with missing maxillary lateral incisors include creating a space to replace the missing teeth or close the space and substitute the canines for the missing lateral incisors. Some of the determining factors include facial appearance, occlusion, skeletal pattern, and tooth and root morphology. Fig. 2.40 is an example of a missing maxillary lateral and a peg lateral. The patient has cl II div 2 malocclusion; this warrants that the attempts to replace the missing tooth would worsen the cl II occlusion (increases OJ, procline upper incisors). These cases are indicated for canine substitution for better looking smile and occlusion. In this case, the patient was treated by extracting the peg lateral incisor, correcting the midline shift and the end-on occlusion, and improving overbite and overjet.

Facial appearance and smile are another important consideration in deciding the appropriate treatment for missing lateral incisors. Figure 2.41 is a case with congenitally missing lateral incisors. The lips are in retrusive position compared to the E-plane. Also, the nasal–labial angle is obtuse. This shifts the treatment decision toward opening the space and replacing the missing teeth. Closing the space for

Fig. 2.39 (**a**) Comprehensive case before treatment. (**b**) Following orthodontic and orthognathic surgery. (**c**) Lateral cephalometric radiograph before treatment. (**d**) Lateral cephalometric radiograph following orthodontic treatment and orthognathic surgery. Multidisciplinary case management of adult patient presented with cl III skeletal pattern, anterior and posterior crossbite, crowding, and missing lower incisor and peg maxillary lateral incisors. Patient received orthodontic treatment and orthognathic surgery. The patient is ready to receive restorative treatment to the maxillary peg lateral incisors; the space is designed based on the restorative dentist plan

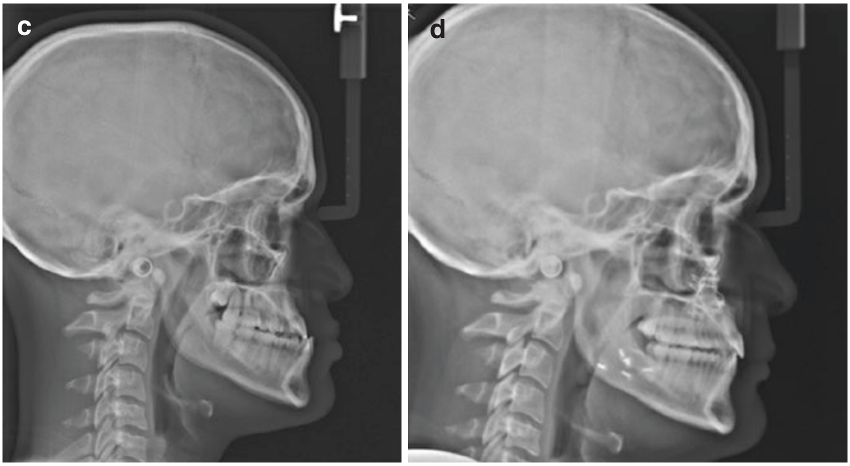

Fig. 2.39 (continued)

Fig. 2.40 (**a**) A case with missing maxillary right lateral incisor, peg left lateral incisors, and deviated midline as a result. The patient has skeletal cl II pattern and cl II div 2 malocclusion. (**b**) The patient after receiving treatment with extraction of the peg lateral incisor and bilateral canine substitution. Management of missing and peg lateral incisors depends on the patient skeletal pattern. Treatment with substitution of maxillary lateral incisor was chosen based on the occlusion (cl II). Opening space to replace the missing maxillary right lateral incisor would result in compromised occlusion, with worsening of cl II appearance

Fig. 2.41 Management of missing lateral incisors depends on patient soft tissue (smile, lip position, and profile). The patient's lips were retrusive in relation to the E-plane. The nasolabial angle is obtuse. For this, patient was treated with opening the space of the missing maxillary lateral incisors for implants. Lateral substitution would have resulted in compromised facial and smile appearance

canine substitution without addressing the appearance of the soft tissue results in unattractive compromised result.

2.8 Conclusions

Orthodontic treatment in preparation for esthetic dental treatment requires accurate diagnosis and effective communication, if needed, between practitioners to determine and agree upon the final position of the maxillary incisors and space management within the dental arches. Analysis of the face, skeletal pattern, and arch space is critical in managing comprehensive cases. One should also keep in mind that IPR is an irreversible procedure that limits enamel in cases of future treatment.

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Periodontal Considerations in Esthetic Dentistry

3

David Montalvo-Arias

Contents

3.1 Introduction

The final esthetic outcome when designing a smile will be strongly influenced by the appearance of the soft tissues surrounding the teeth or the restorations. Color, shape, texture, and thickness of the gingival tissues are just few examples of the factors that will influence the result of our treatment. In addition, how these tissues are related to other structures like teeth, lips, and face are of a great importance when we talk about the smile as an esthetic composition (Fig. 3.1).

In order to achieve a balanced and predictable esthetically pleasant result, special efforts have to be made by all the components in the diagram: esthetic dentists, technicians, specialists, and patients. Everyone plays an important role that must be guided by proper communication between all the team members (Fig. 3.2).

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Fig. 3.1 Teeth, gums, lips, and face should have a balanced relationship in order to achieve a harmonious smile

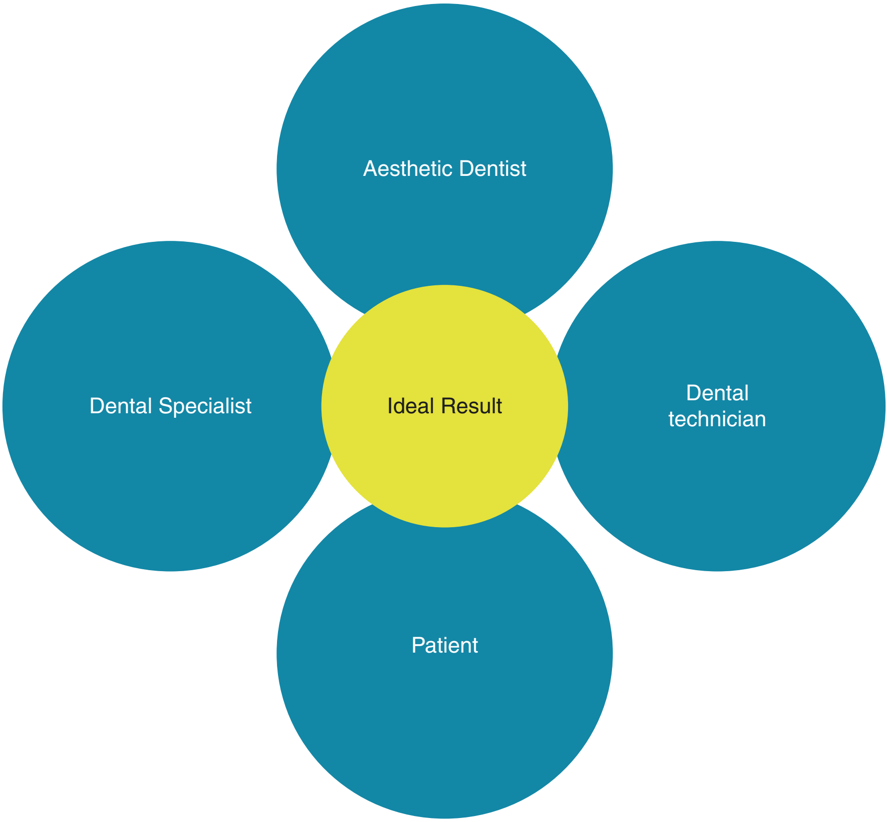

Fig. 3.2 Communication between all the team members, patient included, is a key factor to achieve the desired final result

The final evaluation of the restorative treatment should be judged not only by esthetic and functional criteria but also by anticipating the biologic effect that those restorations will have on the periodontal structures. Knowing the normal anatomy of the dentogingival complex may initially prevent violation of the basic principles. That will help us recognize the point where physiological tolerance may shift to inflammatory reaction. Understanding this has an important role in the long-term prognosis of the proposed treatment.

It is very important to realize how the restoration contributes to the accumulation of plaque and periodontal disease. Poorly designed restorations provide good support for plaque accumulation; therefore, more chances of periodontal problems will be created by the dentist.

Initial periodontal therapy and efficient plaque control have to be addressed before initiating any esthetic restorative procedure; otherwise soft tissue defects may become more apparent as gingival shrinkage occurs after the resolution of the inflammation.

3.2 Periodontal Tissues in Health

3.2.1 The Dentogingival Unit and the Biologic Width

The physiologic dentogingival unit (DGU) has been described as the anatomic and functional complex formed by the gingival margin, the sulcus, the junctional epithelium, and the connective tissue attachment. Its main role is to anatomically attach the gingiva to the tooth. It is composed of an epithelial and a connective tissue compartment.

In the epithelial compartment, three types of anatomically distinct epithelia have been described associated with the dentogingival unit. The first one, gingival epithelium, consists of stratified squamous keratinized epithelium which is continuous at the gingival crest with the second type, stratified nonkeratinized or para-keratinized epithelium. Sulcular epithelium represents the soft tissue wall of the gingival sulcus facing the tooth but not attaching to it and is continuous at the base of the sulcus with the junctional epithelium or the epithelial attachment. Junctional epithelium forms a collar around the tooth, and the surface cells provide the actual attachment of gingiva to the tooth surface.

In the connective tissue compartment of the dentogingival unit, we find the fibrous attachment of the gingiva to the hard tissue wall that also gives support to the epithelium of the dentogingival junction. Gingival collagen fibers will provide fibrous connective tissue attachment to the root surface, maintaining the functional integrity of the teeth and its gingival collar. The most important groups of fiber bundles that compose this gingival unit are dento-gingival, alveolo-gingival, dento-periosteal, trans-septal, circular/semicircular, and inter-papillary fiber bundles.

These components have been described with specific constant numbers in the scientific literature. The autopsy material reported in a study done by Gargiulo et al. showed that the average sulcus depth was 0.69 mm, the average length of the junctional epithelium was 0.97 mm, and for the connective tissue compartment was 1.07 mm. Of these three tissue components, the supracrestal connective fibrous attachment seems to exhibit the least variability, followed by the junctional epithelium and sulcus depth. The sulcus depth can show more variations between specimens [1] (Fig. 3.3).

In 1962, Cohen defined the "biologic width" of supracrestal gingival tissue as those junctional epithelium and connective tissue elements of the dento-gingival unit that occupy the space between the base of the gingival crevice and the alveolar crest. The total dimension would be around 2.04 mm and this number seems to be constant in the literature. That is the non-variable part of the DGU, and it is important to respect it when placing our restorative margins in order to avoid biological complications like chronic pain, inflammation, or recession [2].

Kois, for practical reasons, describes it with a name that would prevent confusion: the "biologic zone." This will refer to the minimum dimension of this space between the most coronal level of the alveolar bone and the most coronal level of gingival margin, and it would be in the vicinity of 3 mm in a healthy and normal gingiva. This is the minimum space required for the tissues to maintain their continuity in a healthy status. This parameter will be important when planning and executing crown-lengthening surgeries. That would be the minimum distance to maintain from the bone margin to the gingival margin [3].

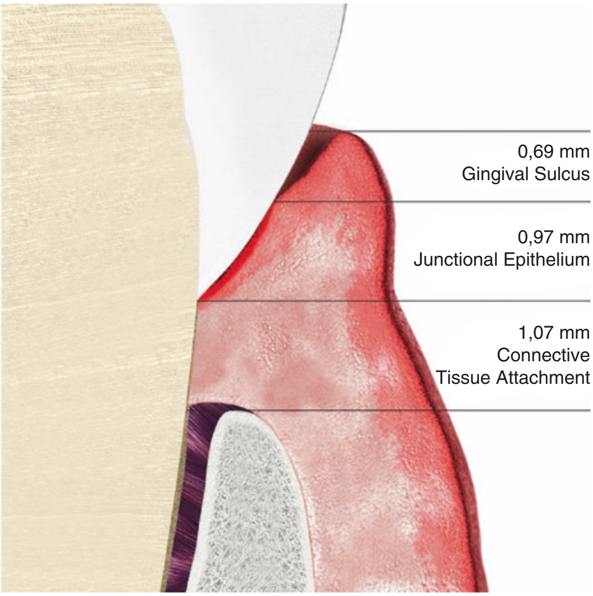

Fig. 3.3 Biologic width is the natural distance between the base of the gingival sulcus and the height of the alveolar bone. This distance is important to consider when fabricating dental restorations, because they must respect the natural architecture of the gingival attachment if harmful consequences are to be avoided

3.2.2 Clinical Features of Healthy Gingiva

Healthy gingiva could be described as the soft tissue surrounding and protecting the teeth from several bacterial and traumatic aggressions, which presents when healthy with a coral pink-colored appearance with multiple degrees of pigmentation. The marginal gingiva follows a scalloped outline on the facial and lingual surfaces in a firm and resilient consistency that does not bleed on gentle probing.

The contour of the gingiva varies considerably, and it is influenced by the shape of the teeth and their alignment in the arch, the location and the size of the area of proximal contact, and the thickness of the underlying alveolar bone. It forms a straight line along the teeth with relatively flat surfaces. On teeth with pronounced mesiodistal convexity or teeth in labial version, the scalloped contour is increased, and the margin is thinned, and the gingiva is located farther apically. On teeth in lingual version, the gingiva is horizontal and thickened.

The level of gingival tissue normally mimics or follows the architecture of the underlying osseous crest, but it is also shaped by the surface anatomy of the teeth. In normal conditions, a parallel arrangement between gingival margins and the underlying bone crest will be assumed, even in the interproximal areas, where peeks of bone are found to achieve a more coronal position [4] (Fig. 3.4).

Lang and Löe proposed that at least 2 mm of keratinized tissue (KT) is necessary around the teeth to maintain periodontal health of the average patient [5]. Later reports also supported this assertion. The current consensus is that at least 2 mm of KT and 1 mm of attached gingiva are necessary around the teeth in order to avoid mucogingival problems [6–9] (Fig. 3.5a, b).

3.2.3 Periodontal Biotype

The identification of the periodontal biotype may be important in clinical practice since differences in gingival and osseous architecture are related to the outcome of different dental procedures including periodontal treatment. Periodontal biotype or morphotype can be classified according to the thickness of the gingiva and the underlying osseous component in three different categories: thin scalloped, thick flat, and thick scalloped as described by De Rouck et al. [10]. He quantified this by placing the probe into the buccal sulcus of the central incisor, hereby terming the gingiva either thick, medium, or thin based on the transparency of the gingiva. This

Fig. 3.4 A healthy gingiva appears pink colored and firm, with an orange peel texture, following the underlying anatomy of the alveolar bone and teeth

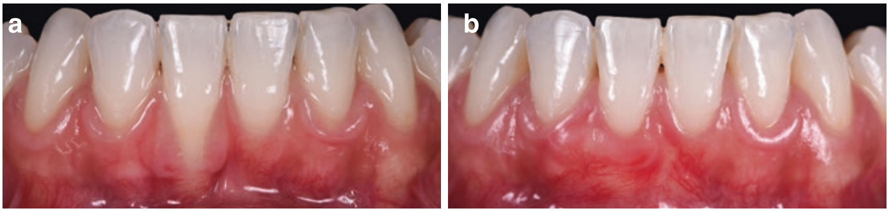

Fig. 3.5 (**a**) Not enough width of keratinized tissue can lead to inflammation of the gingival tissues that will evolve into a recession if the mucogingival problem is not addressed. (**b**) Increasing the amount of keratinized tissues will improve the long-term prognosis of the tooth and the oral health of the patient

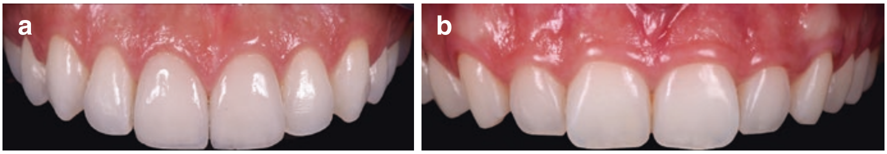

Fig. 3.6 (**a**) Thin, scalloped biotype. (**b**) Thick, flat biotype

method was also used by Kan et al. where he quantified the gingival thickness by classifying thin as ≤1.0 mm and thick as >1.0 mm [11].

The periodontal biotype will be determined by several factors such as alveolar bone and gingival thickness and the width of the tooth in the facial lingual plane. Every group will respond differently to subgingival preparations, and we have to consider that before defining the finishing line of our restorations. The gingiva with scalloped contour is usually thinner and prone to recession with minor trauma, like finishing line preparation or retraction cord packing. Thick gingival tissues display straight gingival contour and are more resistant to trauma [12, 13].

Pontoriero and Carnevale showed in a study on crown lengthening that more soft tissue is regained in patients with thick periodontal biotypes than in thin periodontal biotypes [14]. This will be an important factor to be considered when doing crown-lengthening surgeries. In case of mucogingival surgery, the initial thickness (GT) is associated with complete root coverage when using coronally advanced flap. A critical threshold thickness of >1.1 mm for complete root coverage was found [15]. Recent evidence seems to indicate stability of tissue after surgery when the thickness is >1.44 mm [16]. This suggests that in the cuspid region a connective tissue graft (or a substitute) would improve the outcome of root coverage procedures, since this area tends to show thinner thickness constantly [16] (Fig. 3.6a, b).

3.2.4 Esthetic Gingival Disposition

An ideal smile is an esthetic composition that becomes stronger the more parallelism we find between its reference horizontal facial lines. The gingival line is the tangential line drawn between the facial gingival margin of the central incisors and the canines. It should be parallel to the other horizontal reference lines, corresponding with the vermillion border of the upper lip at full smile. The gingival margin of the lateral incisors is usually located 0.5–1 mm more incisal, or at the same height of central incisor and cuspids, but never positioned in a more apical position than the gingival junction between central incisor and canine (Fig. 3.7).

The height of the gingival contour, also known as the gingival zenith, is located closer to the distal line angle of the central incisors, in average 1 mm distal of the vertical bisected midline (VBM) of the tooth. That line follows the longitudinal axis of the tooth. For lateral incisors, that distance becomes smaller, in average 0.4 mm. Regarding the cuspids, they present almost no deviation from the VBM. This will be very important in cases of diastema closure where we will need to correct the position of the zenith either by surgical or orthodontic means [17] (Fig. 3.8).

The length of the teeth and the position of the incisal edge at rest will determine the levels of the gingiva. At times, the gingival plane may not be parallel to the interpupillary line, and therefore natural asymmetry is often exhibited. This is especially relevant if there is a case of high or medium smile, and so their alignment must be incorporated into the treatment planning. If the gingiva is visible when in full smile or during speech, the incisal and gingival planes must be harmonized with the rest of horizontal facial references [18] (Fig. 3.9).

The interdental gingiva or papillae occupies the space delineated within the area of tooth contact, interdental tip of the alveolar bone, and tooth surfaces. A triangle can be drawn where the base would be the line that connects both zeniths of the teeth, where this triangle occupies constantly the 40% of the clinical crown length of the neighboring teeth [19] (Fig. 3.10).

Fig. 3.7 The gingival margin of the lateral incisors should always be positioned either at the same level of the central incisors or 0.5–1 mm coronally

Fig. 3.8 The green dots show the ideal position of the zenith in relation with the long axis of the tooth

Fig. 3.9 Notice how much of the central incisors are exposed at rest. That will determine the position of the incisal edge, and as a consequence, after measuring the height of the teeth, it will tell us whether the position of the gingival margin needs to be modified or not

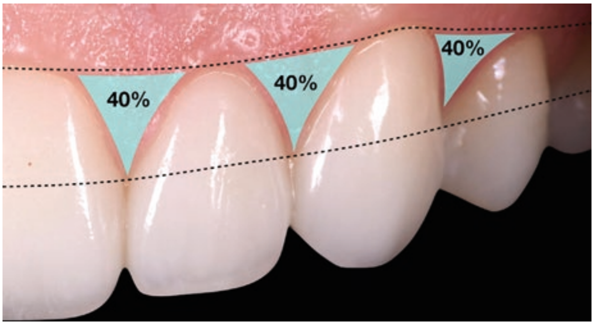

Fig. 3.10 The tips of the papilla gradually follow a pattern in the apical direction, when proceeding from the anterior toward the posterior dentition. However, it will always occupy around 40% of the height of the neighboring teeth

The morphology of interdental gingiva is governed by the size, shape, and position of contact area between adjacent teeth and the level of underlying bone crest. The interdental embrasure and the gingiva filling the space are narrow, mesiodistally, when the proximal surfaces of the teeth are relatively flat; buccolingually, the roots are close together, and the interdental bone is thin mesiodistally. Conversely, with proximal surfaces that flare away from the area of contact, the mesiodistal diameter of the interdental gingiva is broad. The presence and the space occupied by the soft tissue are observed to be relevant to the distance from the contact to the crest of the alveolar bone. Tarnow et al. reported that the papilla was present in all cases when the distance from the contact point to the crest of bone was 5 mm or less. A 1 mm increase in the distance from the contact point to the bone reduces the possibility of an intact papilla almost by half, in which papilla was present in 56% of the cases where the distance was 6 mm and only 27% or less of the cases when this distance was 7 mm or more [20].

When teeth are very close, papillae can look very long and narrow. However, if that distance is lower than 0.3 mm (root proximity), it usually disappears, due to the lack of interproximal bone tip [21].

Fig. 3.11 (**a**) Due to the absence of a contact point, the tip of the papilla remains flat. (**b**) When closing a diastema restoratively, a subgingival position of the finishing line should be created for a natural emergence profile. (**c**) The shape of the papilla will be modified by the pressure applied by the restorations and the presence of a contact point

The interdental space is not filled with papilla also in cases of diastemas, where that tissue appears to be flat since there is no contact point. That will be important to keep in mind when closing a diastema restoratively, where the finishing line of our restorations will need to be positioned subgingivally, in order to be able to push the tissues creating an ideal emergence profile. Positioning adequately the contact point in relation to the interproximal bone tip will be critical to guarantee the complete closure of the papillary area [19] (Fig. 3.11a–c).

3.3 Esthetic Periodontal Problems

3.3.1 Gingival Inflammation and Tissue Loss due to Periodontal Disease

Periodontal disease is the result of the accumulation of dental plaque at the gingival margin leading to inflammation of the periodontal tissues. The early stage of this problem is called gingivitis and proper oral hygiene combined with initial periodontal therapy will bring back those tissues to the original healthy and unaffected situation. However, if that inflammation lasts enough, it can lead to the destruction of the supporting tissues of the teeth, meaning gums and alveolar bone loss. This situation is known as periodontitis. Once it reaches that level, the sequelae of the disease are not reversible, and this will jeopardize an ideal esthetic outcome.

The objective of the periodontal treatment can be summarized as the prevention of tooth loss, maintenance of periodontal support, repair, and regeneration of damaged tissues and their function. Special attention to the modification of patient habits and the oral condition has to be taken, in order to constitute an oral hygiene level that would prevent inflammation of periodontal tissues owing to plaque accumulation, especially if restorative treatments are considered.

Initial periodontal therapy consists of oral hygiene instructions, scaling and root planing, and where present, the elimination of plaque retentive factors, like overhanging restorative margins. This will result in the resolution of the inflammation, something that is mandatory before initiating any restorative treatment. Establishing definitive restorations when inflammatory periodontal problems are present can jeopardize the esthetic outcome, and it can accelerate the rate of periodontal destruction. It is very important to allow the tissues to have enough healing time to express the real marginal position. The initial therapy can create recessions on the gingival tissues that will be shown only after the inflammation has disappeared completely. Not respecting this can create visible margins that will be shown in the smile, especially when the tooth is discolored due to a previous root canal treatment or when using metal ceramic restorations (Fig. 3.12a–d).

3.3.2 Violation of the Biologic Width

Preservation of the healthy status of periodontal tissues is a very significant factor in the long-term prognosis of a restored tooth. There are five major causes of plaque-related inflammatory periodontal disease associated with restorative procedures:

- Severe damage to the periodontal tissues during tooth preparation and impression making.
- Failure to maintain emergence profile.
- Inability to adequately finish and/or seal subgingival margins.
- Placement of subgingival margins at sites with minimum to no attached gingiva.
- Violation of the biologic width.

Fig. 3.12 (**a**) Initial situation where a narrow arch and a slight cant and crowding can be observed in her smile. (**b**) Intraoral view where the inflammation of the gingival tissues can be better appreciated. (**c**) Close-up smile after periodontal treatment that included SRP (scaling and root planing), OHI (oral hygiene instructions), gingivectomy, and orthodontic treatment. (**d**) Notice the improvement on the gingival condition and the changes in margin positions as a consequence of the treatment

Tooth preparations for restorative procedures should be done atraumatically, avoiding any irreversible damage to the supracrestal connective tissue fibers. That could create gingival recessions, exposing the underlying root surface that in cases of discolored teeth could create an unacceptable esthetic result [22, 23].

The cervical one-third of the clinical crown is also referred to as the emergence profile of the tooth. This is the region where the crown emerges from the periodontium, and its supra- and sub-gingival contours should have a flat emergence profile, recreating the profile of the alveolar bone, in order to maintain an area that is cleanable with oral hygiene instruments and provide with a good marginal seal of the restoration. Poor adaptation and roughness of the restoration margin result in mechanical irritation of the sulcular epithelium and can harbor microbial flora. Overhanging margins not only accumulate more plaque than properly finished margins, but also the plaque undergoes a shift in composition to that seen in association with destructive periodontitis [24–26].

An adequate band of keratinized tissue is fundamental to successful restorative dentistry if the margins of the restorations are extended under free gingival margin. Although no solid investigation is present to confirm this observation, augmentation of keratinized gingiva provides stability of the free gingival margin and surrounding gingival tissues so that the gingival health around the restoration can be maintained. Besides vertical dimension of the keratinized gingiva, the thickness of the tissue should be enough to tolerate intracrevicular restorations [27].

The gingival sulcus extends from the free gingival margin to the epithelial attachment. In health, its depth is in the vicinity of 0–3 mm, and it is lined with thin sulcular epithelium. The depth of this sulcus may vary from tooth to tooth and from surface to surface on the same tooth. Invading the apico-coronal width of the connective tissue attachment by placing the restorative margins in to the sulcus creates persistent and irreversible gingival inflammation owing to violation of the biologic width. Apical migration of the junctional epithelium encourages development of periodontal pockets and alveolar bone loss [1].

The finishing line of restorations should follow the contour of the cementoenamel junction and be always kept at least 2.5 mm away from the bone crest. A greater distance between the bone crest and finish line of the restoration is needed to ensure that margin of the restoration could be well reached by the plaque control instruments. The golden standard today is to prepare the finishing line of the restorations 0.5 mm below the marginal gingiva if the sulcus depth is 1 mm and 0.5–1 mm if the sulcus depth is exceeding 1.5 mm. This leaves enough distance for the junctional epithelium and supracrestal fibers and is also close enough to the gingival margin to be reached by oral hygiene procedures. When the healthy sulcus depth is less than 1 mm, placement of the margin 0.5 mm subgingival could result in impinging upon the junctional epithelium. The margin in such cases should be terminated just at or above the gingival margin. In low smile cases, where the restorative margins of the restorations will not be exposed while smiling, equigingival margins can be chosen for better hygiene purposes [28] (Fig. 3.13a, b).

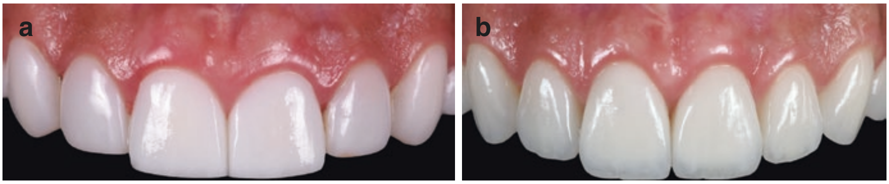

Fig. 3.13 (**a**) Initial situation. Notice the inflammation of the gingival tissues that can be observed due to the invasion of the biologic width by these overcontoured restorations and cement left behind after crown cementation. (**b**) Final situation. Healthy gingival tissues after crown-lengthening surgery to reposition the biologic width and replacement of the previous restorations

3.3.3 Excessive Gingival Display

There are three types of smile depending on the amount of tooth structure and gingival display. A low smile will be showing 75% or less of the tooth structure and none of the gingival tissues. A medium smile will show between 75% and 100% of the tooth structure and some of the interproximal gingival tissues. A high smile will expose 100% of the tooth structure and a band of gingival tissue above the teeth [29] (Fig. 3.14a–c).

The amount of gingival display also plays an important role in a smile's attractiveness [30]. Excessive gingival display (EGD), also known as gummy smile, is defined as a high smile that shows an excessive band of tissue above the upper central incisors when smiling. It is generally considered unattractive, and while a discrepancy exists in the range defined as excessive, 3 mm is agreed upon across different populations. Some authors will consider 2 mm the excessive number, whereas orthodontists will consider it excessive when more than 4 mm are shown [31, 32].

EGD may be caused broadly by dentoalveolar discrepancies or non-dentoalveolar discrepancies. Dentoalveolar discrepancies include short clinical crowns, altered passive eruption, gingival hypertrophy/hyperplasia, and dentoalveolar extrusion. Non-dentoalveolar discrepancies include hyperactive upper lip, short or incompetent upper lip, and vertical maxillary excess. It is extremely important to determine the etiology of the gummy smile before deciding on the treatment plan, in order to establish realistic treatment expectations for the patient [33].

Different treatment methods have been developed to decrease gingival display depending on the cause. While most dentoalveolar causes of EGD can be improved by restorative and periodontal approaches, non-dentoalveolar discrepancies require different approaches. EGD may be treated both surgically and nonsurgically.

Skeletal deformities that involve maxillary overgrowth can be diagnosed by evaluation of the proportions of the face and cephalometric analysis. The ideally proportioned face is divided into three equal parts from the hairline to the eyebrow, from the eyebrow to the base of nasal process, and from the base of the nose to the chin. When the lower third of the face is longer than the other two, a skeletal origin for a "gummy smile" can be expected, due to a maxillary overgrowth. This results in the teeth being positioned farther away from the skeletal maxillary base and a display of gingiva below the inferior border of the upper lip. Orthognathic surgery

Fig. 3.14 (**a**) Low smile. (**b**) Medium smile. (**c**) High smile

Vertical Maxillary Excess Classification		
Degree	**Gingival display**	**Treatment modalities**
I	2–4 mm	Orthodontic Intrusion only Orthodontics and Periodontics Periodontics and restorative theraphy
II	4–8 mm	Periodontics and Restorative therapy Orthognathic Surgery
III	>8 mm	Othognathic surgery with or without adjunctive periodontal and restorative therapy

Fig. 3.15 Vertical maxillary excess classification

has to be considered when a vertical maxillary excess (VME) has been diagnosed, especially when the silhouette of the teeth follows the ideal width/length ratio of around 80%. However, in cases with minor vertical discrepancy, the cost, invasiveness, and postoperative morbidity from the procedure cannot always be justified for the outcome achieved. Garber and Salama described a classification for gummy smile patients where a VME was present, and several alternative treatment options were described for patients that even though they present an excess of maxillary bone as an etiologic factor, they can be treated by periodontal, orthodontic, and/or restorative means. Only in severe cases where more than 8 mm from the gingival margin to lower border of the upper lip is found would orthognathic surgery be strongly encouraged if complete dentofacial harmony wants to be achieved [34] (Figs. 3.15 and 3.16a–c).

Muscular origin of the gummy smile can be treated by different means. It is important to dismiss the option of an anatomical problem by evaluating the length of the upper lip. The distance from the base of the nose to the lower border of the vermilion of the upper lip will give us the length of the upper lip. In average, it will measure between 18 and 22 mm. A shorter measurement indicates the presence of an anatomical condition. The lip dynamic should be also evaluated. Normal lip dynamic will show an average displacement of 6–8 mm, measured from rest position to maximum smile. A higher number indicates a hyperactive upper lip [35].

Several authors have described preventing the muscles responsible for gingival display from contracting by injecting botulinum toxin. This will be used as a temporary treatment for gummy smile when it is caused by mostly muscular hyperfunction. Botox type I inhibits acetylcholine release into the synapse by bonding to the

Fig. 3.16 (**a**) Initial situation. Skeletal and dentogingival origin was diagnosed in this case as the cause of the gummy smile. Six millimeters of gingival display. (**b**) After gingivectomy and veneers to correct the proportions of the teeth and to improve the parallelism of the gingival line with the facial references, the gingival display has been decreased to 3 mm. (**c**) A lip reposition procedure was performed in addition to the previous treatments to improve the excessive gingival display

nerve at the neuromuscular ending, causing the acetylcholine protein located on the cell membrane to be inhibited. In turn, muscle contraction is inhibited, leading to reversible muscle atrophy. The effect of Botox will appear after 2 weeks and persists between 4 and 6 months depending on the muscle thickness and anatomy. It shows an average improvement of the gummy smile of around 99% [36–38].

Removing a strip from the upper labial mucosa (i.e., "lip repositioning"), which diminishes the upper lip mobility, has also been suggested as an alternative treatment, referring a gummy smile improvement of 3 mm in average. The surgery aims to limit smile muscle pull, (i.e., zygomaticus minor, levator anguli, orbicularis oris, and levator labii superioris) by reducing the depth of the upper vestibule. The lower incision is placed at the mucogingival margin, and from there, a distance between 10 and 12 mm apically has to be measured to position the upper incision. This technique has been gaining popularity recently, owing to its simplicity and its potential for eliminating EGD. However, the published literature does not seem to address any point beyond a short-term improved outcome with no regard to etiology technique or long-term stability. In addition, an array of modifications has been introduced to the technique over time, and as studies show the technique and its modifications to be successful, there is little standardized information for clinicians to make informed decisions when choosing this technique for the treatment of patients with excessive gingival display [39–41] (Fig. 3.17a–d).

A very common approach to decrease the gingival display is to increase the crown length [42–44]. The most common reason for using this approach is when an altered passive eruption (APE) is the source of the problem. This is by definition an alteration during the process where the dentogingival union has to migrate apically after the active eruption. When that does not happen adequately, the gingival margin stays in a more coronal position, giving a shorter appearance to the teeth affected by this condition. By exposing the tooth structure that remains covered by the excess of gum/bone, the gingival display during smile will be decreased, improving the gummy smile problem. The APE classification will help us decide what surgical technique will be used to correct the problem [45] (Fig. 3.18).

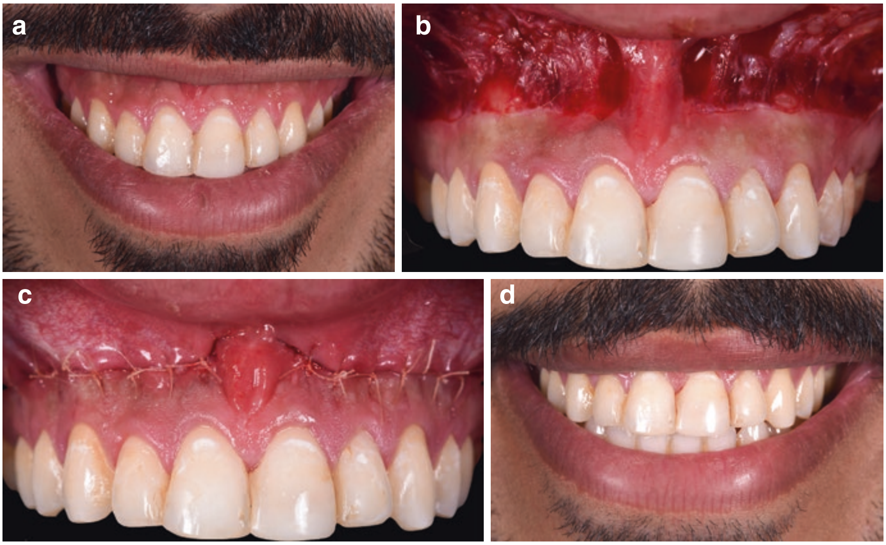

Fig. 3.17 (**a**) Initial situation. Patient complains of the amount of gingival display when smiling. A skeletal origin of the gummy smile was diagnosed and orthognathic surgery was explained to the patient. However, patient refused that option of treatment and asked for alternatives. Therefore, a lip reposition technique was chosen as the best option for him. (**b**) When doing a lip reposition or stabilization technique, a thin layer of mucosa needs to be removed from the vestibule to expose a wounded area. (**c**) The apical and coronal margins of the wound are brought closer in order to decrease the range of movement of the upper lip. (**d**) Final situation 1 month after the surgery

Altered Passive Eruption Classification			
Type I	Wider band of keratinized tissue	Type A	Distance from alveolar crest to CEJ normal ± 2m
Type II	Normal band of keratinized tissue	Type B	Distance from alveolar crest to CEJ ± 0mm

Fig. 3.18 Altered passive eruption classification

In many cases, an excessive amount of gum will be found covering the enamel with the bone crest located 2 mm away from the cementoenamel junction (CEJ). In those situations, just a gingivectomy will be enough to expose the hidden enamel, improving the teeth proportions and, consequently, decreasing the amount of gum display. If the bone crest is closer to the CEJ, bone recontouring will be necessary in addition to the gingivectomy, in order to avoid a possible relapse. Ideally, when reshaping the excessive bone, around 2 mm of root surface from the CEJ to the bone crest should be exposed, allowing enough room for the biologic width components to create a proper attachment without creating a recession. One millimeter of free gingiva is expected to heal over the enamel.

The osteoplasty will be usually performed raising a full-thickness flap to allow us not only to remove the excess of bone over the root surface but also to create a proper bone contour and thickness; one of the factors that can create a relapse of the tissues is if the remaining bone is kept too thick. Flapless bone contouring can be performed in cases where minimal corrections need to be achieved, like 1–2 mm vertical corrections, zenith point displacement, or gingival asymmetries. In those situations, a microsurgical back action scalpel, hard tissue laser, or ultrasonic devices can be applied. Special attention needs to be taken when using a flapless approach. Due to the blind access to the work area, it will be difficult to control the direction and depth of the effect of the instruments used to reshape the osseous morphology, which could end up creating small cavitation on the root surface. In full arch cases where we need to correct not only the bone levels but also the thickness of those tissues, a full-thickness flap is advised. Otherwise, infrabony defects can be created iatrogenically, due to the difficulty on addressing the thickness of the bone. Another important aspect to control the possibility of a relapse will be removing the attachment fibers by scaling the tooth surface after the gingivectomy [46] (Figs. 3.19, 3.20a–c, and 3.21a–f, h, i).

However, treating the APE may not be enough to correct completely the gummy smile since we can only expose up to the CEJ level to avoid root exposure. In some

Fig. 3.19 Flapless approach can be used for specific situations as minor vertical corrections (like 1–2 mm), zenith point displacement, or gingival asymmetries. In this case a Hu-Friedy Fedi periodontal chisel was used (CPF1) (Hu-Friedy MFG. Co. LLC, Chicago, USA) for bone recontouring

Fig. 3.20 (**a**) Initial situation. Patient presents an APE from tooth #4–13 that creates a gummy smile. (**b**) Notice how after a gingivectomy the proportions of the teeth have been improved. The amount of gingival collar removed in this case will be guided by the CEJ. Only the premolars required bone recontouring to assure the stability of the result. Therefore, a full-thickness flap was elevated only in the premolar area. (**c**) Gummy smile corrected by treating the etiology of the problem

Fig. 3.21 (**a**) Initial situation. Patient presents an APE from tooth #3–14 that creates a gummy smile. Some teeth show incisal wear and they are not in an ideal position. However, patient does not complain about that. (**b**) Notice how the proportions of the teeth are far from ideal, and the extra volume of the gingival tissue helps the lip remain in a more apical position when smiling. (**c**) After the gingivectomy, the proportions of the teeth have been improved. (**d**) A diode-laser gingivoplasty was also performed in the papilla area in order to create a more harmonious gingival profile. (**e**) When a full-thickness flap is raised, we can evaluate the proximity of the bone crest to the CEJ and the bulkiness of the buccal bone. (**f**) Right side after bone recontouring around 2 mm away from the CEJ of the teeth versus left side with the bone crest untreated. (**g**) Bone recontouring finished and buccal osteoplasty performed to improve the architecture of the tissues. (**h**) Vertical mattress suture with esthetic palatal knot using polypropylene 5/0. (**i**) Gummy smile corrected by treating the etiology of the problem (2 weeks after surgery)

situations, where a complete correction of the gummy smile is required, combining restorative and periodontal techniques will be necessary. In cases where restorations are going to be involved, visualizing the possible outcome is mandatory prior to starting the treatment. Digital smile design (DSD) has been proven as a very helpful tool to visualize the final outcome prior to the beginning of the treatment, helping the clinicians planning the posterior steps in the process and choosing appropriate techniques necessary to achieve the ideal esthetic outcome [47]. Once the ideal position of the teeth has been decided in the computer, by using a calibrated digital ruler, the exact measurements can be transferred to fabricate an accurate wax-up that will be the blueprint for our future treatment, either periodontal or restorative. Silicon indexes will be created to transfer the information from the wax-up to the patient's mouth. Self-curing bis-acryl material will be used to create an indirect mock-up that will guide us in performing the gingivectomy but also will be used as the provisional restorations that will tell us the future restorative margin position. A full-thickness flap can be raised once the temporaries have been placed, adjusted, and polished, using them as a surgical stent for the osteoplasty, too. An average 3 mm distance from the new restorative margins to the bone should be kept in order to respect the necessary space for the new dentogingival complex that will be created, making sure biologic width is not violated by the restorations. The traditional approach for cases that require restorations and crown lengthening is to perform the surgical procedure 3–6 months prior to the final impressions, the main reason being possible postoperative position changes of the gingival margins [14]. By following this method, very predictable results can be achieved to correct not only the excessive gingival display but also the overall look of the smile [48] (Fig. 3.22a–o).

Fig. 3.22 (**a**) Initial situation. Patient complains about the amount of gingival display and wants to achieve a more natural looking smile. (**b**) Image calibrated using a digital ruler following the DSD concept. (**c**) Smile design with calibrated measurements. (**d**) Digital preview of the desired outcome. (**e**) Calibrated digital measurements transferred from the digital design to the cast. (**f**) Final wax-up based on the digital design. It will allow us to fabricate silicon indexes for preparation, temporization, and surgical guidance. (**g**) Intraoral view of the initial situation. Notice the bulkiness of the prefabricated veneers and the overeruption of the anterior segment. (**h**) Old veneer removal to create enough space for the surgical guide. (**i**) Mock-up used a surgical stent for gingivectomy. (**j**) Mock-up removal for soft tissue collar remotion. (**k**) Bleeding controlled and provisional veneers inserted. Spot-etch technique with Luxatemp and Luxaflow B1 (DMG. Hamburg, Germany) was used for that purpose. (**l**) Full-thickness flap elevated for bone contouring. Notice that bone has been positioned 3 mm away from the prosthetic margin, creating space for the dentogingival complex avoiding the violation of the biologic width. (**m**) Vertical mattress suture with polypropylene 5/0. Two months after final preparation and final impressions were taken. (**n**) Intraoral view of the case 1 year after insertion of the veneers. (**o**) Final situation with correction of the gummy smile showing stability of the results 1 year after

Cases with multiple etiologies require more than one technique to achieve desirable outcomes. For example, some studies have reported using the lip-repositioning method associated with gingivectomy to treat excessive gingival display [49, 50].

3.3.4 Gingival Recessions

Esthetics, dental hypersensitivity, and the prevention of caries and non-carious cervical lesions (NCCLs) are considered the main indications for periodontal plastic root coverage procedures reported in the literature [51–54].

Chronic trauma, caused by vigorous toothbrushing, and plaque-induced periodontal inflammation or occlusal factors are the major causative factors in the development of soft tissue recessions. Beyond those two major causes, dehiscence in vestibular alveolar plate, high frenum, and iatrogenic factors contribute significantly in the etiology of recessions. Elimination of those factors is crucial in both prevention and treatment of recessions in a predictable long-term outcome [55–60].

A classic classification for recessions has been helping us to establish the outcome predictability for full coverage after surgical treatment. Total root coverage is expected in class I and II, whereas full coverage decreases when interproximal bone loss is present, as it happens in class III and IV. This is very helpful to establish realistic expectations for the patients [61].

Class I	Marginal tissue recession that does not extend to the mucogingival junction. There is no periodontal loss (bone or soft tissue) in the interdental area, and 100% root coverage can be anticipated
Class II	Marginal tissue recession that extends to or beyond the mucogingival junction. There is no periodontal loss (bone or soft tissue) in the interdental area, and 100% root coverage can be anticipated
Class III	Marginal tissue recession that extends to or beyond the mucogingival junction. Bone or soft tissue loss in the interdental area is present, or there is malpositioning of the teeth that prevents the attempt of 100% root coverage. Partial root coverage can be anticipated
Class IV	Marginal tissue recession that extends to or beyond the mucogingival junction. The bone or soft tissue loss in the interdental area and/or the malpositioning of the teeth is so severe that root coverage cannot be attempted

Several techniques have been described to attempt full coverage of the gingival recessions, including free gingival grafts, pedicle flaps, tunneling techniques, and combinations of the previous. However, in the esthetic area, specific considerations must be taken in order to achieve the most esthetic result. That is the main reason why using a fully epithelized free gingival graft is not considered as a first option anymore due to the fact that they heal with a lighter and more opaque color compared to the surrounding tissues [62].

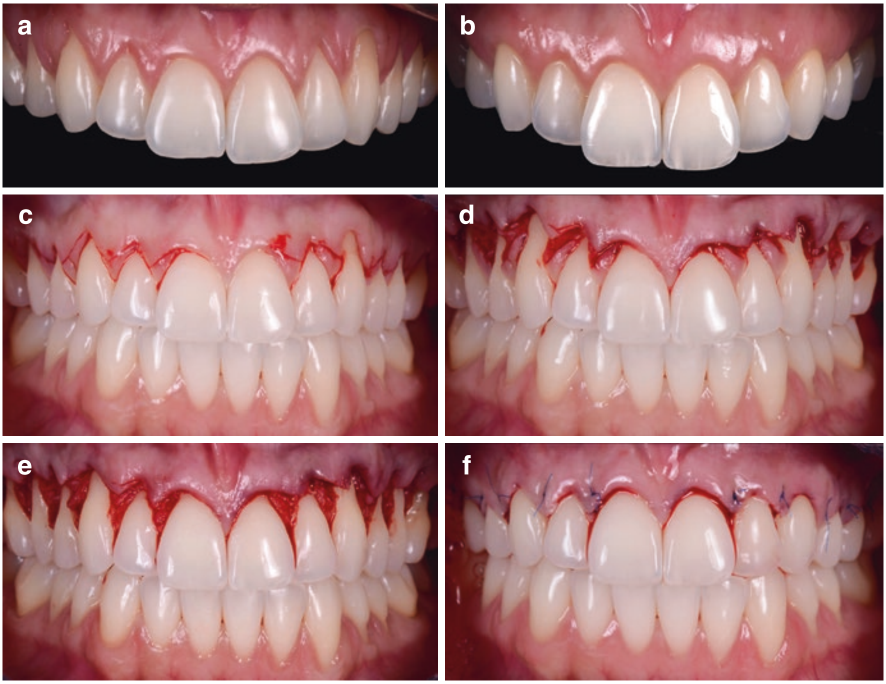

Fig. 3.23 (**a**) Initial situation. (**b**) Final outcome 1 year after surgery. (**c**) Incision design for a coronal advanced flap with no releasing incisions (Zucchelli technique) and no CTG (tissue thickness was considered sufficient). (**d**) Flap elevation (partial–full–partial thickness). (**e**) Papillary epithelium removal. (**f**) Vertical mattress suture with polypropylene 5/0

Subepithelial connective tissue graft (SCTG)-based procedures provided the best outcomes for clinical practice because of their superior percentages of mean and complete root coverage, as well as significant increase of keratinized tissue [54] (Figs. 3.23a–f and 3.24a–f).

However, when multiple recessions are present in the same case, insufficient autologous tissue can lead us to select a different approach. Zucchelli et al. described a modified coronal advanced flap without releasing incisions that demonstrates stable long-term results with high coverage scores. They propose the idea of including a very thin SCTG wherever the keratinized tissue thickness is not enough for long-term stability [63, 64].

The use of enamel derivative matrix (EDM) combined with CAF have shown some benefits compared with that approach alone [65].

Another alternative when there is insufficient donor tissue is the use of allografts like acellular dermal matrix (ADM), a very good alternative when

Fig. 3.24 (**a**) Initial situation. (**b**) Final outcome 1 year after surgery. (**c**) Notice the proper thickness of the tissue besides the premolar area. (**d**) Incision design and flap elevation (Zucchelli technique) for a coronal advanced flap with no releasing incisions (Zucchelli technique) and CTG in the premolar area to increase volume of the tissue. (**e**) Vertical mattress suture with polypropylene 5/0 and suspensory suture around #8 and 9 for coronal advancement on the tunneling area. (**f**) Intraoral view 1 year after surgery

used in combination with tunneling techniques reporting not only stable results but also very esthetic results for both the dentists and the patients [66–68] (Fig. 3.25a–f).

In esthetic cases where restorations are going to be needed, visualizing the final outcome is mandatory before attempting the surgical procedure. It has been described in the literature the concept of restoring the case before performing the actual root coverage procedure. Positioning the final margins of the restorations based on an ideal esthetic disposition will help the surgeon choose the best technique and also will help positioning the flaps in the right position in order to avoid overcorrection and the need of a possible gingival recontouring after the surgery to ideally position the gingival margin for the future restorations [69] (Fig. 3.26a–g).

Fig. 3.25 (**a**) Initial situation with multiple recessions. (**b**) The thickness of the tissue was considered insufficient for long-term stability. Due to the size of the defect, it was decided to use a graft substitute, in this case acellular dermal matrix (ADM) (Alloderm Tissue Matrix, Biohorizons, Birmingham AL, USA). (**c**) A tunnel approach was chosen for this case, due to the correct amount of interproximal tissue and minimal invasiveness of this technique, improving the healing of the surgery. (**d**) Suspensory suture technique for coronal advancement of the tissue with polypropylene 5/0. (**e**) Surgical outcome 3 months after surgery (ready for the restorative phase). (**f**) Final result 3 months after restorative treatment with feldspathic veneers. Notice that gingivectomy was performed on #8 and 9 to harmonize the gingival margin position after the root coverage procedure

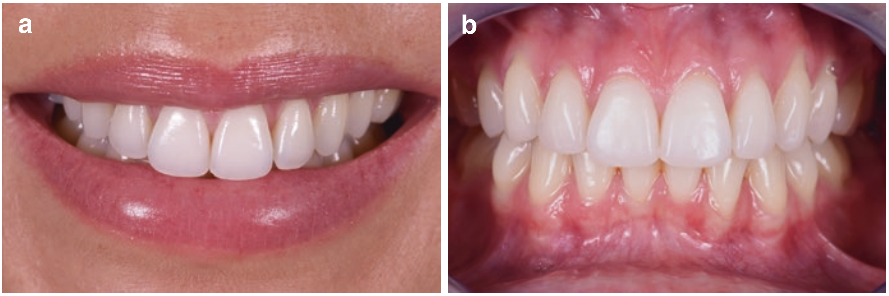

Fig. 3.26 (**a**) Initial situation. Patient complains about misalignment of her teeth and gingival recessions. She had orthodontic treatment before and refuses that option. (**b**) Intraoral view. Notice the thin biotype of the patient. (**c**) Restorative phase performed before the surgery. The esthetic concerns of the patient have been addressed. The position of the restorative margins will guide the surgeon during the advancement and reposition of the flap. (**d**) Notice that the restorative margins have been positioned based on the ideal esthetics for this case, leaving radicular surfaces exposed. (**e**) Surgical initial situation. (**f**) Incision design for a tunnel approach with coronal advancement and no releasing incisions. Notice the ADM already positioned inside the pouch. (**g**) Coronal advancement of the tissue and suspensory suture with polypropylene 5/0. (**h**) 1 year after surgery

Fig. 3.26 (continued)

3.4 Conclusions

As the society gets more interested with looking younger and healthy, our profession becomes more relevant. Due to that, esthetic considerations will become increasingly more relevant in dental treatment planning, extending the vision beyond simply creating pretty teeth to a concept of "dentofacial harmony."

Esthetics is not simply a matter for restorative dentists, it is just one of the disciplines to achieve beauty. Even though the primary objective of periodontal therapy is to restore and maintain the health and integrity of the attachment apparatus, from an esthetic perspective that is often not enough. An irregular gingival arrangement, despite being healthy, may distract the eye, and it will become desirable to establish a certain harmony and continuity of form to the gingival margins. That becomes even more important in cases where an excessive amount of gingival display creates an esthetically unpleasant result.

Therefore, proper knowledge of the anatomy and biology of the gingival tissues, in combination with adequate use of periodontal plastic surgery techniques, will help us in creating balance and harmony to the final esthetics of the smile.

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Material Options for the Esthetic Dental Team

4

Peter Pizzi

Contents

Establishing the ideal restorative case and its appropriate materials is often times difficult to attain and sustain, and we as dental professionals are undoubtedly confronted with multiple challenges along the way. As we have probably learned by now, there is no wizard hiding behind the curtain who will solve all of the many challenges we face in this ever-evolving field of dentistry. Nor is there one product or instrument that will be the end-all answer to everything either. It is important to realize that our toolbox needs to be developed and expanded and so must our knowledge of how to properly utilize this ever-expanding toolbox.

When considering matters of both tooth color and the offered restorative space, our ability to properly select materials is essentially one of the most critical components that we need to understand. All of the ceramic systems on the market have their own strengths and weaknesses; however our keen knowledge of these systems and how to best utilize them properly must be further developed and thereby become our strength. When mimicking nature, the restorative dental team needs to be knowledgeable, not only in factors of nature, morphology, and esthetic parameters but

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also in material optical properties and how they interact with their surroundings and space relationships. The dentists' and technicians' ability to recreate a tooth, similarly to how nature did, relies on several processes. Each of these processes has an esthetic, biologic, and technologic component.

4.1 Tooth Preparation

Although tooth preparation does not really seem to belong in a materials chapter, there are factors within the preparation process that require an understanding for material choices. The goal of the restorative process is to properly manage the functional and esthetic parameters. In the esthetic realm, tooth preparation dictates the support of the tissue and the ability to use restorative materials in order to recreate proper depth and light transmission. The amount of reduction, angulation of the axial walls, incisal/occlusal reduction, and the amount of enamel left behind play a crucial role in the esthetic and functional success of the restoration. To control our outcomes, we must first understand that the role of tooth preparation has several factors. Preparing a tooth because of damage, caries, or esthetic purposes must always be done as conservatively as possible to save its biomechanical structure. Preserving healthy tooth structure must ultimately always be our goal.

The thought process should be focused around four key factors:

1. Biomechanical preservation.
2. Restorative space needed for material options and their ability to protect and balance esthetic outcomes.
3. Margin placement and design.
4. Adhesive or cohesive considerations.

When it comes to material selection, the space required to achieve maximum results can vary. Part of the clinician's role is to provide space for the dental technician to be able to utilize appropriate materials, both esthetically and functionally. Each material option is dependent on the space provided and the ability to adhesively or cohesively place the restorative material. In the past, all full coverage materials required minimal reduction of 1.2–1.5 mm. This reduction is still commonly observed today and influences most substructure-related full coverage restorations. The evolution of dental materials allows us to work in reduced restorative spaces, with some additional advantages and disadvantages (Fig. 4.1).

Veneer restorative cases both save tooth structure and simultaneously challenge the ceramist to create depth with minimal thickness.

Preparations for veneers can be broken into three categories:

1. No-prep or window-type veneers (Fig. 4.2).
2. Minimal facial preparation (Fig. 4.3).
3. Facial, incisal preparation (Fig. 4.4).

Fig. 4.1 Full coverage restorations require 1.2–1.5 mm of restorative space. For veneer preparations this can be adjusted from 0 reduction to aggressively 1 mm of reduction

Fig. 4.2 Zero reductive surfaces, ideally used for interproximal closure and slight tooth form modifications

4.2 Veneer Materials

The proper formulation of each veneer contributes largely to the final functional and esthetic outcome of our restorative work. Technology and material advancements have given us many more options to choose from. Similar to every old and new material, each has their own advantages and disadvantages. First generations of veneers were done by means of either the refractory or foil technique with feldspathic porcelain. Today, although that is still the ideal esthetic option, we do have

Fig. 4.3 Minimal facial reduction. This is ideal for slight contour changes, closing diastemas, or slightly improved esthetics

Fig. 4.4 Allows for the most esthetic improvements in color, form, and tooth position. A quality impression allows for a repeatable cast and insures the veneer fit [Impression Bernadette Sawa DDS]

the ability to use several thin substructures made to be used as either a monolithic, microlayered, or fully layered veneer materials. All substructures must be designed with support in mind for the layered ceramic overlay, functional nuances, and esthetic parameters of each case. This requires a significant understanding of tooth form and is not as simple as pulling teeth from a digital library or dipping dies into a dipping wax (Figs. 4.5–4.7).

Most dental materials are measured in megapascal (MPa) strengths. One could argue that MPa is not the best way of predicting material viability for intraoral use, as this process of testing materials expresses more about hardness of the material rather than the true strength of the material. True strength is a combination of rigidity and flexibility, and together they create strength (Fig. 4.8). In a digital world, the uses of milled products are also rapidly evolving and are becoming very useful for esthetic options, as either monolithic or layered veneers. When layered, the submaterial, also known as a substructure, will typically be milled or pressed very thin to allow space for fully layered or microlayered ceramics.

Fig. 4.5 Refractory veneers. The authors feel that this is still the best for optics as the ceramist could choose the correct opacity or translucency as needed for the space being filled. Retracted view of maxillary arch restored [Clinical dentistry Bernadette Sawa DDS]

Figs. 4.6 and 4.7 Pressed or milled substructures are best when microlayered. Optically when only stained, the light optics will reflect from the surface appearing dead

4.3 Zirconia Monolithic or Layered

As the base material of zirconia has evolved from yttrium based to cubic stages, zirconia has become more translucent and provided technicians with more options due its esthetic appearance. In the past, the chalky white nature of the material and lack of bond ability deemed it a poor choice as a true "veneer" and therefore was

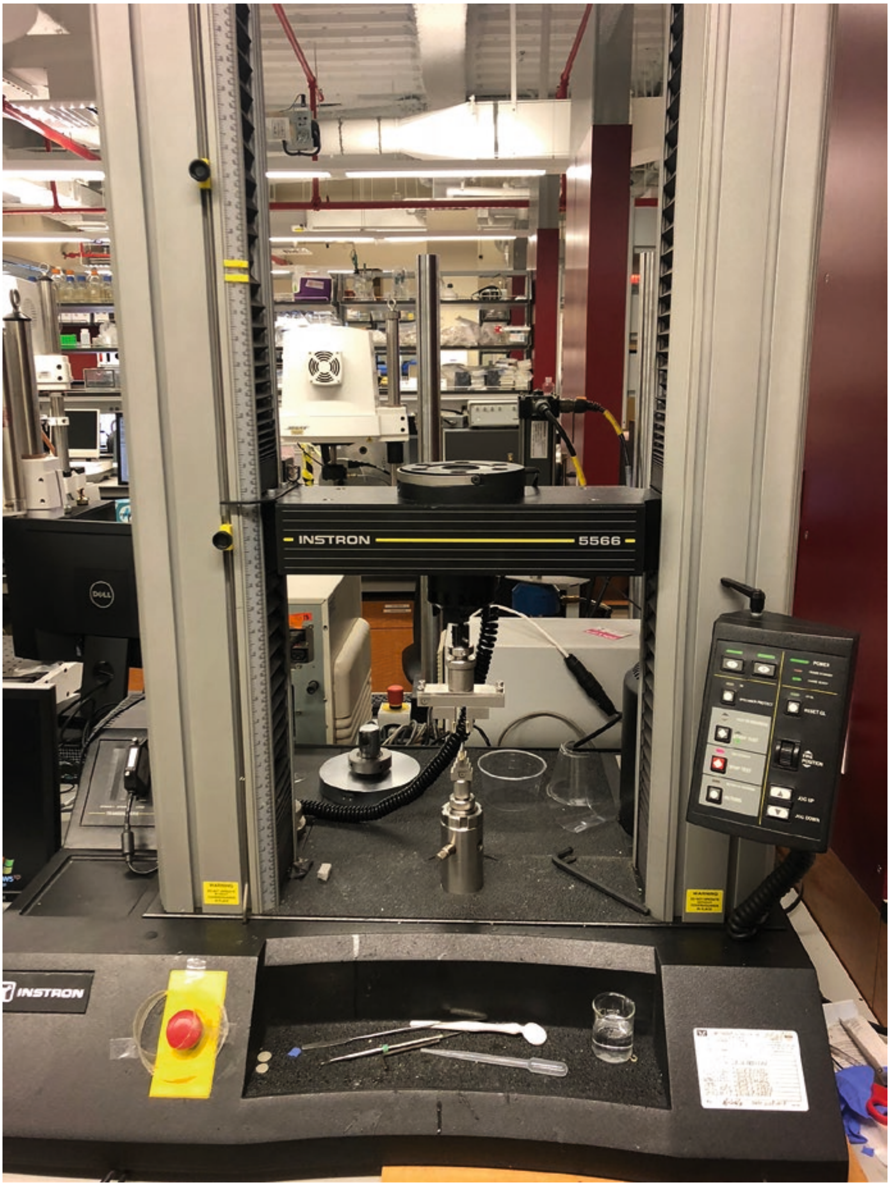
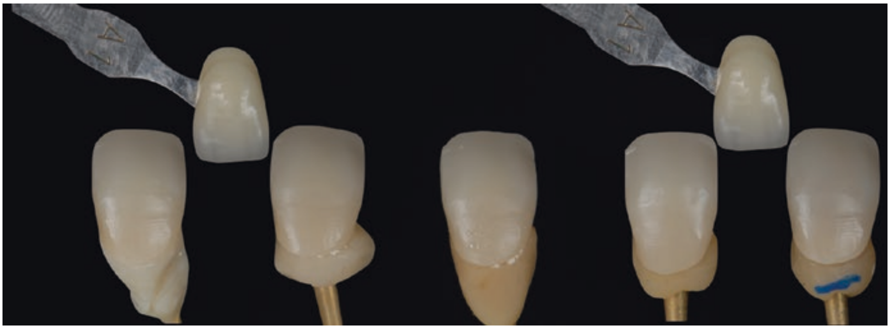


Fig. 4.8 The author feels that a megapascal test may not be the best resource for understanding our materials

utilized mainly as full coverage restorations. Touted as a very strong material, zirconia has been widely accepted in the dental profession today and has advanced in many areas. The MPa strengths decreased as the translucency became greater with zirconia materials.

Today's monolithic materials that are highly translucent and come pre-shaded are certainly abundant. Although there is still much controversy on the bond ability of zirconia, it can be cohesively placed as a veneer. Several challenges remain with milling strategies when utilizing more translucent materials and the more critical the final sintering temperatures has become. The limitations of monolithic materials remain based on managing color and space with only one material, as well as selecting the correct opacity to enhance the existing preparation shade or mask the darkened preparation shade. Staining monolithic materials is applied similarly to metallic oxide stains and alters the reflective light index of the material. This tends to present a "lifeless" appearance and can also wear off over time, because staining materials are only surface stains and will be affected by intraoral chemicals, as well as abrasion over time.

The rigidness of the material has very low flexural rate which can limit the flexural aspects of the natural tooth, which can cause microleakage. As of today, zirconia is still best utilized as a cemented material, and even though there have been many advances in its bond ability, at the point of this writing, bonding zirconia is still not clinically documented over a long-term period (Figs. 4.9 and 4.10). Microlayering of ceramics remains the better process, as different powders provide for more natural coloration and the color remains stable. Creating depth, translucency, and opacity on the zirconia substructure is limited to the space provided and the technician's knowledge of the veneering ceramics.



Figs. 4.9 and 4.10 One advantage of zirconia is its ability to mask prep shades, but the disadvantage is that it is not a bondable material (see Materials section) and requires more preparation reduction to create dowel and ferrule

4.4 Lithium Disilicate or Silicate Substructures

Similar to a zirconia substructure, lithium disilicate or lithium silicate provides many options when it comes to translucencies, and they can be milled or pressed. Pressed LD/S is more observed throughout the dental profession and produces less wear and tear on milling equipment. Milled LD/S is common as a chair-side option and laboratories offer these procedures too.

Pressing LD is the more observed method; however inherited inaccuracies in wax and the investing process can introduce further discrepancies. Several types of LD/S exist today, and as with all materials, they too have both advantages and disadvantages. For the author, the best aspect of using LD/S materials is its ability to be either bond or cement and their ability to be utilized in minimal spaces. This adhesive/cohesive nature allows us to use LD/S in many situations including full coverage, veneers, onlays, and window veneers. For the author, this material is one of the most universal materials with a broad spectrum of indications. The most obvious disadvantage with LD/S materials is their esthetic limitations.

Based on the nature of the material and the process by which manufacturers use to produce a pressable ingot, LD/S tends to have a "low-value" appearance. This is caused mainly due to the ceramic's nature of "glassing out" during repeated firing cycles. To produce a pressed material, the grain size must be manufactured in a much smaller particle size and be repeatedly fired at high temperatures in order to allow the pressing cycle to push the molten ceramic into the vacant mold.

Lithium disilicate/silicate milling tends to have a slightly higher-value appearance, since the process of pressing at high heat rates is eliminated and it can be slightly more color and opacity stable. Like zirconia the options to use LD/S as a monolithic or layered material exist. From the author's perspective, LD/S would be the preferred option over ZR materials at the time of writing this chapter. Like zirconia, LD/S staining on monolithic is surface characterized. Microlayering with lower fusing ceramic materials adds a greater level of esthetics, and it is preferred for higher-level esthetic cases (Figs. 4.11–4.27). Milling lithium silicate is an option that is becoming more supported both chair side and in laboratories. Milled materials have very accurate fits and can but used either microlayered or monolithic (Figs. 4.28–4.30).

4.5 Hybrid Veneers

With the evolution of materials and digital impressions, there are many more options in our dental toolbox, and even more options will follow. When recreating nature, the material choices should closely emulate the natural abilities of what nature has created. As we continue to evolve, our materials will become closer to nature, and we will continue to incorporate them into the oral environment. Composites, either direct or indirect, have some of the closet light interaction and behavior that we see

Fig. 4.11 Pre-op photos of our patient

Fig. 4.12 Acquired smile shows some display but obviously an esthetic liability

Fig. 4.13 Retracted view shows all discrepancies as patient suffers from *fluorosis*

Fig. 4.14 After minimal tooth preparation and impression, a wax-up is done following the provisional shapes

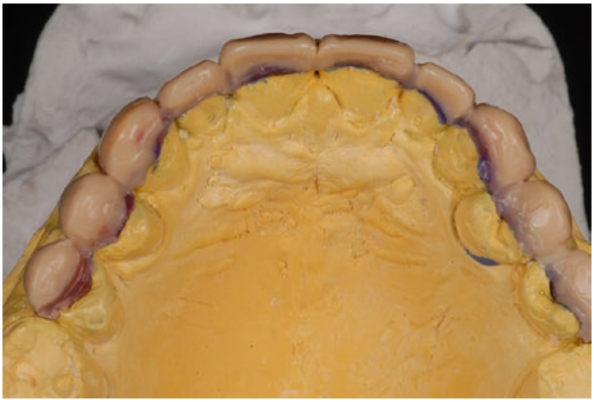


Fig. 4.15 Lingual view shows the preparation type as facial and incisal. Minimal reduction facial and increase of incisal position

in nature, and although there is an art to developing a direct composition veneer, the end results can be outstanding. The challenge is that they encompass a lot of chair time and, like most resin-based products, tend to discolor and wear at a fairly fast rate depending on the nature of the oral environment and how they are treated. Indirect composites can sometimes have a slightly longer intraoral life span, but from the author's point of view, these materials are still best suited for long-term provisional restorations.

Fig. 4.16 Wax-up is adjusted for ceramic layering

Fig. 4.17 Wax-up can be pressed using lithium disilicate or scanned and milled using lithium silicate. The author prefers milling lithium silicate for esthetic results

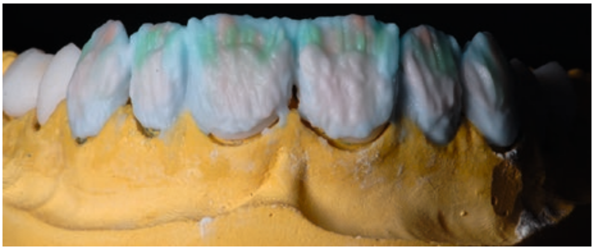


Fig. 4.18 Ceramic microlayering is done controlling chroma, value, and incisal edge (Vita VM materials)

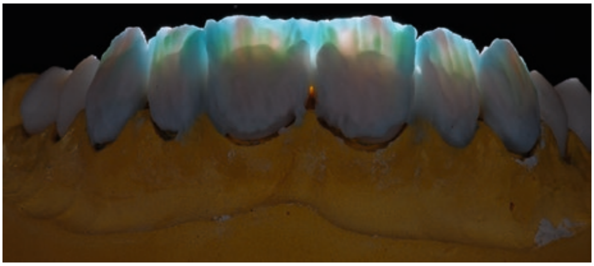


Fig. 4.19 Light transmission of the incisal edge shows the importance of material selections

As we move into the newer generation of composites or nano-hybrids, newer nanomaterials are composed of silicon dioxide, aluminum oxide, sodium oxide, and potassium oxide suspended in a resin matrix, which helps make them behave more like ceramic materials and zirconia. Calling them simply composites makes them sound as if they are resin-filled materials, which would be

Figs. 4.20–4.22 Final restorations on the cast

inaccurate. These materials are the true definition of strength, as they are both rigid and have flexibility. Materials with similar functional abilities to nature like Enamic [Vita EU] are the future of minimally invasive dentistry (Figs. 4.31 and 4.32).

4.6 Feldspathic Ceramic Veneers

The author's opinion is that feldspathic veneers layered, with the proper knowledge and information, are still the ultimate in esthetic dentistry. Today's evolution of material allows us to mill ceramic and creates an excellent opportunity to use technology and artistry in a combined manner. Milling a ceramic substructure that can be layered with feldspathic ceramic is in the author's belief a large part of the future of esthetic dentistry (Fig. 4.33). When developing anterior form, the use of an alveolar cast is always recommended to manage the emergence profile and create final contour. Although fabrication of the alveolar cast can be quite challenging, the

Figs. 4.23–4.25 Final restoration post-cementation

Fig. 4.26 Close-up of the maxillary restorations

Fig. 4.27 Lip dynamic as the new repose position has age-appropriate display

Fig. 4.28 Milled lithium silicate in the pre-sintered stage

information provided by the cast creates the optimal esthetic results for managing emergence profile and papilla support and placement. The alveolar cast is mostly used in a refractory veneer technique but has merit in other restorative options. When working with foil veneers, the gingival integrity is disrupted to allow for the position of the foil past the working finish line (Figs. 4.33–4.57).

Fig. 4.29 Stable fit both pre-sinter and after sinter allows adjustment to be made either time

Fig. 4.30 Sinter time is only 16 minutes and done in a basic ceramic furnace. No color or glaze

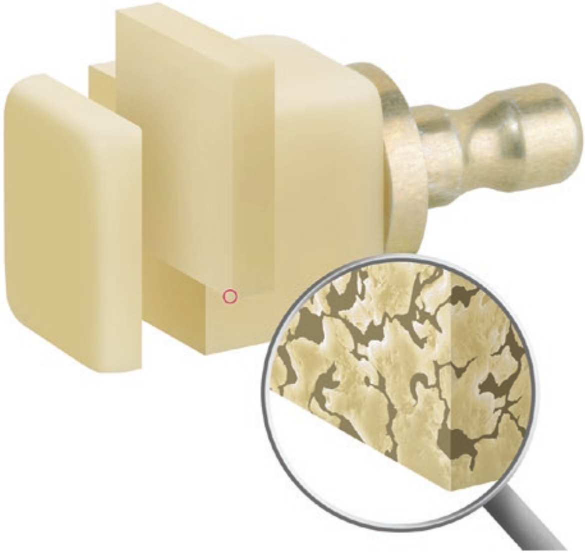
4.7 Cast Fabrication

Several versions of the alveolar cast have been used throughout history in the dental profession. Although each version has its challenges, the evolution of the alveolar cast has created an accurate representation of the oral environment.

Steps:

1. The cast is masked out to allow a pour of the prepared teeth only.
2. Type 4 die stone is poured into the vacant cast filling to the max height of the impression.
3. After the stone has cured, it is removed, and the long axis of both the facial and interproximal is marked to align the final position in the removable die.
4. Using the facial and interproximal lines, the base of the prepared tooth is trimmed similar to the root formation and notched for future retention in the cast.
5. Completed dies are duplicated and poured 2×.
6. Duplicated dies are treated with a sealer and spacer (die 1 sealer from gingival down, die 2 sealer and spacer on the coronal surface).
7. Die 1 is seated in the impression and coated with a lubricant before the pouring of new stone. Die 2 is the reduped and used to fabricate the final working refractory die material.
8. Final cast is verified with the use of a matrix taken from a solid second pour.

Feldspathic veneers require more of a working knowledge of the ceramic materials, as well as the appropriate placement of each. The ceramist's knowledge



Figs. 4.31 and 4.32 A nano-hybrid material, Enamic wears similar to natural tooth with a measurement of 160mp. Although the author uses this material mostly for inlay/onlay and screw retained implant crown, it is highly esthetic for veneers and window veneers especially as a chair-side material

Fig. 4.33 Mark 2 is a milled feldspathic ceramic. This can be used monolithic or microlayered Case Figs. 4.34–4.57

regarding opacity, translucency, and space must be at the highest level. This is why the author stresses the importance of preparation design and adhesive ability. A simple approach to these issues begins with the realization that our job is to fill the space provided by our dental teammates. How we fill this space depends on several factors, i.e.:

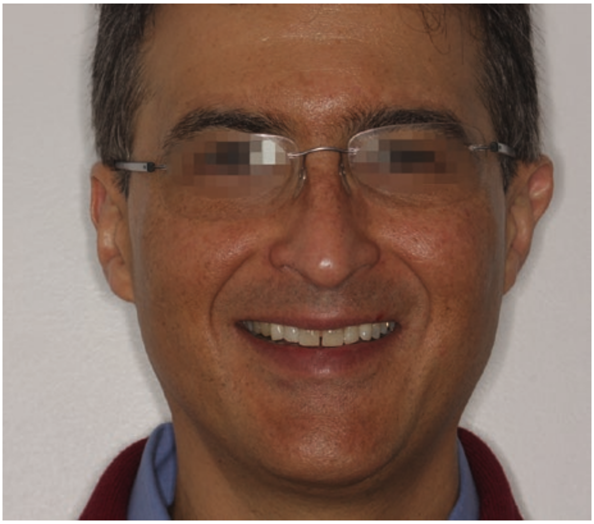


Fig. 4.34 Patient presents for esthetic improvement

Fig. 4.35 Patient is unhappy with diastema, color, and incisal wear

- The information provided.
- The accuracy of the impression and cast.
- The amount of space provided.
- The selection of materials and/or type of restoration.
- The functional ability of what is being replaced.
- Your understanding of natural dentition.

It seems most technicians are comfortable with a two-powder buildup without understanding the ability of other powders or materials. Each opacious dentin, dentin, enamel, marginal, translucent, or modifier has many uses depending on our knowledge of when and where to utilize them. Different colors of the prepared teeth may help or hinder the ability of these powders to look vital. Shade communication and preparation shading must be presented as addressed in other chapters.

Fig. 4.36 Incisal display and lip dynamic can be improved

Fig. 4.37 Retracted view shows all the concerns the patient discussed: color, diastema, and position

Fig. 4.38 After a diagnostic wax-up, teeth are minimally prepared

There are two major challenges within this scenario. Natural dentition, if analyzed, will always show more than one value and/or hue; therefore shade tabs are not a true and accurate representation of natural teeth or our ceramic materials. To verify this, the use of natural teeth and/or photography is essential. Natural teeth can be requested from your local oral surgeons, and although different

Fig. 4.39 Prep shades are indicated

Fig. 4.40 Preparations are finalized and a triple 001cord is packed

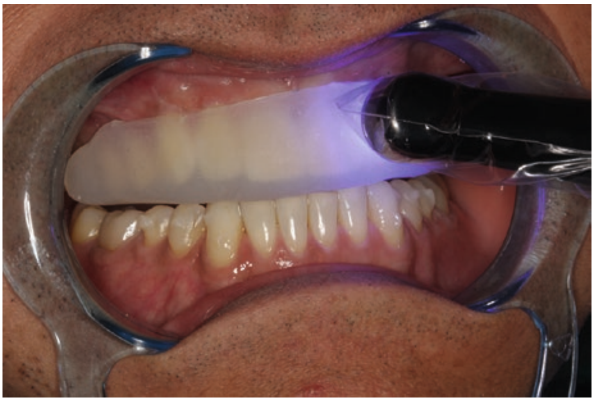


Fig. 4.41 A laboratory fabricated clear matrix is fabricated. This allows for composite materials to be light cured through the matrix

laws apply regarding this transfer, they should be fairly easy to obtain. These teeth must remain hydrated to prevent color loss, since color will be critical to understanding the shape and structure. Each tooth can then be photographed with different light sources and should be modified via bisection, cross section, and enamel removal.

Fig. 4.42 Retracted composite provisionals (Bisco reveal)

Fig. 4.43 New incisal position and plane

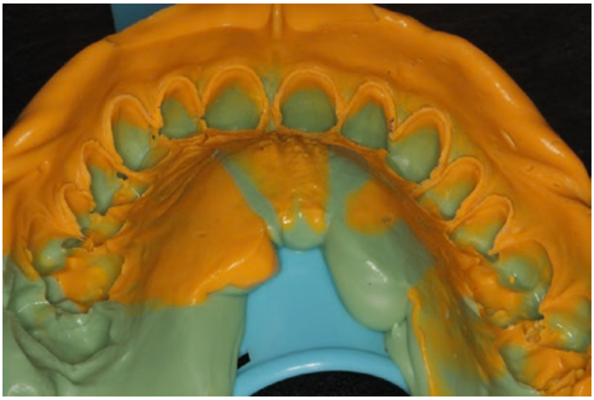


Fig. 4.44 A quality impression allows for a repeatable cast and insures the veneer fit

A key in the observation of these teeth is to notice their heights of contour and their marginal boundaries, which would essentially create their embrasure space and emergence profile. An examination of occlusal surfaces of the posterior teeth will reveal many irregular shapes that are critical to reproduce natural-appearing restorations. Subsequently, we must remember that color in ceramic materials is supported

Fig. 4.45 Cast accuracy is crucial to veneer success

Fig. 4.46 A refractory alveolar cast is fabricated and used for ceramic layering

Figs. 4.47 and 4.48 Fluorescent liner materials are used as a wash bake to seal refractory dies and create internal fluorescent surface

and directly related to its thickness. Most manufacturers tend to colorize their powders based on 1 mm (dentin) and 0.5 mm (enamel) depth. Color pigments are added to emulate the proper chroma saturation based on thickness. Some companies incorporate color pigmentation in each grain of their material, which enables the powder to maintain more accurate color saturation at different thickness. An example of this is evident when matching an A3 shade tab by utilizing 1 mm of A3 dentin powder and 0.5 mm of enamel. A change in dentin thickness would change the chroma saturation, causing a shade that appears either too high or too low in value.

Fig. 4.49 Ceramic materials, base dentin, transparent dentins, effect enamels, mamelons, and effect chromas are applied

Fig. 4.50 Rear light shows effects of opacified materials and translucent materials as light transmits or absorbs

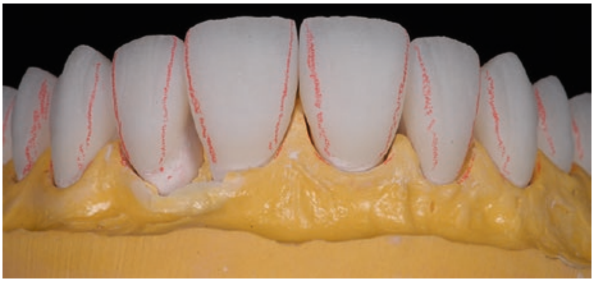


Fig. 4.51 Fired ceramic checked for contour

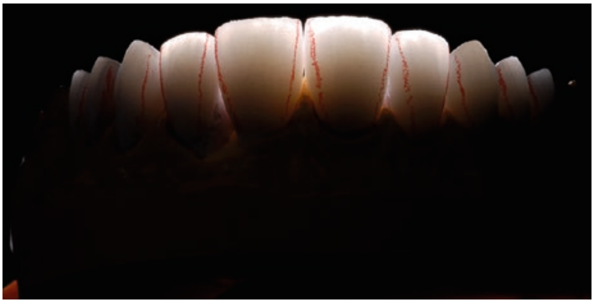


Fig. 4.52 Rear light transmission after ceramic fire shows the optics of the fired material

Fig. 4.53 Final restorations glazed and polished

Fig. 4.54 Inserted veneers shows new incisal position

Fig. 4.55 Retracted view of maxillary arch restored

Fig. 4.56 Full face shows the esthetic changes and the patients' emotions

Fig. 4.57 Sagittal view exhibits a bright but natural esthetic result

The use of shade guides are common and an important tool, but they are not the ends all for color communication, mainly because they lack certain color pigments and because of their press-molded thickness, which can average well beyond that of the space being filled. Yet they provide a comfort zone for our doctors to communicate color. With the advent of digital photography and shade-taking devices, a new door of communication has been opened, and a step outside our comfort zone is welcoming us in. Similar to our doctors' comfort zone, we as technicians tend to work with two or three powders because this has become our comfort zone. However, a proper understanding of the materials we use and natural dentition allows us to utilize these powders more effectively and enables us to transmit light, thus creating a more natural and esthetic restoration. The key to understanding these systems is to realize that each powder has a different index of refraction which is responsible for the amount of light that can be absorbed, refracted, or reflected from its surface. The more opacious the material, the more reflection occurs. The more translucent a material, the more the material absorbs the light.

Establishing a combination of these materials is what will allow light to dance throughout our restorations and appear more natural in the oral environment. The value and contour of our restorations are the most critical factors of how the restoration blends in the oral environment. The author's feeling on this is that slightest color differentials will only make the restoration appear more natural, whereas an incorrect value or form will make it stand out (Figs. 4.58–4.76).

Figs. 4.58–4.76 Veneer cases with ceramic buildups

Figs. 4.58–4.76 (continued)

Figs. 4.58–4.76 (continued)


Figs. 4.58–4.76 (continued)

4.8 Conclusion

Our understanding of material options, optical properties, and the management of space is what will set the technician/dentist teams apart in the years to come. Patient satisfaction will dominate the growth of practices and the quality the practitioners will be rewarded for their artistic creativity and case management skill set. As the material options keep evolving, it will be our adaptability that will help ease the patient acceptability and confidence in their choosing of the dental team.

Shade Evaluation for Porcelain Laminate Veneers (PLV)

5

Irfan Ahmad

Contents

5.1 Introduction

The ability to blend an artificial restoration with natural teeth is fundamental for a successful aesthetic outcome. The marriage of optically disparate materials is challenging and, at times, frustrating for both the clinician and ceramist. Colour is shrouded in mystery; it can conjure emotions, connotations of appraisal or rejection, yet defining this complex entity involves both scientific disciplines and artistic flair. Furthermore, colour defies absolute definition; communicating a particular colour involves referring to another item for its description. For example, describing 'red' may involve referring to 'a red apple' or 'red as blood'—Fig. 5.1. This inadequacy

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Fig. 5.1 Defining a colour in absolute terms is difficult unless reference is made to another item, e.g. 'as red as …'

of absolute definition places further burden when trying to objectively analyse or match a particular colour.

Determining a shade for an artificial restoration involves analysis, comprehension and communication. This sequential strategy ensures that what is seen clinically is conveyed, as precisely as possible, to the ceramist so that an artificial restoration chromatically integrates with the adjacent and antagonist teeth [1, 2]. The starting point for achieving this objective is understanding the chromatic and optical properties of natural teeth.

5.2 Chromatic and Optical Properties of Teeth

The appearance of a tooth is determined by the interaction of light with its surface and underlying layers. Surface topography is both visual and tactile, divided into macromorphology, micromorphology (or texture) and lustre. Macromorphology refers to the gross anatomical form, including line angles, surface undulations, concave and convex contours, incisal edge wear and cuspal inclines. Reproducing macromorphology in artificial restorations determines the amount of light that is reflected and hence the way a tooth is perceived. A convex surface encourages reflection, increasing value, altering hue and giving a tooth more prominence in the arch. The opposite is the case for a concave surface that attenuates reflection, reduces value and makes the tooth appear less conspicuous (Fig. 5.2).

Micromorphology encompasses vertical and horizontal surface texture such as developmental lobes, grooves and perikymata (Fig. 5.3). Perikymata are prevalent in youth dentition but gradually diminish over time due to abrasion as the

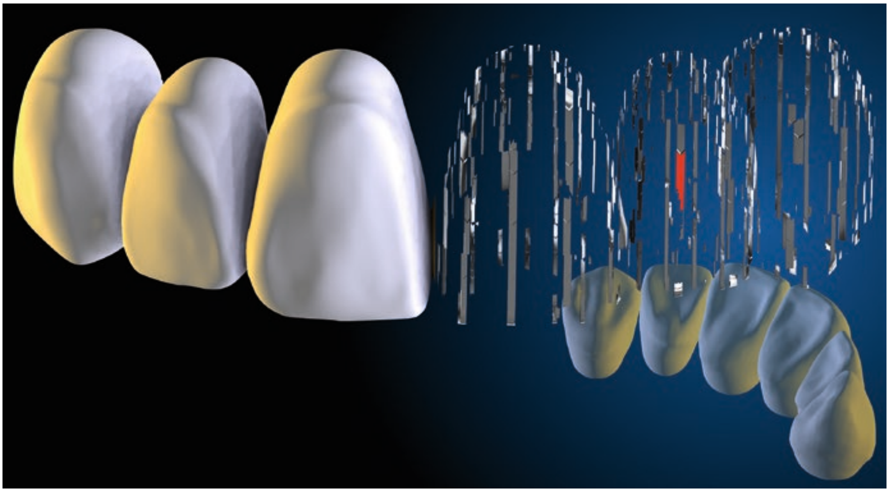

Fig. 5.2 The morphology of a tooth determines the interaction of light at its surface, conveying depth by highlights and shadows

Fig. 5.3 Perikymata form part of the micromorphology and are prevalent in youthful dentitions

dentition ages. Furthermore, textures, such as perikymata, are extremely challenging to recreate in indirect artificial ceramic restorations and need to be periodically adjusted to match physiological wear of the surrounding natural teeth. Also, texture influences light interactions at the surface by specular reflection off a smooth or polished surface, which conveys a brighter, larger and more prominent tooth, compared to a dull surface with diffuse reflections that conveys a smaller, inconspicuous tooth. This is because more light, and hence more wavelengths, is reflected by a polished surface, which also alters hue and makes the tooth appear whiter, brighter and closer. Conversely, a rough surface texture has diminished reflection and makes the tooth appear darker, duller and distant.

The last factor affecting surface light interaction is lustre. Lustre determines not only the amount of light reflected off a surface but also the degree of translucency. Lustre and translucency are inextricably linked but often confused. A highly polished transparent object (e.g. glass) possesses greater translucency but a lower value since more light is transmitted through the object and less reflected off its surface. However, if the surface is roughened, translucency decreases, and value increases as more light is reflected off its surface than transmitted through the object. The interproximal contact areas and mamelons at incisal edges display a high degree of translucency. Also, besides surface texture, enamel translucency is affected by the wavelength, angle of incidence and degree of dehydration (discussed below). If a porcelain veneer has a higher value than the adjacent teeth, the porcelain can be polished to lower its value (by encouraging transmission) and, therefore, increasing its translucency. However, excessively polishing ceramics results in extremely shiny surfaces that encourage glare or specular reflection that is counterproductive to lowering value [3].

The conventional method of improving colour or masking underlying tooth discolouration with indirect restorations is either by using ceramic opaques or by creating more space by deeper tooth preparation, allowing the ceramist to create several porcelain layers for achieving the desired shade. The use of opaques results in a bland, lifeless appearance, while excessive tooth reduction is discouraged in order to keep the preparation within enamel for superior adhesive bonding. From the discussion above, it is obvious that defining the enamel terrain affects light interaction at the surface that affects hue and value and, therefore, the apparent perceived position of a tooth. Hence, this approach offers an alternative for manipulating the shade (or improving colour) and the apparent position of a tooth. By deliberate and judicial changing of macromorphology, micromorphology (texture) and lustre, 'optical orthodontics' is possible by making teeth appear less or more prominent in the arches without physically moving them. This is particularly useful for resolving certain types of imbrications, rotations or misalignment using PLV without resorting to protracted orthodontic treatment.

The interplay of light is not restricted to the tooth surface but also within enamel and dentine and the pulp, which all influence the perceived shade. Incident light can be reflected, refracted, transmitted or absorbed, and it is the proportions in which these occur that influence the ultimate appearance. In addition, translucency, fluorescence, opalescence and iridescence (aka goniochromism) also affect the tooth shade. As previously mentioned, translucency is influenced by the wavelength of the light and its angle of incidence, texture and lustre and the degree of dehydration. Fluorescence confers vitality and is primarily a property of dentine. Adding fluorescent pigments to a porcelain build-up increases value, decreases chroma and is useful for blocking out underlying tooth substrate discolouration. Opalescence is predominantly a property of enamel, usually at the incisal edges, which appear as an orange aura with transmitted light and a bluish glow with reflected light. Opalescence is mimicked in dental ceramics by the addition of opalescent pigments and dyes (Fig. 5.4). Finally, goniochromism is an optical surface phenomenon, akin to 'mother of pearl', peacock feathers or rainbow appearance on soap bubbles (Fig. 5.5).

Fig. 5.4 Optical properties of natural teeth: a 'middle-aged' natural tooth with incisal edge wear viewed with daylight and UV (ultraviolet) illumination. The delineation of enamel and dentine layers and their optical properties such as reflection, transmittance, opalescence and fluorescence are clearly visible: (1) the enamel overly is thickest at the incisal edge and thins towards the cervical margin; (2) the shining band of high luminosity between the enamel and dentine layers is responsible for internal diffusion of light; (3) secondary dentine deposition (deeper chroma) at the incisal edge due to physiological reactionary response to tooth wear; (4) diminishing dentine chroma from the internal (near pulp) to the outer aspects of the dentine layer (towards enamel); (5) fluorescence of both the dentine (predominantly) and enamel layers with UV light; and (6) opalescence bluish appearance of the buccal enamel at the incisal edges with reflected light

Fig. 5.5 Goniochromism or iridescence is an optical surface phenomenon, e.g. a rainbow effect on soap bubbles

Goniochromism is the ability of an object to appear differently depending on the angle of view or the angle of incidence of the illumination. Practically, this means that viewing a tooth from different angles (or varying the position of the light source) may conceal or reveal a restoration or hide or make tooth characterisations more conspicuous. This property is challenging to replicate in synthetic restorations and requires a skilled, artistic and experienced ceramist.

5.3 Tooth Colour Space

The natural tooth colour space is an envelope, or gamut of colour, of the visible electromagnetic spectrum symbolised as a banana shape on the psychometric colour space (Fig. 5.6). It is located between the CIE colour coordinates $+a*$ and $+b*$, which broadly represent colours in the light-red and light-yellow regions [4]—Fig. 5.7. Therefore, lighter, less intense teeth have a greater proportion of yellow, while darker, more intense teeth have a higher proportion of red. Ideally, any

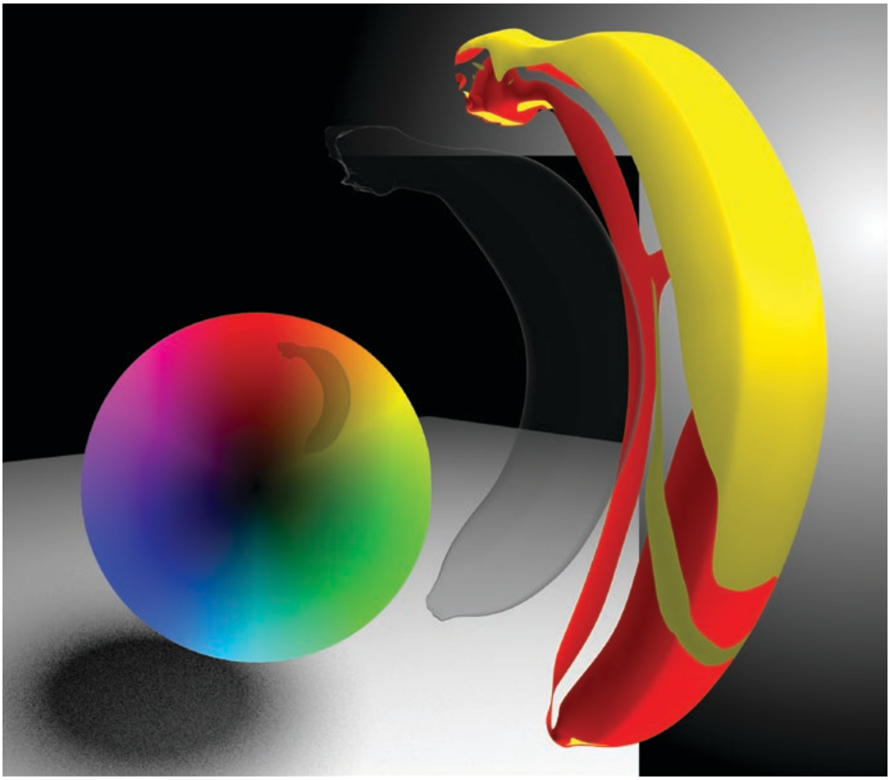

Fig. 5.6 Tooth colour space of natural teeth is depicted by a banana-shaped colour gamut

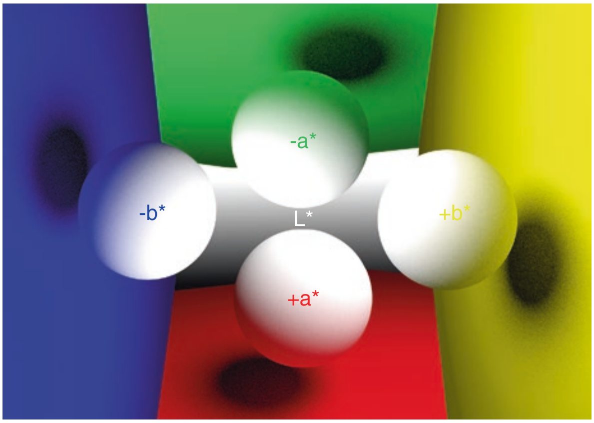

Fig. 5.7 CIE $L*a*b*$ colour coordinates are represented by value ($L*$) and $*a$ (red–green) and $b*$ (yellow–blue) colours

Fig. 5.8 Youthful teeth have high value with surface perikymata that alter the perceived colour of the tooth

comparison method for shade evaluation, e.g. by shade tabs, should represent the full coverage of the natural tooth colour space.

The foremost aspect to realise is that each tooth in a dental arch has a different hue, with unique distribution of value and chroma. Typically, value is lowest at the cervical regions due to a thinner enamel overlay and highest at the incisal edges where the enamel layer is thickest. The thickness of the enamel layer also determines the extent of reflectively and opacity and influences the underlying dentine colour, which is pronounced at the cervical regions with intense chroma. While younger teeth have larger pulps that confer a pinkish glow, aged teeth with secondary and sclerotic dentine display deeper chroma with reduced value (Figs. 5.8 and 5.9). Hence, to mimic natural teeth by artificial restorations and to avoid a lacklustre bland dentition, it is essential to vary hue, value, chroma and translucency within and between individual prosthetic units.

Another important factor is that a natural tooth is in a state of continual chromatic flux, i.e. the shade of a tooth is constantly changing throughout life. This also applies to artificial restorations, which compromise their long-term

Fig. 5.9 Aged teeth have low value with secondary and sclerotic dentine that results in deeper chroma

chromatic stability. Any chromogen that affects the enamel, dentine or pulp causes a colour shift in the tooth. The clinical presentation of colour change is polychromatic and cause related, appearing as bright white, creamy, yellow, orange, red, brown, grey, black or capricious variations such as green, purple, violet or even golden. Therefore, it is essential to elucidate the cause(s) of discolouration before prescribing an aesthetic restoration, which may be ineffective if the cause is unresolved. Tooth discolouration is often multifactorial, with combined aetiology and varied clinical presentation, and is broadly classified as intrinsic, extrinsic and internalised, i.e. post-developmental intrinsic staining [5, 6]. Also, colour fluctuation, and its aetiology, can either be transient, such as dietary pigments, or insidious such as indelible enamel staining due to leaching amalgam restorations.

5.4 Perceptible Versus Acceptable

In order to determine the accuracy of a shade match, the difference between the target or specimen is compared to a reference, and the difference is represented according to the Commission Internationale de l'Eclairage or CIE $L{*}a{*}b{*}$ chromaticity (or colour) coordinates using the following formula:

$$\Delta E*_{ab} = \left(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}\right)^{1/2}$$

where:

$\Delta E*_{ab}$ is total colour change.
ΔL is difference in lightness (0 for white, 100 for black).
$\Delta a*$ and $\Delta b*$ are differences in the chromaticity (or colour) coordinates $a*$ and $b*$.

The $a*$ coordinate represents the red–green colours: a positive value is red, while a negative value is green. Similarly, the $b*$ coordinate represents the yellow–blue colours: a positive value is yellow, while a negative value is blue (see Fig. 5.7). A perfect match between the specimen and a reference equates to $\Delta E = 0$, where 'Δ' is the difference and 'E' represents 'Empfindung' the German for sensation or perception.

Therefore, to achieve a perfect colour match between two objects, the stimuli from two objects must produce the same cone signal in the retina, i.e. $\Delta E = 0$. Currently, there is no concord in the dental literature about the degree of colour difference that is clinically necessary for a restoration to be classed as a good match [7].

The threshold for clinically perceptible and clinically acceptable shade matches varies from individual to individual. In addition, a perceived colour may be judged differently by the same individual depending on innumerable factors such as temperament, fatigue, time of day, etc. [8]. The literature is ambiguous regarding the values for perceptibility threshold (PT) and acceptability threshold (AT) [9]. The consensus is that a $\Delta E = 1$ for PT for 50% of observers, while the AT is higher, with an average $\Delta E = 3.7$ for 50% of observers [10]. However, there is wide variance, and the quoted values for ΔE for PT and AT should not be regarded as sacrosanct [11]. The reasons for these discrepancies are because the perception colour is both a physiological tangible and psychological intangible process [12]. In addition, the methods for measuring colour depend on experimental set-up that are often sui generis, and therefore comparing results of different studies is problematic and meaningless. However, there is general agreement that the ΔE values between visual and instrumental shade assessment are substantial, but within clinically acceptable parameters [13]. However, the new CIEDE2000 colour difference formula defines the PT limit as 1.275 and the AT limit as 2.24 to compensate for discrepancies in previous assessment criteria [14]. Another factor often omitted in the shade conundrum is the patient knowledge base, which has exponentially increased with access to the internet. Whereas in the past a ΔE of 4–6 may have been tolerated or even accepted, but today the informed and knowledgeable patient demands a ΔE value nearer to visual perception rather than clinical acceptance. Furthermore, technology has also raised the bar for photography, which now offers incredible quality that even minor mismatches are instantly noticeable simply by taking a selfie, placing greater burden on both the clinician and ceramist to deliver promised expectations.

5.5 Shade Evaluation Methods

Shade evaluation presents a formidable challenge since teeth are multilayered, semi-translucent, anisotropic, curvaceous, fluorescent, opalescent and iridescent, which complicate the process for precisely determining or matching a shade to these unique entities. There are two basic methods for shade evaluation: visual and digital. The visual method is a subjective approach comparing or matching shade tabs with target teeth. The digital methods are objective and further subdivided into numerical colour data measurements with colour-measuring devices and/or software analysis of 2D photographic images (photodocumentation) or 3D intra-oral scans [15]. At present, it is prudent to use for a combination of visual and digital methods for shade analysis, since both are synergistic to a favourable outcome [16]. In addition, it is important to involve the patient (and their family and friends) throughout the shade-matching process; after all, it is they who are the ultimate arbitrators.

5.6 Visual Shade Evaluation

Matching a reference shade tab to a natural tooth is the basis of visual tooth shade evaluation. It is based on the principle of chromatic differentiation by comparison, dating back to the beginning of the last century [17]. Historically, manufacturers have tried, and struggled, to resolve the issue of inconsistency and unpredictability of tooth shade-matching guides. The first shade guide proposed by Clark [18], nearly a century ago, was based on the Munsell colour system. Since then, several scholars have demonstrated that natural tooth colour space is larger than that depicted by the guide, and subsequent newer guides were introduced to compensate for this limited coverage or coverage error [19]. In addition, some shade tabs were located outside the natural tooth colour space [20]. The extent of coverage is further complicated because tooth colour space is unique to a particular race or ethnicity [21]. Therefore, if shade matching is elusive, it may be necessary to use a different or a combination of shade guides to broaden the colour space coverage. Besides coverage error, other issues that complicate the validity of shade guides are disparate materials used for manufacturing guides, the thickness of the individual tabs and inadequate translucency representation, to name a few.

Although objective instrumental methods yield more consistent and predictable results, the visual method is still the most popular and cannot be completely abandoned [22]. There are two types of shade guides, either hue-based or value-based. The former (hue-based) was the first and is the most popular, such as the VITA classical (VITA Zahnfabrik, Bad Säckingen, Germany), Chomascop (Ivoclar Vivadent, Schaan, Liechtenstein), Esthet-X (Dentsply Sirona, Germany), Bioform Porcelain Shade Guide (Dentsply Sirona, Germany), Noritake Shade Guide (Kuraray, Japan) or Vintage Halo (Shofu, Japan). An example of the latter (value-based) is the VITA 3D-Master (VITA Zahnfabrik, Bad Säckingen, Germany). There are several charts and conversion tables for the different shade guides [23].

Although derided as unsystematic, lacking uniform tooth colour space and erratic incremental shade steps (Fig. 5.10), after more than half a century, the VITA classical shade guide still remains the predominant guide for visual shade evaluation [24–27]. The VITA classical guide is empirically based (16 tabs), while its successor, the VITA 3D-Master (26 tabs) is evidence based (Figs. 5.11 and 5.12). The VITA 3D-Master is a step in the right direction to placate the criticism hurled at its predecessor [28]. It represents natural tooth colour space more precisely and performs shade evaluation more systematically (Fig. 5.13) (following the Munsell three-dimensional colour system), using a sequential assessment of value, followed by chroma and, lastly, hue. Several studies have unanimously

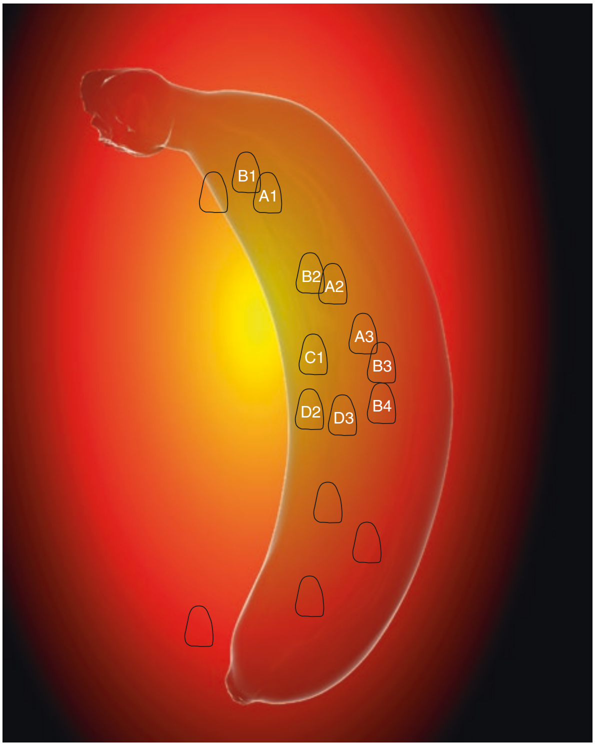

Fig. 5.10 VITA classical guide has a haphazard arrangement of shade tabs, some outside the natural tooth colour space

Fig. 5.11 Hue-based shade guide: VITA classical

confirmed that identifying value is easier than chroma and hue [29, 30], and hence, the value-based guides have a logical approach that produces more consistent and repeatable results [31]. Therefore, shade matching with the 3D-Master is more reliable, with a superior shade-matching capacity, compared to VITA classical [32]. Also, the supplementary three Bleachguide tabs can be added to the regular 26 tabs to expand the guide to include ‘bleached tooth colour space’.

Fig. 5.12 Value-based shade guide: VITA 3D-Master shade guide (with three supplementary Bleachguide tabs)

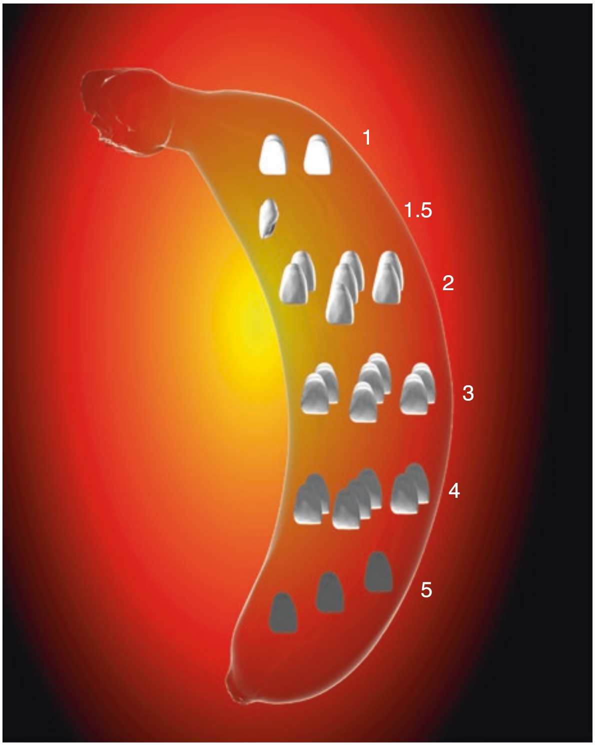

Fig. 5.13 VITA 3D-Master shade guide tabs are systematically and equally arranged in the tooth colour space

Another useful adjunct is the Linearguide tab receptacle, which facilitates comparisons of closely matching tabs by organising them in a linear fashion adjacent to the target tooth.

There is also a useful training tool for the 3D-Master called the Toothguide Training Box (TTB) system, introduced by VITA, for helping clinicians and technicians understand and learn the principles behind value-based guides [33]. The TTB unit was invented in 2002, by Prof. Dr. H.A. Jakstadt, and manufactured by Norwark

Engineering [34] and is a computer-aided, hands-on training apparatus that is easy to use, enjoyable and informative. However, whether TTB improves shade selection is debatable [35]. A study has reported that the interrater agreement is relatively low at only 30% for both the classical and 3D-Master guides [36]. Also, it is worth remembering that the majority of human dentition, greater than 80%, is located within the VITA classical A shade tabs [37, 38] and 50% within the lightness group 3 of the VITA 3D-Master guide.

If commercially available shade guides are unable to match a target tooth; the only option is fabricating a bespoke shade guide using composites or ceramics. This ensures that the shade guide is made from the same particular composite or ceramic that is used for the definitive restoration. Therefore, it avoids issues of mismatch from different manufacturers or material batches and, in theory, delivers more consistent and accurate shade matching. A personalised shade guide can be produced in the clinic or dental laboratory using accessories such as My Shade Guide Mini or Master Kits (Smile Line, Saint-Imier, Switzerland).

5.7 Factors Affecting Visual Shade Evaluation

Having chosen the appropriate shade guide, the next stage is controlling or standardising factors that affect visual shade evaluation. The list below is not exhaustive, but highlights the major variables, and suggests contingency measures for overcoming these obstacles.

Operator factors—It is a broad category signifying that colour perception is unique to an individual depending on constitution, gender [39], age [40], psychological and emotional make-up, experience, fatigue, systematic ailments, medication (prescribed and recreational), colour blindness or specific ophthalmologic diseases [41]. There is broad agreement that many of these variables influence shade selection, e.g. vision deficiencies or age-related corneal degeneration [42, 43]. In addition, genetically acquired colour vision deficiencies such as X-linked recessive hereditary traits, which are more prevalent in men (8%) than women (2%) [44], impact colour perception. However, colour of the iris [45] or wearing prescription spectacles/contact lenses for correcting ophthalmic refraction issues, such as astigmatism, hypermetropia or myopia, has no influence on the shade-matching ability [46]. But for some variables, there is no unanimous agreement, for example, gender, which is a contentious issue [44]. Some studies state that men are trichromatic and females tetrachromatic, giving females the advantage to 'see' more colour [47], but others have found that gender plays little or no part in shade evaluation. There are several simple and effective online colour blindness tests, such as the Ishihara or Farnsworth-Munsell 100 hue colour vision tests, which are useful for determining the degree of colour blindness and whether these errors can thwart successful shade assessment [48, 49].

Training—There is no unanimous agreement whether or not training is essential for shade matching. Some research emphasises that training is essential for predictable visual shade assessment [50], while other research shows insignificant impact between seasoned dental professionals [51], dental students [52, 53] and laypersons [54]. As they say, you don't need a weatherman. Nevertheless, familiarity with a specific shade guide or system does increase predictability and consistency [55]. Also, training and knowledge about colour-matching theories are essential for understanding the principles of shade evaluation.

Afterimages and chromatic adaptation—Other terminology to describe this phenomenon is colour fatigue, hue accommodation or colour minuthesis. In order to mitigate complementary colour or negative afterimages, it is essential that the surroundings are neutral, devoid of lurid colours such as bright lipstick or ostentatious clothing. Tooth shade comparison using shade tabs should be assessed for less than 5 s [56] to prevent the influences of colour (chromatic) adaptation, which also causes colour (or negative) afterimages by microsaccades [57]. Also, the operator should periodically take a 'chromatic break' by looking at an 18% neutral density grey card, before resuming the shade evaluation session. Some authorities suggest temporarily gazing at a blue background or card to give the eyes a rest. However, this fatigues the blue cone receptors in the retina, making the yellow/orange receptors more sensitive to complementary yellow/orange, which causes inconsistent and inaccurate shade matches [58]—Fig. 5.14. Also, shade determination should not be performed after using a dental curing light, especially if the operator has

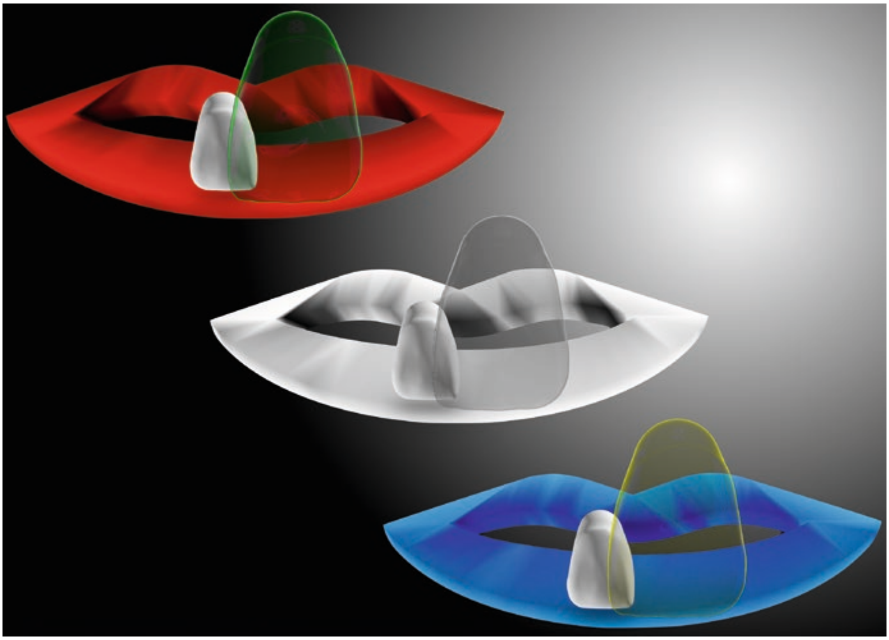

Fig. 5.14 Afterimages: distracting coloured backgrounds cause complementary colour afterimages that result in inaccurate shade determination. For example, a red background causes complementary green afterimages (top) or a blue background causes complementary yellow afterimages (bottom). An 18% neutral grey background (middle) is the ideal surrounding to mitigate afterimages

inadvertently directly stared at the blue light or through an 'orange shied', both of which cause unwanted complementary colour afterimages.

Colour temperature—It is measured in Kelvin (1 K is equivalent to −272.15 °C). Colour temperature is defined as the visible light emitted when a black body is heated to a specific temperature. A low colour temperature confers a warmer glow (e.g. incandescent household lights—3200 K), while a high temperature a cooler ambience (e.g. fluorescent office lights—4500 K). The often quoted daylight temperature of 6500 K (D_{65}) is a combination of sunlight and skylight, while photographic daylight is 5500 K, when all three additive primary colour (red, green and blue) are present in equal proportions. Ideally, shade evaluation should be performed with standardised illumination using both daylight and incandescent lights to avoid metamerism (Fig. 5.15). Although natural daylight is an option, due to erratic weather conditions and time of day, this can result in an inconsistent environment. A better choice is using portable standardised shade-matching light units, which not only offer the correct colour temperature (often with an option to select different colour temperatures) but also have the correct intensity, brightness and colour rendering index.

Colour rendering index (CRI)—The CIE colour rendering index (CRI) [59] represents the quantitative distribution of wavelengths of the visible spectrum, ranging from blue/violet to red (380–720 nm), at a given correlated colour temperature (CCT) [60]. CRI is independent of the colour temperature and measures the ability

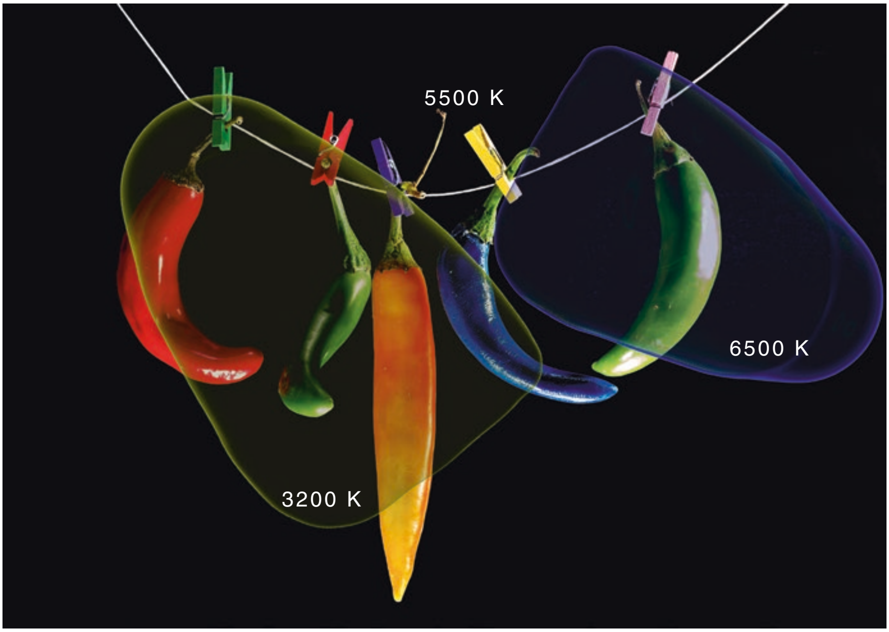

Fig. 5.15 Shade determination at different colour temperatures to avoid metamerism. The background image is 5550 K, the warmer illumination is 3200 K, and the cooler illumination is 6500 K

Fig. 5.16 CRI (colour rendering index) is the ability of a light source to convey realistic or natural colours of objects, which is achieved when the light source has equal proportions of all wavelengths of the visible spectrum

of a light source to show realistic or natural colour of objects compared to a standard reference source, e.g. daylight (Fig. 5.16). If all the visible spectrum wavelengths are not present in equal proportions or certain wavelengths are missing in the light source, the corresponding colour(s) in the object will not be perceived accurately, resulting in surface colour distortion of the missing wavelength(s). The reason for colour distortion is that although the colour temperature of two illuminants may be identical, if they have different spectral power distribution (SPD), the lamps will render object colours differently [61]. This means that inherent colours in an object are only visible if they are illuminated by the corresponding wavelengths in the light source. For example, if wavelengths of red/green are missing in the incident light, the object will appear bluish, and vice versa for other missing wavelengths (Fig. 5.17). Conversely, colour casting refers to a light source that is coloured. For example, a white light covered with a red filter or gel will make all objects, including white objects, appear red. On the other hand, incorrect colour rendering is when an incorrect colour rendering (white) light source illuminates white objects as white, but coloured objects have noticeable distorted colour shifts due to certain missing wavelengths. Also, from a physiological perspective, the distinction between colour temperature and CRI is that the brain adapts to colour tints (such as difference in colour temperatures) by the process of chromatic adaptation, but it is unable to adapt to colour shifts due to poor colour rendering (white) light sources [62].

CIE CRI rating is expressed as R_a (general colour rendering index), which is synonymous with, and simply quoted as, the CRI rating. CRI is measured on a scale of 1–100; the lower the CRI rating, the poorer the colour rendering. A R_a (CRI) 100 indicates that all wavelengths of the entire visible spectrum are present in equal proportions or the light has an equal energy mixture. An incandescent light source has a R_a 100 that is similar to a reference light source (blackbody radiator or daylight). This is the reason that incandescent bulbs have been used for indoor lighting

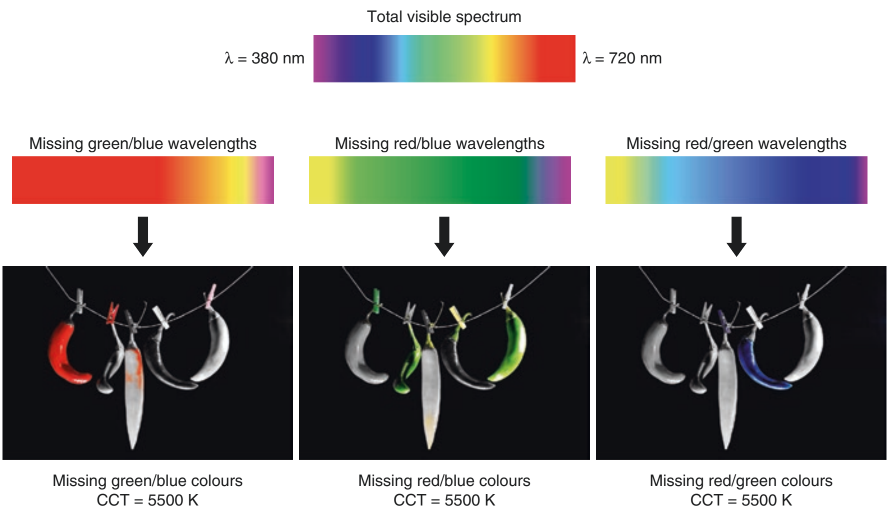

Fig. 5.17 CRI—the missing wavelengths in the light source will not be represented in the surface colour of the objects, e.g. if green/blue wavelengths are missing, only red will be visible, even though the correlated colour temperature (CCT) is identical (e.g. 5500 K)

for more than a century. CRI has recently become more important since incandescent lights are being replaced by LEDs [62], which do not deliver a broad colour spectrum, resulting in inaccurate colour rendering (Fig. 5.18). For most applications such as residential, office or retail, an R_a of 80 is sufficient. However, for hospital environments or for shade matching, it is beneficial to have a broad-spectrum light source that has a high CRI > R_a 90. Finally, for side-to-side comparisons, a colour shift only becomes apparent if the R_a difference is >5.

Metamerism—It is a phenomenon when the colour of two objects matches with a particular illumination but mismatches when viewed with another light source. In order to overcome this optical nuisance in dentistry, the spectral reflectance curves of restorative materials (e.g. ceramics or composites) should be identical or as close as possible to enamel and dentine. Another prerequisite for mitigating metamerism is that the lighting in the dental laboratory and clinic should have a similar CRI index [63], and shade evaluation is performed with light sources of different colour temperatures, e.g. incandescent, fluorescent and colour-corrected LEDs.

Intensity and brightness—The acceptable luminescence quoted for dental offices ranges from 500 to 1000 lux [64], which ensures that visual shade matching is performed under accepted standardised parameters. Also, the emitted light should be diffuse rather than directional to avoid speculate reflections off shiny surfaces such as enamel. The best option is using commercial standardised shade-matching lights, which deliver illumination at the ideal colour temperature, CRI and intensity.

Standardised shade-matching lights—The dental literature has irrefutable evidence that shade matching is more accurate and repeatable using commercially available standardised shade-matching lights. There are numerous lights on the

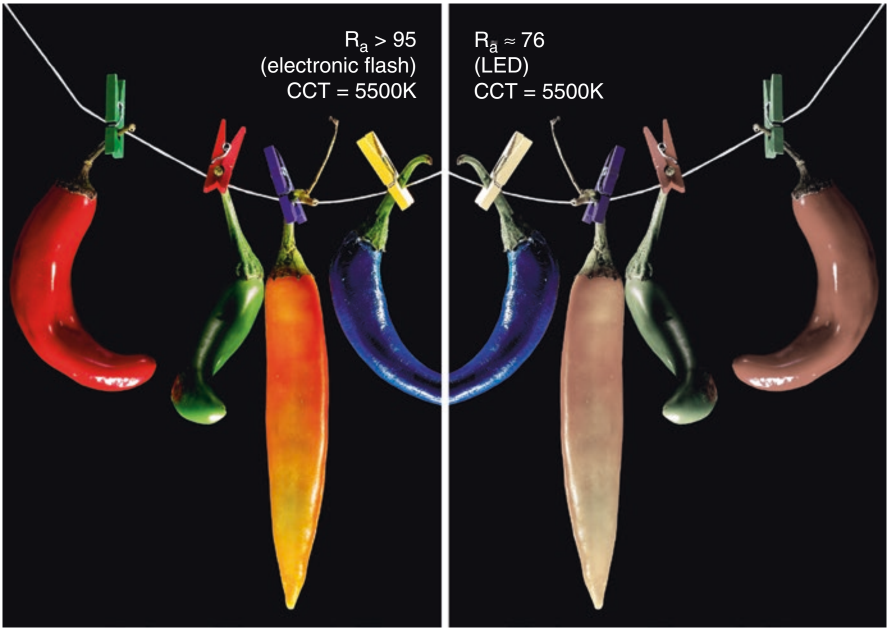

Fig. 5.18 A high R_a or CRI rating light source reveals realistic object colours, while a low CRI rating results in colour distortions, even with identical correlated colour temperatures (CCT)

market, catering for different budgets, using either LED or halogen light sources with correct intensity, colour temperature and a CRI > 90 [65–67]. In addition, many of these devices allow selection of different colour temperatures for counteracting metamerism [68]. Some examples of these units include Demetron Shade Light (Kerr, Bioggio, Switzerland), Rite Lite 2 (AdDent, USA), Optilume Trueshade (Optident, UK) or Smile Lite (Smile Line, Saint-Imier, Switzerland). Also, it has been suggested that attaching a polarising filter onto the light avoids unwanted specular reflections. However, a recent study comparing daylight and the Smile Lite, with and without a polarising filter attachment, showed that attaching a polarising filter did not improve the efficacy of shade matching [69].

Dehydration—Although macromorphology, texture and lustre are best assessed when the teeth are dry, excessive desiccation is counterproductive for shade determination. When teeth are dehydrated by an air syringe, saliva ejectors, cotton wool rolls or rubber dam, an incorrect hue and chroma assessment is inevitable. As teeth dehydrate, water is replaced by air, which transiently causes an increase in opacity and value and decrease in chroma and translucency due to reduced transmission and increased reflection. This makes the tooth appear brighter and highlights internal characterisations such as fluorosis, cracks, intrinsic stains and shade nuances and distribution. A simple analogy is dry crushed glass that appears white with a high value, but when water is added, its translucency increases and value decreases (Fig. 5.19). The resulting ephemeral 'chromatic mirages' are counterproductive for

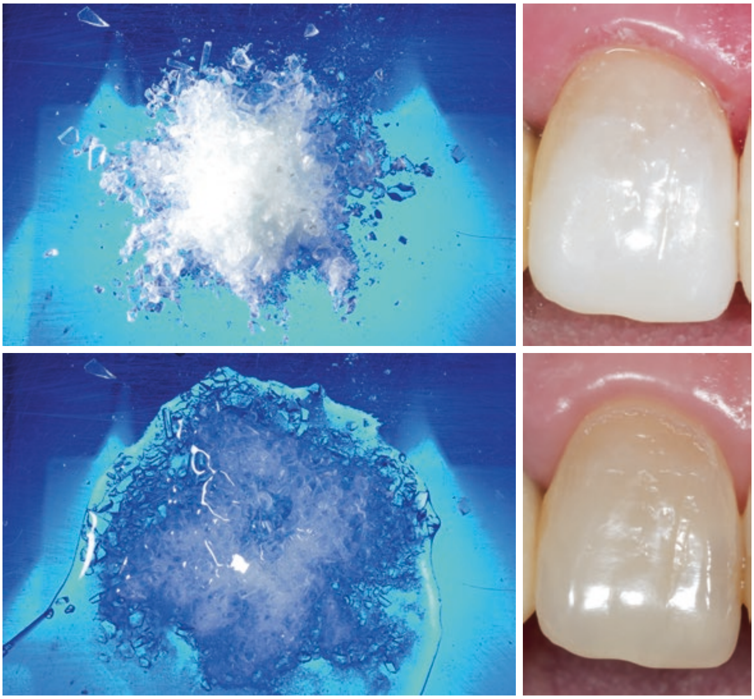

Fig. 5.19 Crushed dry glass appears opaque and bright (high value) because the fragments are surrounded by air and not optically connected with each other. Adding water optically connects the fragments by replacing air with water, which alters refractive index, becoming more translucent and lower value. This is similar to dehydrated teeth that appear opaque and brighter, compared to hydrated teeth that appear translucent and subdued

accurate shade analysis as they 'disappear' after 48 hours when the teeth fully rehydrate [70].

Bleached teeth—Bleached teeth have a similar appearance to dehydrated teeth, i.e. opaque with a higher value. The degree of bleaching can be gauged by using supplementary bleach shade tabs, e.g. VITA Bleachguide 3D-Master [71]. However, shade matching for new restorations should be delayed for at least a month after bleaching to allow shade rebound and stabilisation [72].

Positioning—The angle of viewing and the position of the shade tabs is also important for shade analysis. The shade tabs should be in the same optical axis as the teeth during shade determination or when taking a photograph (Fig. 5.20). The angle of view of the operator is adjusted depending on whether value or hue/chroma is being assessed. For determining value, it is advisable to look slightly to the side of the target tooth/tab/restoration so that peripheral rod vision in the retina is engaged. However, for hue/chroma, the angle of view is head-on to ensure that the foveal axis is perpendicular to the target tooth/tab/restoration [73]—Fig. 5.21. Also, a study has reported better shade assessment accuracy when the shade tabs are located in the shade guide receptacle rather than individually hand-held [74].

Fig. 5.20 Shade tabs should be in the same optical axis as the target teeth/restoration

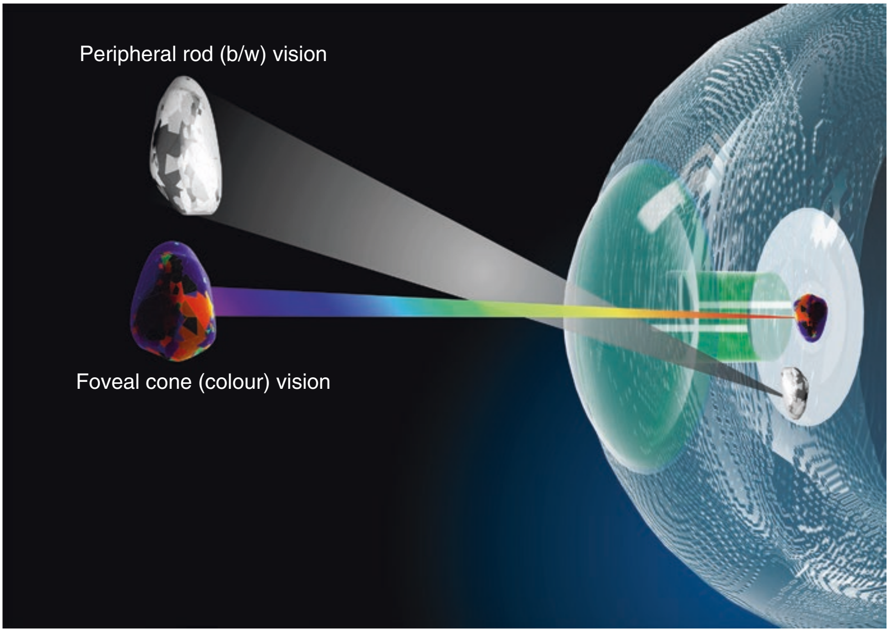

Fig. 5.21 Value is assessed by looking to the side to engage peripheral rod (black and white) vision, while hue/chroma is assessed with foveal cone (colour) vision by viewing perpendicular to the foveal axis

Vectoring—It is evaluating tooth shade from different angles or perspectives [75]. This is particularly significant for mapping the distribution of translucency (prevalent at the interproximal and incisal regions), chroma (deepest at the cervical aspect) and value (predominant at the incisal edges or cuspal peaks). In addition, viewing a tooth from different angles, or with different angles of illumination, allows assessment of goniochromism.

Distance of viewing—A substantial amount of literature about dental aesthetics stresses that tooth morphology and alignment take precedence over shade mismatches. While discrepancies in chroma or hue are discernible only at intimate distances (a few centimetres), morphology (form), value, lustre, texture and opacity are noticeable at social distances (approximately 1–2 m). Therefore, matching the actual wavelength (hue) is less important than other aesthetic factors, especially an incorrect value, which makes a restoration appear unduly conspicuous or unemphatic [76]. Hence, the preferable distance for assessing value is around 1 m and hue/chroma at closer distances of about 30 cm or less [77]. The apparent distance (or magnification) is also important when photographing shade analysis: for assessing value the magnification ratio is 1:5 and for hue/chroma a higher magnification of 1:1.

Background colour—The colour of the background for the shade-matching process has been widely investigated. The choices of background are the oral cavity, 18% neutral grey card, blue card (complementary to ‘yellow’ teeth), or a pink card simulating the oral soft tissues. While background colour influences the simultaneous contrast principle, the data from studies regarding a specific, ideal background for shade matching is lacking and inconclusive. Photographing a natural tooth with adjacent teeth (which creates a light background), and a shade tab held below with the darker oral cavity as the background, has the effect of accentuating simultaneous contrast, i.e. the natural teeth appear darker compared to the shade tab that appears lighter [78]—Fig. 5.22. For this reason, some research indicates that having a single background colour of grey or pink cards for both the teeth and shade tabs produces an egalitarian shade-matching environment [79].

Another form of unintentional background is brightly coloured or highly reflective jewellery, which should ideally be removed beforehand. Similarly, chromatically ostentatious or reflective clothing should be replaced with sombre attire. This also applies to lurid-coloured surgical gowns that cast unwanted coloured shadows onto the teeth.

Preparation (stump) shade—Besides pre-operative shade matching, the shade of the prepared abutment tooth, or stump, is essential. PLV preparations are either

Fig. 5.22 Simultaneous contrast: the natural teeth have a lighter background (surrounded by adjacent teeth), compared to the shade tabs that have a darker background (oral cavity)

within enamel, dentine, composites, glass ionomers or a combination of natural tooth substrate and restorative materials. The shade of the prepared tooth, or core build-up, may be an acceptable colour or discoloured and require masking, which affects ceramic layering for achieving the anticipated aesthetic result. Therefore, an image of the prepared tooth and matching shade tab forms part of the shade prescription for the proposed veneer(s).

Single versus *multiple PLVs*—A shade prescription for multiple adjacent PLV is simple, since the clinician and ceramist have carte blanche to manipulate shades that achieve treatment objectives and satisfy patient wishes. However, shade evaluation is more challenging when matching a single veneer, especially in the aesthetic zone, to surrounding and antagonist teeth or existing restorations. A shade mismatch in this visually sensitive arena is catastrophic, not to mention the accompanying exasperating consequences.

Porcelain factors—Having selected the appropriate shades of porcelain powder according to the clinical shade evaluation, a colour shift can still be encountered during several PLV fabrication stages. These include shade shifts due to repeated firings or varying thickness of the porcelain layers [80]. Another issue is whether or not a [dense] ceramic core is utilised. If no ceramic core is used, the PLV is thinner and significantly influenced by the underlying tooth colour substrate [81]. Conversely, if a ceramic core (lithium disilicate or zirconia) is utilised for masking underlying discolouration, the shade of the core will influence the perceived shade by chromatically interacting with the veneering porcelain.

Cement shade—The usual luting agent for PLV is usually a resin-based cement, available in a selection of hues and values. For the majority of PLVs, the cement colour is insignificant. However, if the PLV has extremely thin cross section (<0.3 mm), the tint or value of the cement will significantly alter its colour [82].

Communication—The methods and media for conveying shade, characterisation, morphology, texture, translucency and other nuances to the ceramist require divine intervention. Despite meticulously following guidelines for accurate tooth shade evaluation, if the message or the sign on the wall cannot be conveyed, all effort is in vain. The more information the ceramist has, the more he/she is able to use his/her artistic skills to emulate nature. With increasing demanding, informed and even petulant patients, the days of *PFM crowns for teeth 11 and 21: shade A2* laboratory prescriptions are historical eulogy.

It is clear from the above that the drawbacks of visual shade evaluation are substantial, tainted by subjectivity, operator factors, materials from which the tabs are fabricated, illumination, ambient environment, training and communication [83]. For example, the same individual may have difficulty repeating a shade selection for the same tooth on different days [84]. Furthermore, the shape, texture and location of the tooth in the mouth all affect shade evaluation. These are a few reasons why digital shade analysis excels, since it eliminates many of the above variables associated with visual assessment by offering an objective alternative.

5.8 Instrumental (Digital) Shade Evaluation

Instrumental shade evaluation is one of the digital methods offering absolute colour measurements without making a comparison with (reference) shade tabs. The measurements with colour-measuring devices record CIE $L*a*b*$ colour coordinates or $L*C*h*$ parameters, which are subsequently analysed by software that converts the readings to equivalent shade tabs of the chosen shade guide, e.g. VITA classical, VITA 3D-Master, Shofu Vintage Halo, etc. [85]. However, the CIE $L*a*b*$ values from one device to another cannot be used for inter-instrumental comparisons [86].

Digital shade-analysing instruments use a variety of technologies including filter colorimeter, reflectance spectrophotometers, spectroradiometers and digital image captures, which can be used alone or in combination. Filter colorimeter measures the tristimulus values for red, green and blue of the visible spectrum, whereas spectrophotometers assess the spectral reflectance of the entire spectrum at 1–25 nm intervals along the object surface. Spectrophotometers measure spectral reflectance curves, which are more precise than the tristimulus method. The digital colour-measuring devices use integrated standardised illumination, usually with 45/0° geometry configuration for ensuring optimal lighting conditions. The type of geometry is the manner in which the target specimen is illuminated and the angle of view of the detector. If the illumination is 45° and the detector viewing angle is 0°, then the device has a 45/0° geometry. In contrast, a sphere geometry is diffuse spherical illumination with a detection angle of 8°. The 45/0° geometry is a preferred configuration for most colour-measuring devices as it avoids the inaccuracies of edge loss [87]. In addition, most devices are indifferent to ambient light [88], which is advantageous compared to visual shade assessment, where contrived lights in the operatory are a concern [89]. A study using an intra-oral spectrophotometer found no difference in the CIE $L*a*b*$ values under different surrounding lighting conditions [90].

The dental colour-measuring devices are portable 'hair-drier style' units that assess shade by either spot measurement (SM) using a narrow aperture (window or diameter) covering an area of a few millimetres (3–5 mm) or complete tooth surface measurement (CTSM)—Fig. 5.23. The CTSM allows construction of a 'chromatic map' consisting of shade distribution of the entire tooth from the incisal edge to the gingival margin. The SM narrow window devices only assess shade over a small area, and several measurements at different sites are necessary to build up a chromatic map of the tooth.

Several manufacturers use a combination of technologies, for example, digital image analysis combined with a colorimeter or spectrophotometer (Table 5.1). The most accurate devices are the spectrophotometers, but they are slower than colorimeters, which produce less consistent results [91]. However, under standardised conditions, there is no difference in accuracy between spectrophotometers and colorimeters [92]. Also, the reported instrumental shade accuracy is superior to visual assessment, with a spectrophotometer boasting 47% greater consistency compared to the shade tab method [93, 94].

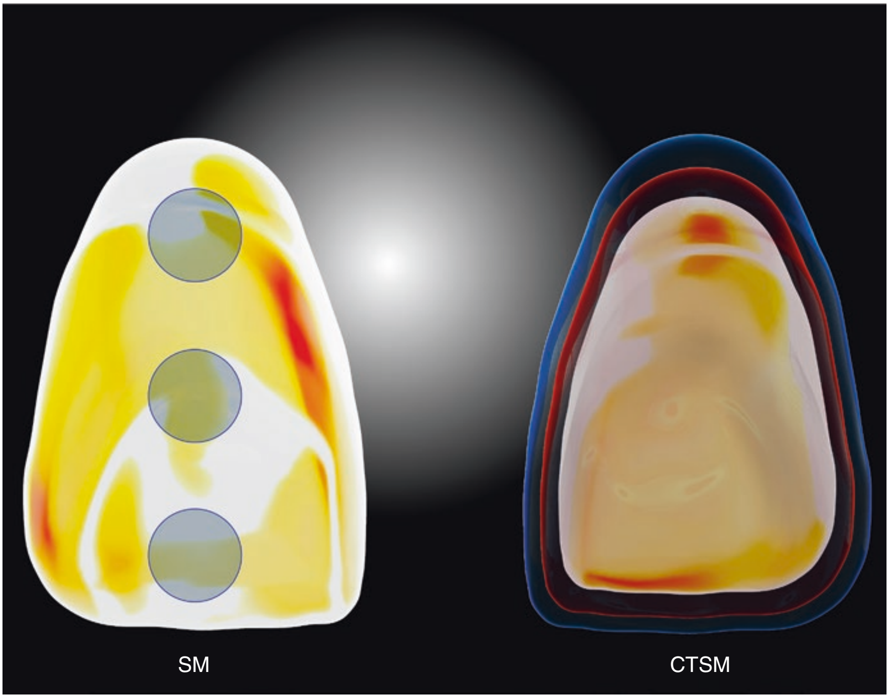

Fig. 5.23 Instrumental shade evaluation is either spot measurement (SM) at several regions, e.g. cervical, middle and incisal, or complete tooth surface measurement (CTSM)

Table 5.1 Dental colour-measuring devices

Device	Technology	Measuring area[a]	Manufacturer
ShadeEye-NCC	Colorimeter	SM	Shofu, Japan
Digital Shade Guide DSG 4 Plus	Colorimeter	SM	A Rieth, Schorndorf, Germany
ShadeVision	Colorimeter	CTSM	X-Rite, Grandville, MI
ShadeScan	Colorimeter	CTSM	Cynoprod, Montreal, Canada
Easyshade V	Spectrophotometer	SM	VITA Zahnfabrik, Bad Säckingen, Germany
ShadePilot	Spectrophotometer	CTSM	DeguDent, Hanau, Germany
Crystaleye	Imaging spectrophotometer	CTSM	Olympus, Tokyo, Japan
SpectroShade Micro	Imaging spectrophotometer	CTSM	MHT, Verona, Italy

[a]*SM* spot measurement, *CTSM* complete tooth surface measurement

Imaging spectrophotometers take advantage of both direct shade measurements and digital images to analyse the entire surface of the tooth. A paper comparing three colour-measuring devices, ShadeVision, Easyshade and SpectroShade, concluded that SpectroShade produced the most reliable and consistently repeatable results [95]. Another research comparing instrument and visual agreement rate and colour difference ($\Delta E*_{ab}$) concluded that all three devices tested, ShadePilot, Crystaleye and ShadeVision, produced $\Delta E*_{ab}$ that were higher than the threshold for clinical acceptability and ShadePilot delivered the highest agreement rate of 56.3% compared with visual shade determination [96].

However, instrumental measurements also have drawbacks. First, the shade analysis is essentially 2D, devoid of vectoring and lacking information about translucency, texture and detailed analysis of shade transition or gradients. The lack of shade gradient is particularly a disadvantage with SM spectrophotometers that take probe or spot measurements rather than imaging spectrophotometers that analyse the entire tooth surface from gingival margin to incisal edge [97]. This allows a chromatic map to be created with shade gradations that is invaluable for the ceramist for incorporating colour nuances in the artificial restoration. Another contentious issue is the target or type of tooth being evaluated, with different instrumental–instrumental agreement rates for shades of the maxillary central incisors, laterals and canines [98]. Furthermore, the software extrapolates missing areas and, therefore, introduces potential errors and inaccuracies. In addition, the ageing of the filters in the devices over time affects results and periodic calibration is essential.

5.9 Photodocumentation (Digital) Shade Evaluation

The second digital shade evaluation method is dental photography. Probably the best method of clinical communication is photodocumentation, both still photography and video footage. Furthermore, adding annotations to images for emphasising salient features, or highlighting specific areas, is invaluable for a laboratory prescription. Also, visual shade evaluation and photography complement each other and should be used together for enhanced shade determination.

The prerequisite for photodocumentation is standardising equipment and settings. This involves using predefined parameters including appropriate illumination, white balance, depth of field, field of view, magnification ratio and correct positioning of the shade tabs so that they are in the same optical axis as the target teeth. For example, diffuse lighting, or a polarising filter, is ideal for minimising specular reflection for assessing chromatic distribution within dentine, while directional lightning is more conducive for visualising macromorphology, micromorphology, surface texture and lustre. Another important issue is positioning the flashes (ring or lateral flashes) so that the 'red' soft tissues of the oral are not excessively illuminated and reflect back a red glow onto the palatal surfaces of the teeth causing them to have a reddish appearance. This is particularly relevant when taking submental oblique images when the camera (with flashes) is positioned below the incisal edges of the maxillary teeth. In addition, judicial use of contrasters is ideal for visualising areas of translucency, especially at the incisal edges of incisors that have pronounced mamelons. Another important factor for PLV shade assessment is photographing the prepared teeth so that the ceramist can gauge the shade of the stump or abutment. This not only records the extent of remaining enamel for adhesive bonding but also reveals whether the underlying tooth substrate is an acceptable colour. If the abutment is discoloured, a collaborative decision is required between the clinician and ceramist to manipulate the shade during fabrication, by either masking with ceramic opaques/porcelain layering techniques or using resins of different tints and values at the cementation stage or a combination of both methods (Figs. 5.24, 5.25, 5.26, and 5.27).

After taking the clinical photographs, the images are imported into appropriate photo-editing software (e.g. Adobe® Photoshop), and the white balance is calibrated with the 18% grey card reference image. Post-processing digital images is invaluable for highlighting certain features for shade analysis. A formidable challenge is assessing the value (brightness and darkness) of a tooth, since the hue and chroma components of colour dominate a composition. To eliminate this influence, an achromatic image is necessary for judging value, especially at the incisal edges where the enamel layer is thickest. The easiest way for creating a black and white image in photo-editing software is moving the saturation tool slider to zero. However, a more

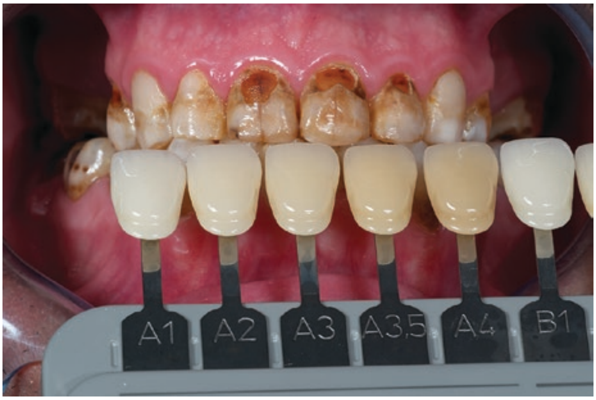

Fig. 5.24 Pre-operative shade evaluation of fluorosed teeth requiring PLV for the maxillary anterior teeth

Fig. 5.25 Tooth preparation for PLV, 3 weeks after home bleaching

Fig. 5.26 Documenting the prepared abutment allows assessment of the degree of discolouration of the underlying tooth (hydrated tooth)

Fig. 5.27 The amount of remaining enamel with frosted appearance for adhesive bonding (desiccated tooth)

sophisticated approach is individually assessing value and hue/chroma by chromatically isolating certain parts of the image. To assess value, the teeth are isolated to black and white and for hue/value the oral cavity to black and white. For the three dimensions of colour (hue, value and chroma), direct measurements are possible by assessing the percentage of the three additive primary colours (red, green and blue), CIE $L*a*b*$ colour coordinates or numerical readouts for each additive colour on a 0–255 greyscale. The colour swatches in Figs. 5.28 and 5.29 represent four numerical values on a greyscale from 0 to 255: red numbers represent the red channel, green numbers the green channel, blue numbers the blue channel and the white numbers the value or brightness. The readings can be converted by software with a reference shade library (e.g. ClearMatch software—Smart Technology, Hood River, OR) to shade tabs of popular shade guides or used to formulate a porcelain powder shade recipe for the ceramist [99]. However, this approach is limited to shade evaluation, since substantial information about the multilayer tooth is absent including chromatic distribution, translucent regions or characterisations. Finally, it is important to remember that photographic shade evaluation is a relative, rather than absolute, assessment.

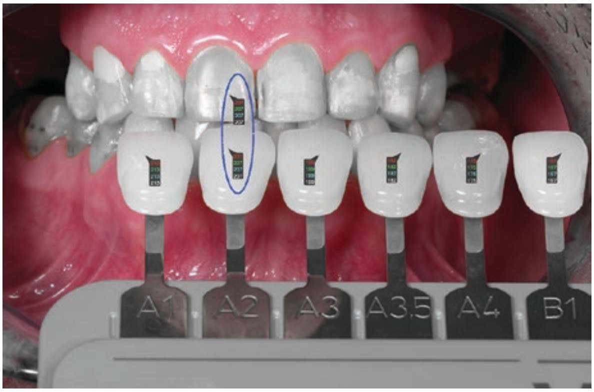

Fig. 5.28 Photographic value assessment: comparative colour readouts (red, green, blue and value in white text) of the prepared abutment and VITA classical shade tabs. Notice the exact numerical match of the A2 shade tab and the maxillary right central incisor (blue circle)

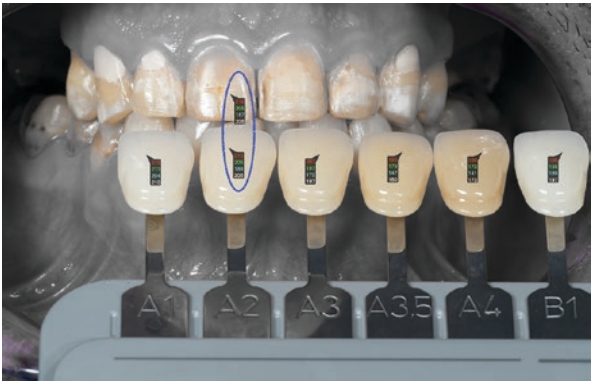

Fig. 5.29 Photographic hue/chroma assessment: comparative colour readouts (red, green, blue and value in white text) of the prepared abutment and VITA classical shade tabs. Notice the closest numerical match of the A2 shade tab and the maxillary right central incisor (blue circle)

Besides direct shade measurements, other approaches for photographic shade evaluation have been proposed. These include digitally adding images of reference shade tabs adjacent to target teeth for shade assessment [100, 101]. However, the drawback of selecting a collage of digital tabs from a shade tab library is complicated by varying lighting conditions or different white balance and other photographic equipment and settings [102]. If photographic parameters are standardised, the production of a digital shade guide is feasible, which can be retrieved for shade matching with target teeth that are photographed with identical equipment and settings [103].

Another use of photographic images is visualising the colour distribution within a tooth. Although photographic digital shade analysis is not an absolute method of colour determination, it is, nevertheless, invaluable for analysing the chromatic nuances within teeth. As well as mapping geographical distribution of shades, an image can show characterisations such as areas of translucency, mamelons, incisal halos, fracture lines, intrinsic staining and so on. The starting point for chromatic mapping is taking an image with minimal specular reflections, either with judicial light or using a polarising filter. After importing the image into the photo-editing software, the brightness is reduced and contrast increased, which emphasises not only 'hidden' tooth characterisations but also the gradual colour changes traversing from the cervical regions to the incisal edges [104]—Figs. 5.30 and 5.31. In addition, drawing software can be used to map chromatic distribution and annotate specific characterisations (Fig. 5.32).

Fig. 5.30 Chromatic mapping: unadulterated, virgin image

Fig. 5.31 Chromatic mapping: the brightness is reduced and the contrast increased to better visualise chromatic distribution and characterisations such as translucency, dentine mamelons and incisal halos

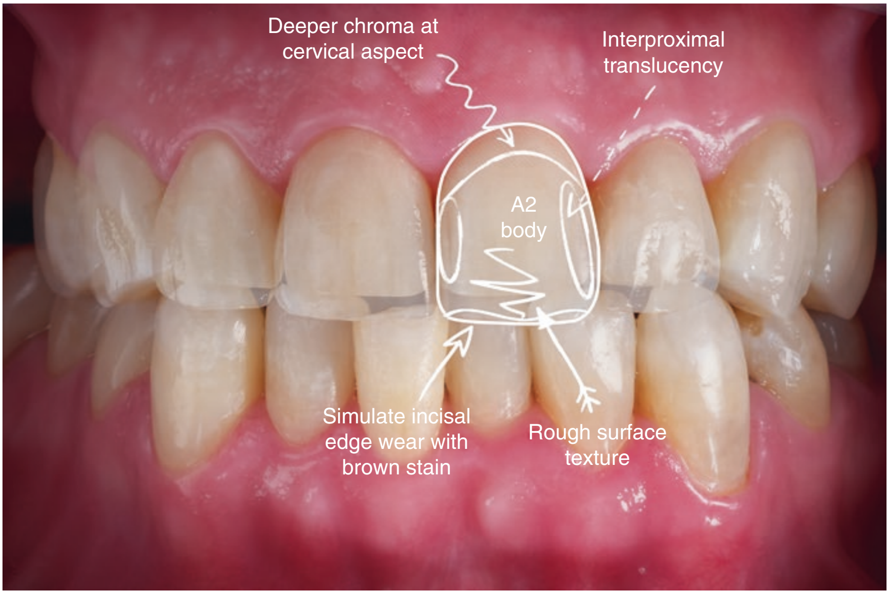

Fig. 5.32 Annotations are useful for providing a prescription for shade distribution and characterisations

Fig. 5.33 Post-operative aesthetic result of PLVs for the maxillary anterior sextant

For complex shade nuances or intricate characterisations that require mimicking in an artificial restoration, the dental laboratory can fabricate bespoke porcelain shade tabs based on photographic and visual/instrumental shade assessment. The tailor-made tabs can then be assessed adjacent to the tooth being matched, photographed and further analysed or adjusted until desired. This method requires a skilled ceramist, perseverance and considerable expenditure [105]. Finally, photographic shade evaluation is also useful for confirming that the outcome of treatment is as anticipated and is an indisputable record for dento-legal documentation (Figs. 5.33 and 5.34).

Fig. 5.34 Post-operative shade evaluation showing that the closest match of PLVs for the central and lateral incisors is the VITA classical A2 shade tab (grey circles), while the canine PLV shade approximates the A3 shade tab (blue circles)

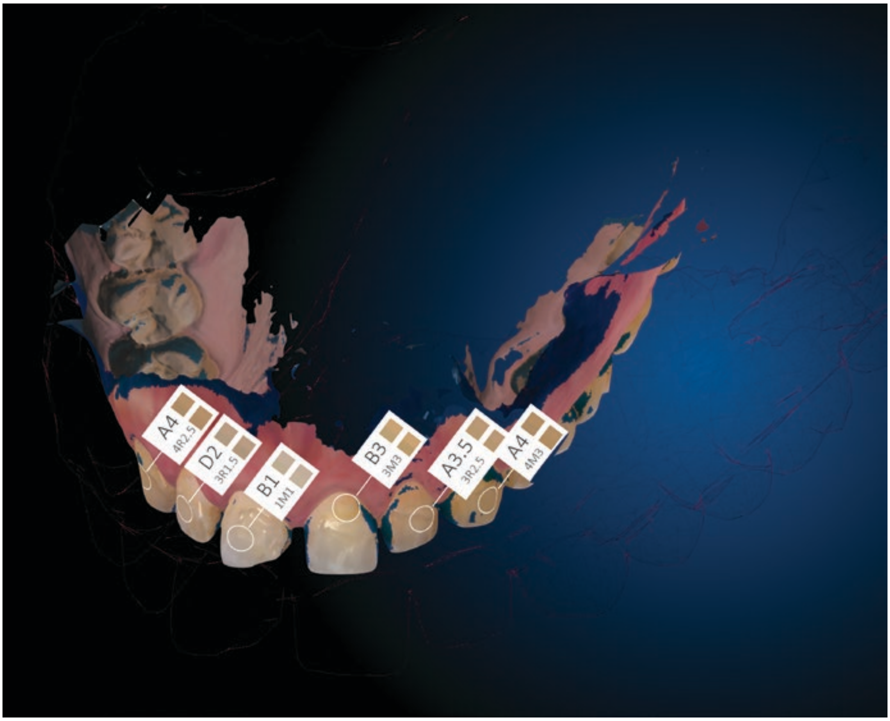

Fig. 5.35 Recording tooth shade concurrently with a digital impression offers convenience and expediency but at present lacks scientific credence

5.10 3D IOS (Digital) Shade Evaluation

The last digital shade evaluation method is analysing 3D scans from intra-oral scanners (IOS), which are becoming increasingly popular for digital impressions. The accompanying in-built IOS software usually incorporates a shade evaluation tool/function (Fig. 5.35). The opportunity to concurrently record tooth shade and a digital impression offers expediency and convenience. However, at present, shade evaluation with IOS is at a nascent stage, with few studies validating or comparing the results with other methods of shade evaluation. However, with further developments and research, this form of digital shade analysis may be worth considering.

5.11 Synopsis

This chapter has covered the basics of colour science, chromatic properties of natural teeth, tooth colour space, perceptible versus acceptable shade matches and methods of shade evaluation for indirect PLVs. The two main approaches for shade determination are visual and digital; the former is subjective and creative, while the latter is objective and unquestionable. Since aesthetic dentistry is highly subjective, it is recommended that both methods are combined to complement each other and, most importantly, to involve patients during the shade evaluation process. Finally, it is worth remembering that the overwhelming increase in knowledge base has resulted in a discerning and perhaps fastidious populous, who are unlikely, and unwilling, to entertain compromises or excuses if treatment outcomes fail to deliver satisfaction.

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Photographic Communication in Esthetic Dentistry

6

Sivan Finkel

Contents

6.1 Introduction

In the world of esthetic dentistry, photography has become an indispensable tool. Thanks to the advent of digital photography and the accompanying technology such as Dropbox, email, and simple photo manipulation software, digital photos can be easily obtained and quickly shared anywhere in the world. It is said that "we cannot

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treat what we cannot see," and to address the challenges we are presented with daily, familiarity with high-quality macro photography is a must. To respond to the fact that photography is barely taught in dental schools, in recent years, there has been a surge in the number of dental photography courses available to clinicians, and even dental societies and conferences centered solely around the subject. In the author's opinion, however, there is a large emphasis being placed today on artistic photography, which is exciting but not essential for performing successful esthetic dentistry. To obtain stunning professional quality before and after portraits, certainly, a full sized soft box studio setup is ideal, but it will not improve the laboratory–dentist communication or the outcome of our cases. In fact, artistic photography techniques utilized at the wrong time will actually lessen the quality of dentist–ceramist communication photos.

This chapter is not about artistic photography. The aim of this chapter is to present a practical photographic protocol using just the minimal armamentarium necessary to get the job done—without cutting any corners. As Einstein once said, "Things should be made as simple as possible, but not simpler."

This chapter will first introduce the most basic information about camera equipment and settings, without a full-on explanation of camera physics. Next, a photo protocol will be introduced, split into two sections: diagnostic photos and shade communication photos. These will be what the author considers to be the bare minimum number of photos necessary, and a rationale for each photo's inclusion will be explained. Finally, a challenging clinical case will be used to demonstrate proper shade taking protocol.

6.1.1 Why Take Photos?

Aside from the central focus of this chapter, which is dental photography as it pertains specifically to esthetic cases, there are many good reasons to take high-quality photographs of our patients routinely: treatment planning and diagnosis, laboratory communication, interdisciplinary communication, patient education and motivation, monitoring progress, legal documentation, marketing, and, finally, self-evaluation.

6.2 Basic Equipment

The camera setup is made up of four basic components: a body, a commander, a lens, and a flash system (Fig. 6.1). The camera *body* houses the controls and the image sensor and is the part the user actually holds. For the purposes of esthetic dentistry, at a bare minimum, the body must be able to shoot in manual mode, record at least 10 megapixel images in both RAW and JPEG formats, and must be able to accept an external flash and a macro lens. The sensor of the camera can be either full frame or "cropped." A cropped sensor simply gives a smaller image with less information in it, while a full frame photo includes more detail over a larger image. With the minimum criteria in mind, it is advisable to physically visit a camera store and hold different camera bodies in your hands, to see which feels best. Generally, Nikon and Canon are the two options.

A *macro lens* is a lens designed for close-up photography, with the ability to capture almost a microscopic level of detail. The minimum criteria for a macro lens

Fig. 6.1 A Nikon D750 setup with a commander, macro lens, and dual flashes mounted on brackets

are that it has a manual setting (vs. strictly "auto focus"), magnification markings clearly displayed (1:1, 1:5, etc.), and a focal range of 90–105 mm. The focal length of the lens is the distance between the lens and the image sensor when the subject is in focus and is described in millimeters. For our purposes, a lens with a focal range of 90–105 mm is ideal because it allows us to shoot everything from a portrait photo to an extreme close-up of just one tooth. Additionally, a 90–105 mm lens allows a comfortable working distance from the mouth.

The *commander* of the camera is the component that communicates between the body and the flashes, although several newer camera bodies can function without a commander. The commander allows the user to define how many different flash groups will be triggered and the power (1/1, 1/2, etc.) at which each flash group will be firing.

In terms of flash systems, a general rule of thumb is that the best lighting for a photo is lateral, or rather, with the light coming from the sides and not from directly behind the lens. The goal is even, balanced illumination encompassing the subject of the photo, similar to what we would see in real life. A direct flash, such as the built-in flash on the camera body, will tend to wash out our images when we shoot so close up, wiping out the detail we so critically need to capture. A widely popularized solution to obtain balanced lighting is a "ring flash," in which there is light emitted in a circle all around the lens. While the ring flash certainly provides more balanced illumination than a camera's built-in flash, this solution still has its shortcomings, as the light is still coming from immediately adjacent to the lens. As a result, photos taken with a ring flash lack depth and volume. In the author's opinion, for *most* types of dentistry, a ring flash photo lacking depth and volume is adequate—i.e., orthodontic progress photos, documentation of surgical procedures—but not for esthetic dentistry, where we must concern ourselves with the most minute micro-esthetic details such as line angles, translucency, opalescence, surface texture, and luster. For esthetic dentistry, it is more appropriate to use a *dual flash setup*, in which the lighting can be more lateralized and thus reveal more depth, details, and lifelike reproduction of what we are capturing. An example of a dual flash system is the Nikon R1C1 kit, which includes two SB-R200 flashes and a mounting ring. This ring will hold the flashes slightly farther away from the lens than a ring flash, which is an improvement, but even better is to mount the dual flashes on extendable *brackets*, which allow much more versatility. This chapter will assume the reader is using this setup, and the next section will begin with a description of the different positions for these brackets' use.

The three main accessories used in esthetic dental photography are retractors, mirrors, and contrastors. *Retractors* (Fig. 6.2) hold the patient's lips and cheeks away, reducing shadows and giving the flashes the ability to reach posterior portions of the mouth. There are many styles on the market, made of different materials such as metal, clear plastic, and black plastic. Generally, the author prefers the metal wide style retractors for all photos, for two reasons. First, the metal retractors are generally wide enough to get the lips out of the frame when taking occlusal photos, and second, the plastic retractors often look unhygienic and dirty after several rounds in the autoclave. It is best to allow the patients to hold these, rather than the assistant, because the patient will not pull on their lips and cheeks to the point of pain or discomfort, whereas an assistant might.

Mirrors (Fig. 6.3) are typically made in two styles: occlusal mirrors and narrower buccal mirrors. The author does not use the buccal mirrors, as usually the patients can self-retract at least to the first molar and let the photo be taken directly.

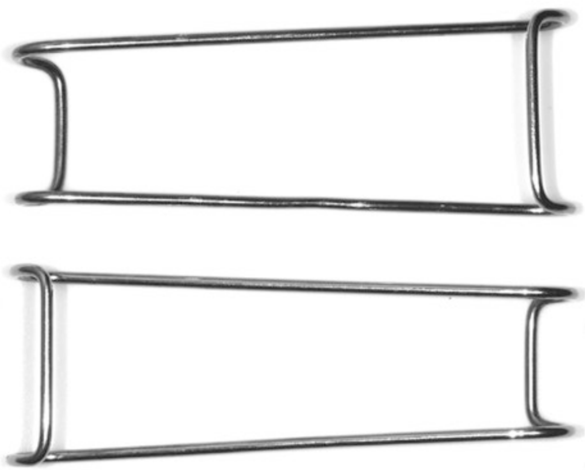

Fig. 6.2 A set of metal retractors

Fig. 6.3 An occlusal mirror

Fig. 6.4 A rubberized black contractor

The occlusal mirror, with one larger side and one smaller side, is essential, however. Intraoral mirrors are made of either highly polished stainless steel or glass; the latter gives sharper images but is much more easily scratched.

Contrastors (Fig. 6.4) are either metallic or rubberized black surfaces that are held behind the teeth to give a clean, uncluttered view of the teeth being studied. More important than creating a clean image, however, placing the contrastor behind the teeth simulates the darkness of the back of the mouth, allowing us to visualize translucencies, craze lines, and other nuances in the enamel. This is especially critical in cases when we are creating a single restoration to match an adjacent natural tooth.

6.3 Basic Settings

1. *Flash positions*—As discussed above, the most ideal lighting for our purposes will be lateralized, i.e., not coming from directly behind the lens. A dual flash setup is recommended, along with extendable brackets. The following flash positions are the three minimum positions the clinician should know [1]:
   (a) The first position, referred to as *next to lens* (Fig. 6.5), approximately simulates the position of a ring flash, with the flashes right up against the lens and facing straight forward. This position is only utilized for mirror shots because a more lateral position would not allow the light to reach the subject. For our purposes, the only time this position will be used is for the maxillary and mandibular occlusal shots. When shooting in this position, to avoid the risk of the light washing out the photo, the flash power should be reduced via the commander.

Fig. 6.5 The “next to lens” flash position, used only for occlusal (mirror) shots

Fig. 6.6 The “3–2” flash position used for most intraoral photos

(b) The *3–2 position* (Fig. 6.6) is the flash position used for almost all intraoral photos. The flashes are positioned approximately 3 in. to the side of the lens and 2 in. behind and aimed at 45° to our subject. The exact measurements are not as important as having the left and right sides positioned symmetrically to one another, for the most uniform and accurate lighting.

(c) *Far from lens* (Fig. 6.7) positioning is used for our full face photos. Simply stated, here, we are shooting from a much farther distance from our subject, and so we want the light to reach and envelope the entire face. This is also why we shoot portraits at a much lower f-stop than intraoral photos (to be described below). The brackets are extended completely straight out to the sides, with the flashes facing forward. Alternatively, a different flash known as a “speedlight” can be used for the portrait shots [1], but this requires the extra step of removing the commander and mounting the speed light in its place. While it results in slightly more even lighting, the “far from lens” bracket position gives just as much information, and so a speed light is not a

Fig. 6.7 The “far from lens” flash position, used for portrait shots

critical addition to the armamentarium for the beginning dental photographer, or those looking to minimize the amount of equipment needed.

2. *Magnification*, aka reproduction ratio
Magnification, or reproduction ratio, is the term used to describe the relationship between the size of the subject being projected on the camera’s sensor and the size of the subject in real life. For example, if the image is the same size as the subject, then the reproduction ratio is said to be 1:1, or life size. If the image is twice the size, it is a 2:1 ratio. And if the image is half the size, it is a 1:2 ratio. Figure 6.8 shows the magnification markings on a macro lens, which are set by rotating the barrel. Typically, most intraoral shots are taken at a reproduction ratio of 1:2–1:3, depending on the size of the camera sensor. A close-up of just two central incisors would require a ratio of around 1:1, and a portrait would be taken at around 1:10. Different sized camera sensors, and different sized subjects, make these numbers not absolutely set in stone—but what is important is to maintain CONSISTENCY between all shots of the same type. This consistency will allow before and after images to be compared without distortion, and for the purposes of digital planning, the images to be overlaid upon one another (i.e., retracted full face view and smiling full face view) will “stack” upon one another more neatly. To achieve this consistency, when taking our photos, once the magnification has been set, the user has to move his/her head back and forth until the subject comes into focus, rather than rotating the lens.
3. *Aperture*, aka f-stop (depth of field)
The “f-stop” is a phrase used to describe the amount of light reaching the sensor through the “aperture,” which is the adjustable metal diaphragm within the lens. The higher this number, the smaller the aperture, and thus, the smaller the amount of light reaching the sensor. Finding the appropriate aperture is a bit of a balancing act, because as the sensor is exposed to more light, our depth of field decreases. In dentistry, we usually want a deep depth of field, i.e., as many teeth to be in focus as possible. Notice Fig. 6.9a, taken at f-stop 20, is brighter (“more exposed”) but with only the central incisors in focus (“shallower”), while Fig. 6.9b—taken at f-stop 32—is darker (“less exposed”) but with more teeth in

Fig. 6.8 A Nikon 105-mm macro lens, showing the magnification markings

focus ("deeper" depth of field). Generally, an f-stop of around 32 is appropriate for all intraoral photos (the dental–facial and dental views), and an f-stop of 9 is appropriate for portrait shots.

4. *Shutter speed* is the length of time, expressed in fractions of a second, that the camera sensor is exposed to light. A longer shutter speed will allow more light in but will also result in a blurry photo if a tripod is not used. In dental photography, a tripod is not used, and our hands—and patients—might move slightly as we shoot, so a photo with a long shutter speed would most likely be blurry. Thus, for dental photography, it is advisable to use a fast shutter speed of 1/125 s, a setting which should be set once and never have to be changed.
5. *ISO* is the term used to describe the sensor's sensitivity to light. A higher ISO allows the camera to capture more information in a low light setting, but this comes at the expense of adding "noise" or graininess to the image. Thus, in dental photography where we can control the light and make it very abundant, the idea is to shoot at the lowest ISO possible to obtain the highest quality image.

Fig. 6.9 (**a**) A photo taken at f-stop 20 will be brighter but with only the central incisors in focus. (**b**) A photo taken at f-stop 32 is less exposed but has more teeth in focus (a "deeper" depth of field)

Typically, it is recommended to shoot at ISO 100 for Canon and 200 for Nikon. Again, once set, this camera setting is usually never changed.

6. *White balance* or "color temperature" is a critical concept, especially in the domain of esthetic dentistry where communicating shade and color is so important. A photo with a "warmer" look would appear more yellow, while a photo with a "cooler" color temperature would look more blue. The appropriate color temperature for shade taking is generally considered to be 5560 K, which is said to be roughly the color temperature of sunlight on a sunny day at noon. Thus, the "white balance" setting on the camera should be set as close to 5560 K as possible [2]. If the camera is unable to accept a custom white balance setting, the built-in color temperature settings "flash," "daylight," and "cloudy" will give a temperature close to the desired value. The clinician should always compare the temperature of the photos to the actual warmth of the subject (i.e., "do the teeth appear as yellow/white in real life as they do in the image?"). Figure 6.10a–c shows the same photo with a warmer color temperature, the appropriate color temperature, and a cooler color temperature.
7. *Angulation*
   While not an actual setting of the camera, before the photo protocols are introduced, it is important to discuss angulation. When shooting facial or intraoral photos, it is critical that the barrel of the lens be at 90° to the subject or rather held straight in front of, not below and not above, our subject [3].

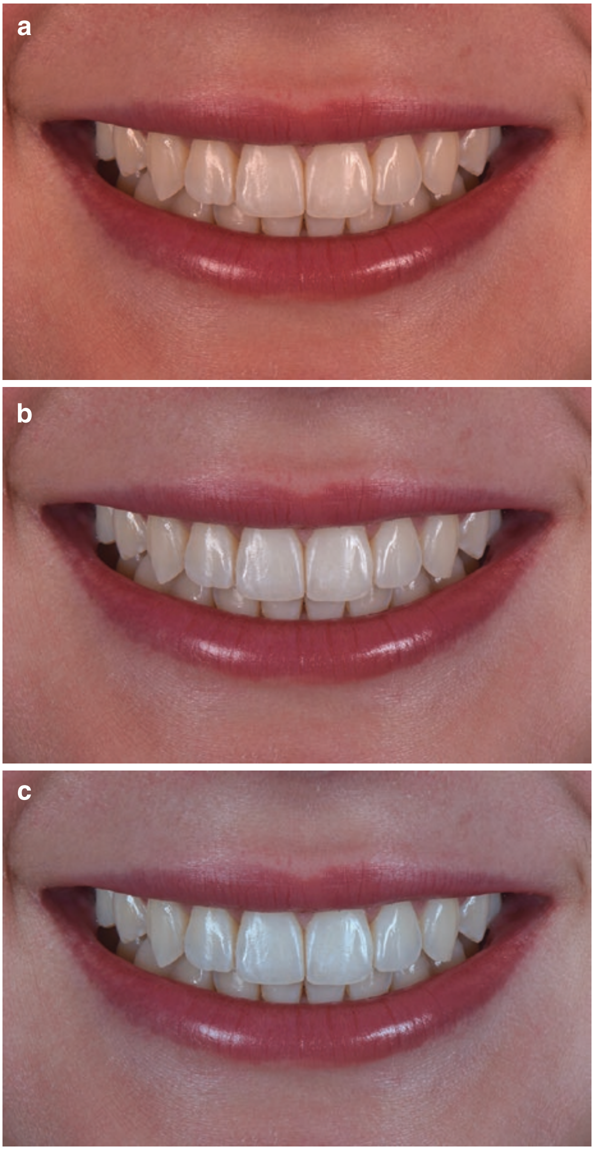

Fig. 6.10 (**a**) A warmer color temperature making the teeth appear yellower than reality. (**b**) A photo demonstrating the appropriate color temperature. (**c**) A cooler photo temperature makes the teeth appear bluer than reality

Consider the example of a full smile photo. A photo taken from slightly below (Fig. 6.11a) will give the perception of a reverse smile, i.e., the canine tips positioned lower than the edges of the maxillary centrals. A photo taken from slightly above (Fig. 6.11b) will result in an exaggerated smile curve, where the canines would appear deficient in length relative to the centrals. Positioning the camera at exactly 90° to the smile (Fig. 6.11c) results in an accurate portrayal. Any sort of treatment planning, and especially digital

Fig. 6.11 (**a**) A photo taken from an angle below the subject, inaccurately portraying these teeth as having a "reverse smile" arrangement. (**b**) A photo taken from an angle above the subject, inaccurately portraying these teeth as having an extreme incisal curve. (**c**) A photo taken from the appropriate angle (90° to the subject) allows us to communicate reality to the technician and design the smile accurately

design where we trace lines directly on the image, requires that each photo is taken at the proper angulation, or the entire smile design can be thrown off.

6.4 Photo Protocols

The photo protocols detailed next will be divided into two sections: diagnostic and shade communication. As it pertains to an esthetic case, the diagnostic series are those photos which will allow the clinician-ceramist team to go from the initial consult to the diagnostic wax-up phase of treatment. The shade communication photos are taken later on, on the day of tooth preparation and temporization. Once again, these series are meant to keep things "as simple as possible, but not simpler," i.e., just the minimum photos needed to get the job done, with no extra or redundant shots.

6.4.1 Diagnostic Photo Series

When analyzing a patient's face and smile, it is useful to envision three distinct type of photos, each moving in closer to our subjects: facial (entire face), dental–facial (teeth and lips), and dental (teeth only) [4]. Each set of photos reveals details and important information not available in the other categories. The facial photo series gives us information pertaining to the smile harmony with the overall facial features as well as the horizon. The dental–facial provides details such as how the lips frame the teeth both in a full smile and at rest, the height of the smile, and the amount of teeth displayed. Dental photos, coming in even closer, allow us to study the "micro-esthetic" elements such as papilla position, gingival zeniths, shade information, incisal translucency, and opalescence. It is advisable that all three diagnostic photo categories be obtained in every esthetic case, even if treating a single tooth.

1. *Facial photo series*—For the facial photo series, with the exception of the profile view, the patient is instructed to face the camera straight on, with the hair behind the ears. Both ears should be equally visible, and the head should not be tilted to either the right or the left ("natural head posture"). The camera, as in all the photos, should be held horizontally as possible and at 90° to the subject. For this reason, if the patient is taller than the clinician, it is advisable for both people to be seated so the camera can be positioned at the appropriate angle.
   (a) *Full face lips together* (Fig. 6.12)
      - F-stop: 9

Fig. 6.12 Full face, lips together

- Magnification: 1:10
- Flash position: far from lens

The patient is instructed to not smile and keep the lips together. This view allows us to assess the symmetry of the facial features when there is no muscle involvement in the eyes or mouth.

(b) *Full face natural smile with teeth together* (Fig. 6.13)

- F-stop: 9
- Magnification: 1:10
- Flash position: far from lens

The purpose of this photo is to capture a natural, unexaggerated smile from the frontal perspective and relate the smile to the horizon and the facial features. This photo shows us how the dental midline relates to the facial midline, the presence of any canting, the number of teeth displayed in the smile, and the degree of negative space in the buccal corridors.

(c) *Full face Duchenne smile* (Fig. 6.14)

- F-stop: 9
- Magnification: 1:10
- Flash position: far from lens

The purpose of this photo is to assess lip mobility. By instructing the patient, "show me your gums," we are looking to see how high the lip can go and whether the gingival levels should be considered in this case. Generally, a posed smile will have less gingival display than a truly natural or "Duchenne smile" [5], and so the natural smile photo is not enough to rely on for this.

Fig. 6.13 Full face natural smile, teeth together

Fig. 6.14 Full face Duchenne smile

Fig. 6.15 Retracted full face, teeth apart

(d) *Retracted full face* (Fig. 6.15)
- F-stop: 9
- Magnification: 1:10
- Flash position: far from lens

Teeth must be slightly apart so the forms of the incisal edges can be read. This is the photo that would be used to perform a "digital facebow" and also is an essential view for Digital Smile Design [6]. It allows us to relate the incisal plane and gingival levels to the true horizon, interpupillary line, and other references. Because in any sort of digital planning, this photo is overlaid with the NON-retracted full face photo, it is imperative that the magnification, angulation, and patient head position remain consistent. This retracted photo should be taken immediately before the next photo, full smile with teeth apart, and the patient should be instructed to remove the retractors smoothly without moving his/her head.

(e) *Full face smile with teeth apart* (Fig. 6.16)
- F-stop: 9
- Magnification: 1:10
- Flash position: far from lens

The teeth apart smile might feel less natural for the patient, but the separated teeth allow the maxillary and mandibular incisal edges to be read. As discussed above, there is diagnostic and treatment planning value in overlaying this view with the retracted full face photo.

(f) *Relaxed profile* (Fig. 6.17)
- F-stop: 9
- Magnification: 1:10
- Flash position: far from lens

Fig. 6.16 Full face smile, teeth apart

Fig. 6.17 Relaxed profile

Keeping hair behind the ear, the patient is instructed to turn their entire body to the side and look straight ahead, lips together. This view helps us assess whether the profile is convex or concave, and basic orthodontic measurements such as the nasolabial angle and Ricketts' E-plane can be obtained [4].

(g) *12 o'clock view* (Fig. 6.18)
- F-stop: 32
- Magnification: 1:3
- Flash position: 3–2

This is a crucial photo in treatment planning, as it allows us to visualize where the edges of the anterior maxillary six teeth lie relative to the wet/dry line of the lip. When fabricating a diagnostic wax-up, this photo shows the ceramist which teeth need to be built facially outward and, alternatively, which teeth do not require much wax on the facial surface.

This is the final photo in the facial series because it requires that we transition the patient to the dental chair, where the remainder of the diagnostic photos will be obtained. The patient is leaned back, and the camera is positioned squarely behind the head at an angle which captures the edges of the maxillary six anterior teeth during a full smile. It is important that the eyes are included in this view, as this will allow us to calibrate this photo to the frontal view if there is any canting of the facial features. Note that this is the only facial view where the f-stop is raised to 32, the magnification is brought in closer (about 1:3), and the flash positions are moved to the "3–2" position. These three settings will be maintained for the next set of photos, which are the dental–facial views.

2. *Dental-facial photo series*—These photos provide details regarding how the lips frame the teeth both in a full smile and at rest, the height of the smile, and the amount of teeth displayed. To obtain these shots, the patient can either be sitting upright or seated in the dental chair. The flash positions should be in the "3–2" position, the magnification at 1:3, and the f-stop at 32.

Fig. 6.18 12 o'clock view

Fig. 6.19 Lips at rest, aka "emma"

(a) *Lips at rest* (Fig. 6.19)
- F-stop: 32
- Magnification: 1:3
- Flash position: 3–2

This is also known as the "emma" photo. This photo is used to assess the degree of maxillary central incisor edge display at rest, which is a common starting point for esthetic treatment planning [4]. Combined with the information we gain from the Duchenne smile photo, we learn the full range of the patient's lip mobility [7]. To obtain the photo, the patient is instructed to say the word "emma" and freeze the lips with no muscle activity.

(b) *Natural full smile* (Fig. 6.20)
- F-stop: 32
- Magnification 1:3
- Flash position: 3–2

This is the classic smile photo which will give us information on the number of teeth displayed, buccal corridor, gingival display, gingival zeniths, gingival and incisal smile lines (aka smile curves), embrasures, contact points, papilla position, and axial inclinations. Additionally, this view provides shade information that cannot be obtained from the full face smile photo. Generally, this photo should be taken with the teeth together, to observe how the incisal curve echoes the lower lip. Another metric we can obtain from this photo, by being consistent with our magnification and overlaying this with the "emma" photo, is the position of the maxillary canine cusp tips in relation to the lip at rest (Fig. 6.20a). This measurement is chosen by some authors as the proper starting point for a smile design, instead of the display of the maxillary central incisor [8].

(c) *Oblique full smile—left and right* (Figs. 6.21 and 6.22)
- F-stop: 32
- Magnification: 1:3
- Flash position: 3–2

Fig. 6.20 Natural full smile

Fig. 6.21 Left oblique full smile

These views are helpful, as they offer the patients a view of their smile they never see themselves, but that the world sees just as much as the direct frontal view. Often, an esthetically conscious patient will think they need to treat only the most anterior teeth in their smile, but these oblique views will demonstrate that the premolars and even molars may need some enhancement as well. The proper angulation of this photo is to capture a slight amount of the contralateral central incisor.

Fig. 6.22 Right oblique full smile

Fig. 6.23 Retracted maximum intercuspation, frontal view

3. *Dental photo series*—Finally, we come to the most "zoomed in" of the diagnostic photos, which are of the teeth and gingiva without the frame of the lips or the face. The retractors are used for this set of photos.
   (a) *Retracted MIP frontal* (Fig. 6.23)
      - F-stop: 32
      - Magnification: 1:3
      - Flash position: 3–2

      This photo, taken with the retractors held by the patient and pulled outward away from the face, helps in occlusal analysis and also gives information on the relative esthetic properties of the maxillary and mandibular anterior teeth.
   (b) *Retracted MIP—left and right* (Figs. 6.24 and 6.25)
      - F-stop: 32
      - Magnification: 1:3
      - Flash position: 3–2

      Aside from providing esthetic information, these views are used to study the occlusal relationship between the arches, namely, whether the patients' Angle molar classification is class 1, 2, or 3. Thus it is important that this photo captures at least the first molars. The author prefers to forego the cheek-sized mirror for this shot and take the photo directly; with both

Fig. 6.24 Retracted maximum intercuspation, left

Fig. 6.25 Retracted maximum intercuspation, right

retractors in, the patient is instructed to relax one side but keep it in, while pulling the retractor on the other side straight back to the ear.

(c) *Maxillary anterior retracted* (Fig. 6.26)
- F-stop: 32
- Magnification: 1:2
- Flash position: 3–2

This photo should have at least the anterior six teeth in focus and captures the micro-esthetic elements so critical for matching nature in our restorations: shade information, craze lines, incisal translucency and halo, opalescence, enamel luster, incisal wear, and gingival health [4].

(d) *Maxillary occlusal* (Fig. 6.27)
- F-stop: 32
- Magnification: 1:3
- Flash position: next to lens

This photo provides information on the patient's maxillary arch form, the structure of the teeth including existing restorations, and the degree of any spacing or crowding. The full arch should be visible from central incisor to second molars, and in terms of the angulation, the facial surfaces of the maxillary centrals should be showing slightly. Ideally, the retractors

Fig. 6.26 Maxillary anterior retracted

Fig. 6.27 Maxillary occlusal

Fig. 6.28 Mandibular occlusal

and mirror edges are not visible in the frame. This photo is taken with the patient lying back, with the photographer standing at the 12 o'clock position; the assistant holds the mirror at 45° to the arch, and the camera is held at 90° to the mirror.

(e) *Mandibular occlusal* (Fig. 6.28)
- F-stop: 32
- Magnification: 1:3
- Flash position: next to lens

This photo provides information on the patient's mandibular arch form, the structure of the teeth including existing restorations, and the degree of any spacing or crowding.

6.4.2 Prep and Temp Photo Series

A properly taken, complete set of diagnostic photos, as described above, will help move the case from the record taking appointment to the fabrication of a diagnostic wax-up. Once the wax-up and corresponding treatment plan are accepted, the patient is scheduled for the preparation and temporization appointment. The photos taken on this day will provide the lab with shade information, as well as facial, dental–facial, and dental views of the patient in provisionals—crucial information which will help ensure a predictable outcome.

As color was discussed at length in a separate chapter, it will not be discussed in detail here, although a familiarity with the different dimensions of color (value, chroma, hue) is necessary. Generally, it is accepted that value is the most important parameter to match [9]. The author advises the use of the VITA 3D master "language," which is 1M1, 1M2, and so on, rather than the "classic" shade language of A1, B1, and C1. The reason is that the 3D language allows us to describe value, chroma, and hue independently; in 1M2, for example, the "1" denotes value, the "M" is the hue, and the "2" is the level of chroma. Each parameter could be adjusted or discussed without changing the other two. In comparison, saying "A1" or "B1" is somewhat arbitrary, and the classic language is thus a less useful system. The author's shade guide of choice is the VITA 3D linear shade guide (Fig. 6.29a) which includes the same tabs as the 3D master system (Fig. 6.29b), but organized in a less confusing way.

The VITA 3D linear shade guide includes one tab arranging one representative from each value group, 0–5, with the value decreasing as the numbers go up (i.e., the 0 shades are brightest and the 5 group is the darkest). The rest of the kit contains tabs organized by members of the same value group, but with increasing chroma (Fig. 6.30). This allows the clinicians to make a value determination of the tooth/teeth to be matched first and then narrow it down to the appropriate chroma level within that value group.

In terms of camera position and shade tab position, it is crucial that the tabs are held in the same plane of light as the teeth we are measuring (Fig. 6.31), i.e., not in front of or behind. Figure 6.31 also illustrates that the camera must be positioned at 90° to the teeth and shade tabs, to ensure that the flash illuminates both subjects evenly.

To illustrate the photographic workflow and the use of the 3D linear guide, the example of matching a single central restoration will be presented.

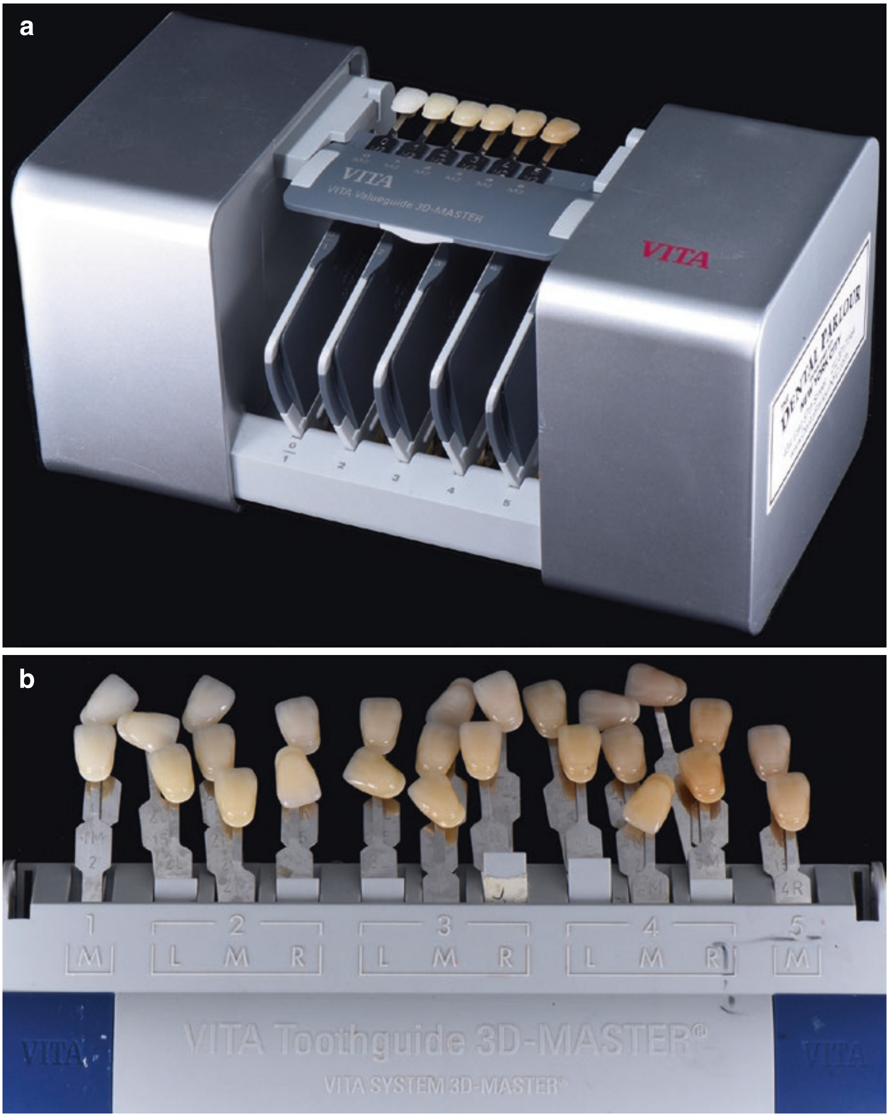

Fig. 6.29 (**a**) VITA 3D linear shade guide (VITA North America, Yorba Linda, CA); (**b**) VITA 3D master shade guide (VITA North America, Yorba Linda, CA)

Fig. 6.30 Expanded view of the VITA 3D linear shade guide (VITA North America, Yorba Linda, CA), showing the separation of tabs into value and chroma groups

Fig. 6.31 Proper orientation of the shade tabs to the teeth and proper angulation of the camera lens to the tabs and teeth

6.4.3 Example Case

This patient presented to the author's private practice with a chief complaint of an existing crown on #9 that did not match the surrounding natural dentition (Fig. 6.32). A thorough and complete examination was completed, including the entire set of diagnostic photos detailed in the previous section. These initial records guided the fabrication of the wax-up. After an intraoral evaluation of the wax-up on the second visit, the treatment plan was accepted, and the preparation appointment was scheduled. The sequence of this appointment would be as follows: desired shade photos, anesthesia, removal of the existing crown, gingivectomy, refinement of the preparation, preparation photos, impression, provisionalization, and photos of the provisionals. Note that the *very* first step is photographing the tooth we are matching; it has been shown that local anesthesia, which reduces blood supply to the tooth, could affect the perceived shade of a tooth (making it falsely higher in value) [10]. In addition, it is well known that desiccation occurs when the patient has their mouth open and teeth isolated for an extended period of time [11]. This too would make the tooth/teeth in question appear falsely higher in value. Thus, we begin with

Fig. 6.32 Dental–facial natural smile view of a patient with chief complaint of mismatched crown #9

Fig. 6.33 Value photo

the desired shade photos before any other steps. The series are as follows—in this case, the contralateral tooth (#8) is our subject, but the same photo sequence would be applied to any other case involving any number of teeth. Note that the photos in this case show a white balance card adjacent to the shade tabs, which allows for digital color calibration [12], but the author and his ceramist typically leave this part of the process out. Digital calibration can be a useful tool but was not used in the case shown below or in the vast majority of the author's cases.

1. *Value* (Fig. 6.33)
   (a) F-stop: 32
   (b) Magnification: 1:3
   (c) Flash position: 3–2

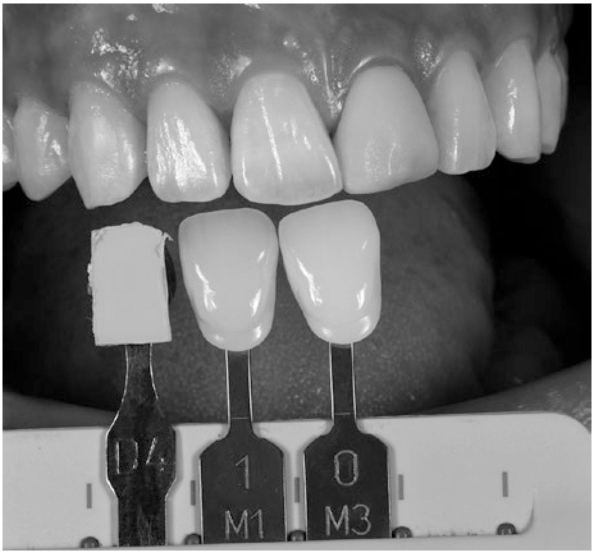

Fig. 6.34 Value photo switched to monochrome for easier value determination

The two closest value tabs are chosen from the 3D linear value shade group and photographed directly below tooth #8. In this case, the tooth we are matching to is quite high in value, so the two tabs chosen are from the 0 to 1 value groups.

Next, the *value confirmation* (Fig. 6.34) is obtained by switching the previous photo to monochrome. This can be done either on the camera directly (for instance, Nikon cameras have a "Retouch" menu with a monochrome option) or easily on the computer by decreasing the saturation to zero. A monochrome image discards all color information and lets us see differences in value more clearly. In this case, the monochrome version of this photo confirms that the value of the tooth #8 is, overall, closer to 0 than 1.

2. *Chroma* (Fig. 6.35)
   (a) F-stop: 32
   (b) Magnification: 1:3
   (c) Flash position: 3–2

   Once the decision has been made as to which value group is best represented by the tooth in question—in this case, the 0 group, not the 1 group—several representatives from this same value group are photographed. In other words, these shade tabs will all be of the same value, but differing chroma (0M1, 0M2, 0M3). If there is still any uncertainty at this point as to which value group is right, two different value group photos can be taken and assessed later.
3. *Cross-polarized photos*
   (a) F-stop: 32
   (b) Magnification: 1:1, 1:2, 1:3
   (c) Flash position: 3–2

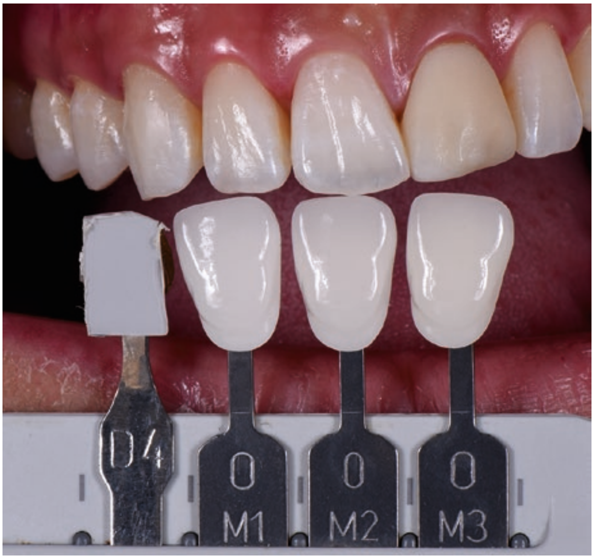

Fig. 6.35 Chroma photo

Fig. 6.36 A Nikon dual flash setup with Polar_Eyes affixed to the lens and flashes, in 3–2 flash position

A recently introduced tool has become essential for shade communication photography, especially in cases involving esthetically challenging single restorations: the "Polar_Eyes" cross-polarizing filter (Fig. 6.36). Developed by Dr. Panos Bazos, the Polar_Eyes system involves filters affixed to both flashes and the lens, which eliminate all reflections from the photo. This allows the clinician and ceramist to more accurately read the zones of differing shades and the anatomy of the dentin mamelons beneath the enamel surface [12]. A comparison of

Figs. 6.37 and 6.38 demonstrates the difference between the regular photo and the cross-polarized version. One is not better than the other. Both are important, as information on tooth luster and texture can only be seen in the non-polarized version. The cross-polarized photos should be taken at different distances to include shots of the teeth with shade tabs (Fig. 6.38) and a close-up photo of the tooth we are matching (Fig. 6.39). A black contrastor behind the teeth is again helpful to visualize the translucencies and nuances of the enamel.

At this point, anesthesia was delivered and the existing crown was removed. The gingivectomy was performed and the crown preparation was cleaned up and

Fig. 6.37 A non-polarized dental view (taken at the initial diagnostic records appointment) demonstrating surface texture and line angles of the tooth to be matched (#8)

Fig. 6.38 A cross-polarized dental view demonstrating the transitioning zones of color and translucency within the tooth

Fig. 6.39 A cross-polarized photo of the tooth to be matched (#8) alongside shade tabs

refined. The next photo in the sequence was then taken: the preparation shade photo.

4. *Preparation shade* (Fig. 6.40)
   (a) F-stop: 32
   (b) Magnification: 1:3
   (c) Flash position: 3–2

   After impressioning and provisionalization, a photo sequence echoing the diagnostic series is taken: facial, dental–facial, and dental photos. These photos serve as confirmation that the provisionals fulfill our esthetic objectives on all three levels. A physical model of the provisionals is always provided to the ceramist as well.
5. *Anterior six retracted* (Fig. 6.41)
   (a) F-stop: 32
   (b) Magnification: 1:2
   (c) Flash position: 3–2
6. *Natural smile* (Fig. 6.42)
   (a) F-stop: 32
   (b) Magnification: 1:3
   (c) Flash position: 3–2
7. *Lips at rest* (Fig. 6.43)
   (a) F-stop: 32
   (b) Magnification: 1:3
   (c) Flash position: 3–2

Fig. 6.40 The prep shade photo, crucial in any case, but especially when we are utilizing all ceramic restorative materials

Fig. 6.41 Dental view of the provisional

Fig. 6.42 Dental–facial view of the provisional

Fig. 6.43 Lips at rest ("emma") view of the provisional

8. *Full face smiling* (Fig. 6.44)
   (a) F-stop: 9
   (b) Magnification: 1:10
   (c) Flash position: far from lens

   One month later, the patient returned for a try-in appointment. Although not perfect, both patient and doctor found the restoration to be esthetically acceptable. After the try-in, a Polar_Eyes photo (Fig. 6.45) was taken for additional confirmation that the shade match was adequate, and cementation was performed. Again, the dental (Fig. 6.46), dental–facial (Fig. 6.47), and facial (Fig. 6.48) photographs were obtained.

Fig. 6.44 Facial view of the provisional

Fig. 6.45 Cross-polarized photo of try-in before cementation

Fig. 6.46 Dental view of cemented restoration

Fig. 6.47 Dental–facial view after cementation

Fig. 6.48 Facial view after cementation

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Adhesion to Glass–Ceramics: Concepts and Clinical Implications

7

Andressa Borin Venturini, Catina Prochnow, and Luiz Felipe Valandro

Contents

The longevity of glass–ceramic restorations depends on an effective treatment plan in using the glass–ceramic material according to its appropriate clinical indication and a specific protocol employed for adhesive luting [1]. Due to the particular characteristics of each glass–ceramic material (i.e., differences in chemical composition and microstructure), understanding the correct combination related to restorative material, surface treatment, and cementation strategy will define the clinical success of the ceramic restoration. For that, knowledge of the glass–ceramic properties and material selection will determine which surface conditioning and resin cement must be employed to achieve long-term durability and with that satisfaction of the patients.

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In this chapter, information regarding some available glass–ceramic materials will be presented, as well as their clinical indications and the best alternative to perform the ceramic pretreatment.

7.1 Glass–Ceramic Materials and Their Acid Sensitivity

Dental ceramics are a composition of two or more entities, in which the matrix is usually a glass lightly or heavily filled with particles (crystalline particles or glass particles that melt at high temperatures) [2]. While the glassy phase is responsible for the esthetics, the crystalline phase is associated with mechanical strength. According to Kelly [2], dental ceramics can be classified into three main categories of composition: predominantly glass, particle-filled glass, and polycrystalline. This chapter deals with adhesion aspects related to predominantly glass (feldspathic) and some particle-filled glass ceramics (leucite enhanced and lithium disilicate based).

Predominantly glass ceramics present high glass content and best mimic the optical properties of enamel and dentin [2]. This glass compound of dental ceramics is mainly derived from a group of mined minerals called feldspar and based on silica (silicon oxide) and alumina (aluminum oxide) [3]. In particle-filled glass ceramics, filler particles are added to the glassy matrix to control optical effects and to improve mechanical properties such as strength, thermal expansion, and contraction behavior [2, 3]. These fillers are usually crystalline or particles of a higher melting glass, which are often dissolved or pulled out during etching to create micromechanical retentive features enabling adhesive bonding [2].

Since the ceramic surface treatment is not standard for all the ceramic systems, it is important to understand the particularities of the glass–ceramic microstructure and composition because surface conditioning that allows better bond strength to resin cement in a specific ceramic may not enable the same outcome in a ceramic material with some different compounds. Therefore, dental ceramic materials have been classified into two groups according to the sensitivity of the surface to be selectively etched (topographical changes) when in contact with hydrofluoric acid: they can be either acid sensitive or acid resistant [4–9].

Structural and topography analyses of etched acid-sensitive (glass or predominantly glass) ceramics have shown that different surface patterns are created according to the ceramic microstructure and composition, being directly related to the concentration, etching time, and type of etching agent employed [10–27]. The adhesion mechanism of silica-based ceramics (i.e., glass-ceramics, herein: feldspathic, leucite enhanced, and lithium disilicate based) to resin cements seems to be well-established in the literature, since the bonding is promoted by hydrofluoric acid etching followed by a silane coupling agent application [18, 25, 28–30]. The presence of silica in the ceramic substrate composition will yield potentially useful information on the clinical success of the bonding procedures, since the silica will be selectively removed by the hydrofluoric acid etchant's action, promoting topographic changes that contribute to micromechanical retention [6, 18, 25] and chemical bonding when using a silane coupling agent and resin cement [7, 12]. The literature has shown that applying only one of these methods (hydrofluoric acid etching or silanization) appears to be insufficient to promote high and stable bond strength [6, 12, 31, 32].

7.2 Hydrofluoric Acid Etching: Time and Concentration

In 1983, Horn and Calamia [33, 34] suggested the use of hydrofluoric acid to etch feldspathic laminate veneers to increase bond strength. The hydrofluoric acid mechanism selectively reacts with the ceramic glassy matrix (silica content) and exposes silicon oxides (SiO_2), thereby creating topographic changes (i.e., surface roughness) on the surface [30, 35], which leads to micromechanical retention when combined with a resin cement [6, 18, 25, 36]. The roughness owing to the ceramic surface etching increases the surface area available for bonding and the surface energy prior to application of the silane agent [37–39]. Thus, increasing the area and the surface free energy will reduce the contact angle, facilitate penetration of the bonding agents, and consequently increase the resin cement wettability for enhanced resin–ceramic bonding [40, 41].

Ceramic etching is a dynamic process, and its impact is dependent on the substrate constitution, surface topography, acid concentration, and etching time [10–12, 26, 40]. Based on this, many in vitro studies have reported different combinations of hydrofluoric acid concentrations and etching duration on the bond strength between glass–ceramics and resin cements [12, 18, 25, 36, 42–46]. However, different glass–ceramics may be more or less sensitive to the hydrofluoric acid etching since they differ in chemical composition and microstructure [20]. Hence, overetching has been reported as deleterious to the glass–ceramic material's flexural strength [10, 11, 22, 27]. Therefore, clinicians should be aware that each bonding procedure needs to be established considering the glass–ceramic type and the exact time/concentration of hydrofluoric acid for better performance. Chairside ceramic etching can be performed with a brief application of 5–10% hydrofluoric acid on the internal surface of the veneer. Table 7.1 presents suggestions for surface treatment and clinical indications of the main glass–ceramics according to the manufacturers.

7.3 Feldspathic Ceramic

Feldspathic ceramics normally present a microstructure based on aluminum-, potassium-, and sodium-based silicate with grains of about 4 μm [47, 48]. Despite the high aesthetic and good adhesion to resin cements and tooth substrate, feldspathic ceramics have a low flexural strength of about 150 MPa [49].

After evaluating the microstructure of a feldspathic ceramic (Vita Mark II), Belli et al. [50] affirmed that this material presents one glassy phase embedding two distinguished particulate phases, both reaching up to 15 μm in size: a highly etchable glass and an acid-resistant crystal. The etching pattern obtained in Vitablocs Mark II is due to the dissolution of the high-fusion glass particles by the

Table 7.1 Surface treatment indicated by the manufacturers according to the glass–ceramic (acid-sensitive) composition

Ceramic type	Commercial name (brand)	Clinical indications	Surface treatment
Feldspathic	Vitablocs Mark II (VITA)	Veneers, inlays, onlays, anterior and partial crowns, overlay veneers for multiunit frameworks	5% HF[a] for 60 s + silane
	Vita PM9 (VITA)	Layered veneers; overlay veneers for multi-unit frameworks	
Leucite enhanced	IPS Empress Esthetic and IPS Empress CAD (Ivoclar Vivadent)	Veneers, inlays, onlays, anterior and posterior crowns	5% HF[a] for 60 s + silane
Lithium disilicate based	IPS e.max Press and IPS e.max CAD (Ivoclar Vivadent)	Veneers, inlays, onlays, anterior and posterior crowns, anterior and posterior implant abutments; three-unit bridges up to premolars; overlay veneers for multiunit frameworks	5% HF[a] for 20 s + silane
	LiSi Press (GC)	Occlusal veneers, thin veneers, veneers, inlays, onlays, anterior and posterior crowns, crown on top of an implant abutment, three-unit bridges up to the second premolar and placed on top of an implant abutment	5–9% HF[a] for 20 s + silane
Nano-fluorapatite glass–ceramic	IPS e.max Ceram (Ivoclar Vivadent)	Layered veneers, veneering of Y-TZP frameworks and lithium disilicate substructures	5% HF[a] for 20 s + silane
Fluorapatite glass–ceramic	IPS e.max ZirPress (Ivoclar Vivadent)	Veneers, pressing over Y-TZP frameworks	5% HF[a] for 20 s + silane
Zirconia-reinforced lithium silicate[b]	Vita Suprinity (VITA)	Veneers, inlays, onlays, anterior and posterior crowns	5% HF[a] for 20 s + silane
	Celtra DUO (Dentsply)		5% HF[a] for 30 s + silane
Feldspar ceramic network reinforced by a polymer network[b]	Vita Enamic (VITA)	Minimally invasive reconstructions, non-prep veneer/table top, inlays, onlays, anterior and posterior crowns	5% HF[a] for 60 s + silane

[a]*HF* hydrofluoric acid
[b]New materials that will be addressed in the next chapter

hydrofluoric acid, while the low-fusion glassy matrix suffers a less selective dissolution [50]. Thus, after hydrofluoric acid etching, the microstructure of feldspathic glass–ceramic presents only one phase and is characterized by a very porous material [48], described in the literature as a honeycombed surface (Fig. 7.1a). According to the manufacturer, good adhesion is achieved by conditioning this ceramic material with ~5% hydrofluoric acid for 1 min (Vita Zahnfabrik).

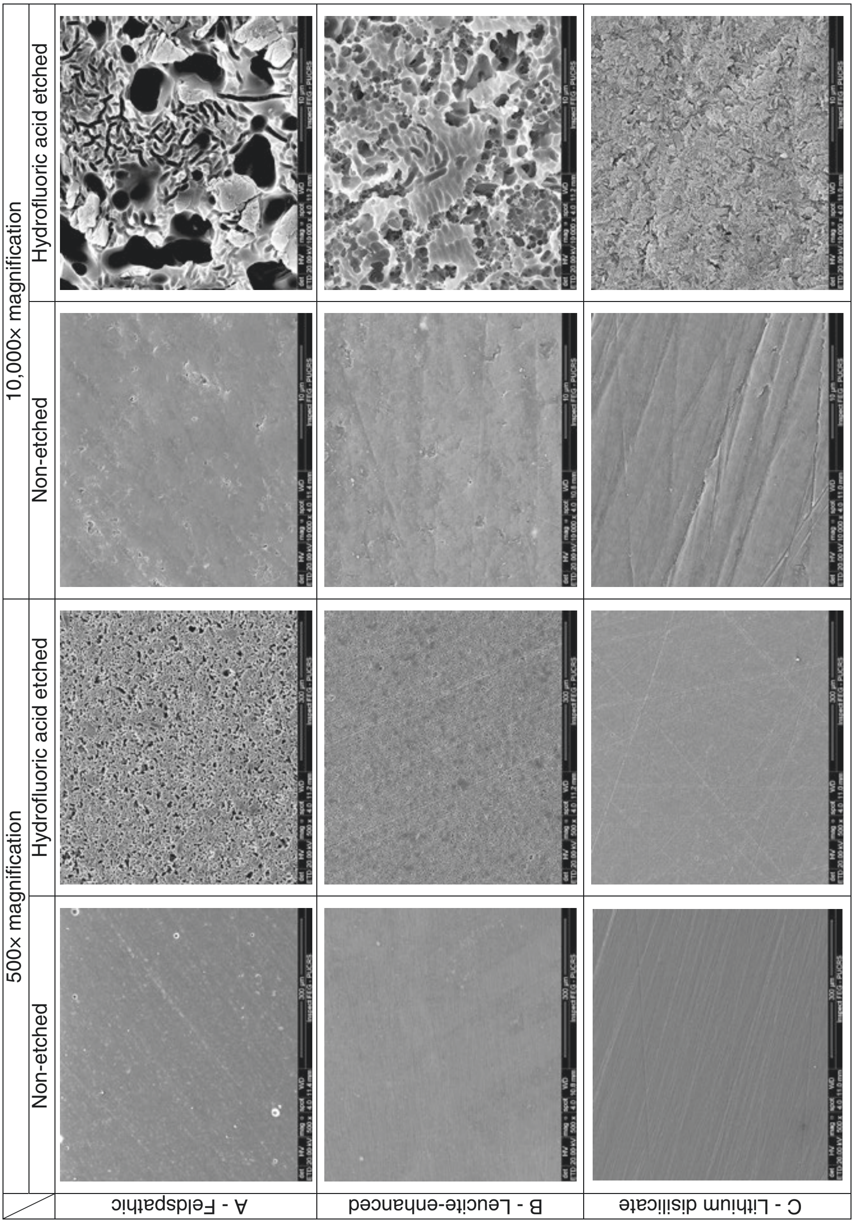

Fig. 7.1 FE-SEM of the glass–ceramic materials discussed in this chapter comparing non-etched polished surfaces with hydrofluoric acid etched surfaces according to the manufacturers' recommendations

7.4 Leucite-Enhanced Ceramic

Leucite-enhanced glass–ceramics obtain their strength by finely dispersed leucite crystal reinforcement [11]. The leucite filler is uniformly dispersed throughout the glass as a reinforcing crystalline at a concentration of 35–45 (% in volume). This material (IPS Empress) exhibits a flexural strength of 120–180 MPa (Ivoclar Vivadent; [11]). According to Belli et al. [50], etching of leucite-enhanced ceramics results in well-dispersed round and slightly elongated cavities in a range of 0.5–3 μm, being the shape and size of dissolved crystallites. See Fig. 7.1b.

According to Apel et al. [51], the crystalline content of leucite-enhanced ceramics is not so effective in promoting crack deflection (toughening mechanism), commonly observed in lithium disilicate glass–ceramics [52, 53]. However, the high glass phase content (~60% in volume in IPS Empress CAD) plays an important role for aesthetics and for hydrofluoric acid sensitivity, which enables adhesion [54]. The manufacturer recommends conditioning the leucite-enhanced ceramic with 5% hydrofluoric acid for 1 min to increase the bond between the luting composite and the ceramic restoration (Ivoclar Vivadent).

7.5 Lithium Disilicate-Based Ceramic

The first generation of lithium disilicate glass-ceramic was introduced as IPS Empress 2 (Ivoclar Vivadent) in 1998. Next, a pressable lithium disilicate glass–ceramic (IPS e.max Press, Ivoclar Vivadent) was developed with improved physical properties (flexural strength of about 440 MPa) and high translucency through different firing processes [55]. Also, the same glass–ceramic material has been offered for CAD/CAM processing technology with flexural strength of about 360 MPa (IPS e.max CAD, Ivoclar Vivadent).

The reinforcement of about 70% in volume of lithium disilicate crystals [56, 57] incorporated into the glassy matrix significantly increased the mechanical properties [56]. The lithium disilicate crystals have a needle-like shape of about 0.5 up to 4 μm [20] and are randomly embedded into a glassy matrix. The randomly disposed crystals act as "crack stoppers" and give higher flexural strength and load-bearing ability under fatigue to lithium disilicate than other glass–ceramic materials [58]. After hydrofluoric acid etching, the glassy matrix surrounding the crystals is removed, and some crystals can be seen pulling out from the surface [17, 20]. The indicated etching for lithium disilicate ceramics is ~5% hydrofluoric acid for only 20 s (Ivoclar Vivadent).

Figure 7.1 (see below) shows the field emission-scanning electron microscope (FE-SEM) analyses of feldspathic (Vita Mark II; Fig. 7.1a), leucite-enhanced (IPS Empress CAD; Fig. 7.1b), and lithium disilicate-based (IPS e.max CAD; Fig. 7.1c) glass–ceramics. In those images, it is possible to observe the topography pattern alteration promoted by hydrofluoric acid etching when compared to polished ceramic surfaces. In the FE-SEM images, the pointers show the formation of micropores that occur due to attack of the matrix glass by etching the ceramic surface with a honeycombed appearance in feldspathic ceramic and with exposure of the crystalline content in lithium disilicate and leucite ceramics, as well as removal of some crystals. In addition to the type of crystals, the volume and interlocking between crystals are the main differences related to the crystalline content between lithium disilicate and leucite ceramics. As aforementioned, the crystals in the lithium disilicate glass–ceramics are interlocked needle-like without orientation, while the leucite-enhanced glass–ceramic presents a less dense microstructure characterized by a single formation of leucite crystals without interlocking between the crystals [56, 59].

7.6 Adhesion and Fatigue Behavior of Bonded Glass–Ceramic Restorations

Ceramic restorations are constantly under cyclic loads in wet conditions, and their success mainly depends on the quality and durability of adhesive bond besides the mechanical reliability of the ceramic material [60]. Hydrofluoric acid etching modifies the resident flaw population (pores) on the intaglio surface of ceramic restorations to promote micromechanical interlocking [61]. Herewith, these flaws can act as sources of crack initiation propagating until a ceramic bulk fracture [10, 19, 22, 24], since clinical failures start as radial crack from the cementation surface of ceramic restorations [62, 63] (Fig. 7.2), where hydrofluoric acid etching is performed. In this sense, overetching (i.e., higher exposure time and higher acid concentration) could negatively influence the mechanical strength [27] and, consequently, the long-term success of ceramic restorations.

In addition, defects can also be introduced by internal clinical adjustments of fixed dental prostheses. These internal adjustments using diamond burs appear to have a negative effect on the fatigue behavior of bonded glass–ceramic restorations [64]. From this standpoint, it is essential to proceed cautiously with the necessary internal adjustments, as well as with the acid etching time.

Summarily, the pre-cementation procedures should promote maximum chemical and micromechanical bonds, preventing strong topographical alterations of the intaglio surface, in order to optimize the adhesion for fatigue behavior improvements of ceramic restorations [13, 65], without introducing critical defects, which induce radial cracks and failure overtime. Potentially, the one-step bonding agents for ceramic conditioning appear to be taking place for this propose, since this concept scopes minimum topographical changes and maximum chemical bonds. It is a trend!

7.7 Hydrofluoric Acid Toxicity and New Alternative Materials

Although hydrofluoric acid can effectively improve the bond strength between glass–ceramics and resin cements, it is considered a highly toxic material [66], even in low concentrations and/or for short periods of exposure [67, 68]. It is important

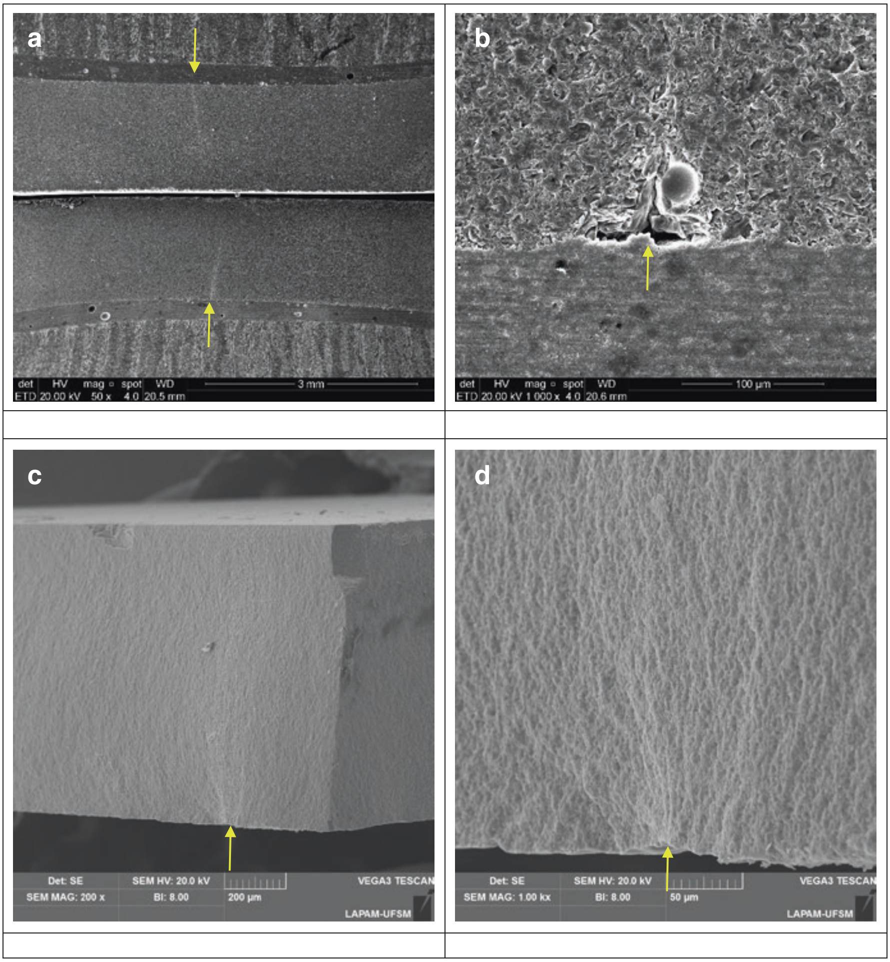

Fig. 7.2 Fractographical examination under FE-SEM of simplified-feldspathic ceramic crown (**a**, **b**) and lithium disilicate restoration (**c**, **d**) that were cemented on a dentin-like material and subjected to cyclical intermittent loading. The yellow arrows indicate the path of crack propagation observed in cementation surface under tensile stresses and flaws promoted by surface treatment, which acted as source of crack initiation (**b**, **d**)

to elucidate that clinicians in some countries are not able to buy and use this product inside the office; the laboratory technician, aware of many demands, performs the hydrofluoric acid etching and sends the prosthetic restoration already etched to the clinician [69].

The tissue damage produced by hydrofluoric acid exposure is based on two mechanisms: corrosive burns from free hydrogen ions and chemical burns from tissue penetration of fluoride [70]. In a different way from other acids, the fluoride ion of hydrofluoric acid quickly penetrates the skin, being able to cause destruction of deep tissue layers, including bone. However, pain associated with exposure to hydrofluoric acid solutions (1 up to 50%) may be delayed for 1–24 h [70]. If hydrofluoric acid is not immediately neutralized and the fluoride ion bound, tissue destruction may continue for days and result in limb loss or death [69]. An ex vivo study reported that the initial extent of hydrofluoric acid burning depends on the concentration, temperature, and the contact time with the acid [67].

Carpena and Ballarin [69] reported that 10% hydrofluoric acid is prohibited in some countries. In their manuscript, they also report the accidental death of a Japanese child after wrongful exposure to hydrofluoric acid. Therefore, Japanese dentists cannot buy hydrofluoric acid to etch ceramics. In Japan and the United States, the dental technician performs hydrofluoric acid etching according to the dentist's instructions [69].

The manipulation of hydrofluoric acid, at a minimum, should be performed using double nitrile gloves or butyl rubber gloves, even for working with small quantities [69]. Also, plastic facial masks should be preferred, and protective glasses should always be mandatory since eye contact with hydrofluoric acid would result in severe damage with concentrations from 0.5%. In addition, it is highly recommended to keep hydrofluoric acid refrigerated and not exposed to sunlight since it is volatile, being in the gel form above 28°C.

The potential damage to health and high toxicity of hydrofluoric acid are factors that have motivated the search for new alternative materials to substitute hydrofluoric acid in dentistry. Previous studies have tested different ceramic surface treatments, such as alumina particle abrasion, laser irradiation, nonthermal plasma treatment, silica (Si) vapor phase deposition, selective infiltration etching, and associated treatments [40, 71–75]. However, those alternative surface treatments were not preferable to hydrofluoric acid etching associated with silane coupling agent application or are poorly supported by the literature, thus requiring more studies.

A recent material introduced into the market is a self-etching ceramic primer (ME&P; Monobond Etch & Prime, Ivoclar Vivadent). This primer is a simplified alternative to the conventional protocol (hydrofluoric acid etching + silane) for treating the glass–ceramic surfaces, since it is less harmful and requires a shorter time due to less application steps (Ivoclar Vivadent). It contains ammonium polyfluoride responsible for creating a rough pattern, replacing the role of hydrofluoric acid, and trimethoxypropyl methacrylate to promote the chemical bond, since it is one compound found in the composition of silane agents [15]. Despite the etching promoted by this primer creating a less pronounced roughness pattern than hydrofluoric acid (Fig. 7.3), recent studies have demonstrated effectiveness for bonding and have shown promising results, but more studies are still needed [15, 21, 65, 76–84].

7.8 Considerations About Silane Coupling Agents

By definition, bifunctional trialkoxy silanes contain two different functional end groups, alkoxy and C–C, which can connect to inorganic and organic materials, respectively. In this sense, silane coupling agents are being employed for adhesive cementation, promoting very effective bonding between silica-based restorative

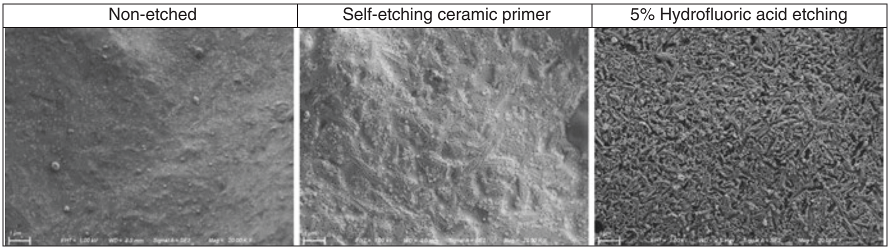

Fig. 7.3 FE-SEM images (20,000× magnification) of CAD/CAM lithium disilicate glass–ceramic comparing non-etched surface, a self-etching ceramic primer (Monobond Etch & Prime) surface treated according to the manufacturers' recommendations (20 s active application +40 s passive), and 5% hydrofluoric acid etched surface

materials (i.e., resin composite luting cement) to acid-etched glass–ceramic restorations [85]. This effectiveness is based on chemical bonding and improved surface wettability promoted when a silane agent is applied onto ceramic surfaces. The dual reactivity is given by one non-hydrolyzable functional group with a carbon–carbon double bond that will polymerize with resin composite monomers containing double bonds and one hydrolyzable alkoxy group (e.g., methoxy–O–CH_3, ethoxy–O–CH_2CH_3) which will react with a hydroxyl group from the ceramic surface [86].

Silane agents should be deposited in thin films: if the siloxane film is too thick, it may lead to cohesive failure, while a film which is too thin may lead to incomplete coverage of the ceramic surface by the thin silane layer and insufficient contact between the silanized ceramic substrate and the resin cement [86]. In this sense, the low viscosity exhibited by silane agents is imperative to assist wetting, making this material come into close contact with the ceramic substrate [86]. During the drying and reaction period, the silane will form a branched thin siloxane film of about 20–100 nm on the etched surface [86]. The siloxane film thickness is mainly determined by the concentration of the silane solutions, curing time, and temperature [86].

Unfortunately, siloxane links are sensitive to moisture in the interface between resin and ceramic surface: aging methods, water storage, and thermocycling have been described as detrimental for the siloxane–ceramic bonds [87]. As the resin composites are permeable to water, the bond between silane and resin composite has been expected to deteriorate by hydrolysis over time [39]. Studies have shown that when only silane was applied on the ceramic surfaces, the bond strength did not improve because of insufficient mechanical retention [6, 32, 88, 89].

7.9 Adhesion to Tooth Substrates

In addition to the correct ceramic surface treatment, the retention and consequently longevity of indirect restorations also rely on the bond strength of the resin cement to tooth structures [90]. Nowadays, adhesive systems can be divided into two types depending on the clinical approach of the smear layer produced by the cavity preparation and the adhesion mechanisms. The first system, the total-etching adhesive, basically includes a separate etch and rinse phase, followed by a priming step and the application of adhesive resin (three-step total-etching adhesive), or the one-step application (same bottle) of combining the primer and adhesive resin (two-step total-etching adhesive). The second system involves a self-etching adhesive, which contains a non-rinse acidic monomer to condition and prime the enamel and dentin simultaneously. Most common self-etching adhesives have two application steps, with the self-etching primer followed by an adhesive resin application (two-step self-etching adhesive).

More recently, all-in-one adhesives (universal adhesives) have been developed, which are the next modification of self-etching priming systems that combine etching, priming, and adhesive potentials into one step. The recently introduced self-etching systems enable simplifying restorative procedures, saving time, as well as eliminating the need for acid etching before application, significantly reducing technique sensitivity [91]. However, studies have shown that some all-in-one adhesives exhibited relatively low bond strengths when compared with two-step total-etching systems [92].

Since adhesive luting is a highly sensitive technique, improvements are being made to make this process less technique sensitive and time-consuming. In this sense, self-adhesive universal luting materials have been introduced since the beginning of the twenty-first century [93]. However, an in vitro study showed that cementation with conventional technique had higher survival rates compared to self-adhesive cements [94], showing debonding of the restorations cemented with self-adhesive cement and confirming that enamel etching and primer application are essential for a successful bonding strategy. For all the resin cements tested in that study, significantly higher bond strength values were measured when the enamel surface was etched compared to no pretreatment [94]. The selective enamel etching is an important step, since it significantly improved marginal adaptation in indirect ceramic restorations [95] and increased survival rates for etched enamel in partial crowns over 6.5 years, which were cemented with self-adhesive resin cements [96].

For dentin, the adhesion is generally more susceptible to failure than enamel–resin cement or ceramic–resin cement interfaces. The micromechanical bond between resin cement and dentin is obtained by a hybrid layer, on which a low-viscosity resin will penetrate into the collagen fibril network and be polymerized [97]. To achieve a hybrid layer with the total-etching approach, dentin is pretreated with an acidic agent, followed by priming and the application of a low-viscosity resin. Also, the smear layer can only be modified and included into the hybrid layer by using self-etching adhesive systems [98].

Importantly, the effectiveness of bonding to tooth substrate is technique based and should be performed according to the manufacturer's instructions. However, selective etching of enamel is recommended as an additional step for self-adhesive resin cements, since it improves bonding by means of additional micro retentions.

7.10 The Influence of Resin Cements on the Adhesion

The selection of the cement and luting technique affects the clinical success of indirect ceramic restorations since the cement will link the ceramic material to tooth substrate/supporting material. Due to brittleness (low strength to tensile stresses) and limited flexural strength of glass–ceramics, adhesive cementation using composite resins should be performed to increase the fracture resistance of the restoration [99–103]. Silica-based glass–ceramic restorations luted with resin composite exhibited better clinical survival than restorations luted with glass ionomer [104] or zinc phosphate [105].

Resin cements have the same composition as the composite resins, but have a lower amount of inorganic filler, providing low viscosity and the fluidity necessary to the cementing agents. They can be classified according to the activation process and the mechanism of interaction with the dental substrate. According to the interaction method with the substrate, two subgroups of resin cements can be listed: (1) resin cements associated with the use of conventional or self-etching adhesives and (2) self-adhesive cements, which do not require any tooth conditioning before cementation [106]. In relation to the activating process, the luting agents can be auto- (chemical curing), light-, or dual-polymerizing resin cement.

A major advantage of light activation is that it allows longer working time than dual or chemical curing materials [107]. Another advantage of these cements is their superior color stability, which influences the esthetic result of ceramic restorations. A greater color alteration was observed for dual-polymerizing cements than light-polymerizing cements due to the oxidation of aromatic tertiary amines present in the dual cements as accelerators of the auto-polymerizing reaction [108, 109]. Therefore, conventional cements with light polymerization are preferred for luting procedures of glass–ceramic laminate veneers [110].

It is important to elucidate that chemical and physical properties of resin cements are also important for the clinical success of indirect restorations. Ideally, those properties should include the capacity to promote bond durability between the restorative material and the tooth surface, strength to tensile and compression stresses, a satisfactory elastic modulus, biocompatibility, color shade, good viscosity (filler content) to allow an adequate resin cement thickness, and the entire fitting of the restoration [111, 112].

Regarding the resin cement thickness, some studies have reported higher stresses developing in the cementation line as the cement thickness increases [101, 113]. A resin cement layer of less than 50 μm creates better bond to glass–ceramic materials compared to a layer greater than 50 μm [114]. Moreover, a cement thickness of 50 μm was more favorable for the fatigue performance of feldspathic crowns, since these crowns were more resistant than those cemented with 500 μm thickness [115].

An appropriate resin-bonding protocol will increase the fracture resistance of the dental ceramic and maximize the performance of indirect esthetic restorations [116, 117]. In this sense, the load-bearing ability and the survival probability of ceramic restorations could be improved because resin cements block the progression of cracks by filling (healing) these cracks and irregularities in the intaglio surface of the restorations [19, 24, 101, 102] and by better transmitting the loads throughout the assembly [13, 101].

The long-term duration of resin-ceramic bonding does not completely rely on a high degree of polymerization and cement mechanical properties [118]. At the same time that a longer and higher intensity of light exposure may enhance the polymerization of the resin cement, it may cause more rapid shrinkage of the material which might be detrimental to the bond due to rapid stress increase [118]. Thus, manufacturers should indicate the radiant exposure required for proper curing in the resin cement instructions for use. In the case of anterior teeth after adhesive bonding, there will probably be little difference as the contact lens becomes more resistant after proper polymerization of resin cement [102]. However, ceramic restorations with thin thicknesses (i.e., laminate veneers) are hyper-fragile prior to cementation, and care must be taken since it is necessary to perform manual pressure in order to overflow any excess of resin cement and place the ceramic piece in proper position [69]. At this time, there is the probability to fracture the ceramic contact lens. Thus, proper pretreatment of the ceramic piece is a determining factor for clinical success as it may influence its mechanical fatigue behavior.

7.11 Important Things to Know Before Etching and Silanization of Glass–Ceramic Restorations

The clinician must be in intimate contact with the dental technician, having knowledge about which kind of glass–ceramic material they will be handling. After hydrofluoric acid etching the glass–ceramic restorations (see the appropriate etching time, Table 7.1), some precipitates and salts are formed on the surface because of the glassy matrix removal. In this sense, the best reported method to remove residues formed by acid etching in feldspathic ceramics is the ultrasonic bath with distilled water [44, 119, 120]. Belli et al. [121] concluded that air/water spray, phosphoric acid etching, phosphoric acid and ultrasonic bath cleaning, and only ultrasonic bath were all similarly good for removing the residue layer and produced good bond strength for leucite and lithium disilicate ceramics. Also, Magalhães et al. [122] found that only air/water spray for 30 s is enough to remove precipitates formed on lithium disilicate surfaces after 20 s of hydrofluoric acid etching.

In addition to the sonic devices, some neutralizing agents have also been employed to clean the ceramic surface after conditioning, removing the reaction precipitates. However, some studies concluded that the acid neutralization step appears to be dispensable, since this procedure did not improve the bond strength or stability between resin cement and glass–ceramics compared to only washing/drying [123, 124]. A universal cleaning paste (Ivoclean, Ivoclar Vivadent) is available on the dental market, aiming to clean an already etched surface or surface contaminated with saliva and/or blood before cementation. This product is based on sodium hydroxide and appears to effectively remove various contaminants from the ceramic surface and provide a clean surface for resin bonding when used before and after etching [125–127]. Another cleaning product is ZirClean (Bisco) that helps to achieve reliable adhesive cementation results by removing the phosphate contamination of zirconia and glass–ceramic surfaces after intraoral try-in.

The silane agent application changes according to the chosen product. For intraoral repair or for the etched ceramic surfaces, the exposed ceramic surface is usually hydrated from the adsorbed water after washing off the hydrofluoric acid. A concern in chairside silanization is to remove the excessive water adsorbed by the ceramic surface. Several methods have been developed for this task, like intensive dry and warm air or application of volatile drying agents prior to silanization, or washing off the ceramic conditioner (acid) with a pre-activated silane with no intermediate air/water rinsing. Also, silane drying and post-silanization heat treatment have been performed to eliminate solvents and optimize the effect of silane on the resin adhesion to ceramic [128, 129]. However, heat treatment procedures for the pre-hydrolyzed silane either in a furnace or with hot air application cannot replace the use of hydrofluoric acid etching [130].

7.12 Clinical Implications

Glass–ceramic veneers offer a predictable and successful treatment modality providing dental tissue preservation. Clinical failure rates of ceramic veneers, including loss of retention or fracture, were less than 5% at 5 years [131, 132] and approximately 5.6% after 12 years [133]. Long-term studies reported similar survival rates: 91–93% over 10 years [134–136] and 82.93% at 20 years [134]. However, Beier et al. [134] included patients diagnosed with bruxism (50%) in the study population, and consequently, the main reason for failure reported in their study was ceramic fracture. In this sense, significantly increased failure rates of glass–ceramic veneers are very often associated with bruxism, clenching, and non-vital teeth [134, 135].

A recent systematic review and meta-analysis suggested that the longevity of a tooth-supported ceramic prostheses made by CAD/CAM manufacturing is lower than that of crowns made by the conventional technique [137]. The material type and process (CAD/CAM generations and software limitation) were the most frequent reasons for CAD/CAM failures [137].

In relation to the survival of ceramic veneers made of different materials (feldspathic, leucite, and lithium disilicate), a systematic review showed very low complication rates and no significant differences in the event rates among the different materials [138]. In this study, the most frequent complication reported was marginal discoloration (9% at 5 years), followed by marginal integrity (3.9–7.7% at 5 years) [138]. Marginal integrity and discoloration are worse when the restoration margin is located within dentin [135].

The fatigue strength of the ceramic material, the prosthetic preparation, the cementation technique (reliable adhesive bonding), and the finishing procedures are considered key factors for the long-term success and esthetical result of the ceramic veneer restorations [139, 140]. Taking into consideration the different degrees of dentin exposure after preparation design, porcelain laminate veneers present higher survival rates (2 years of follow-up) when bonded only to enamel and to enamel with minimal dentin exposure [141]. Large areas of exposed dentin (more than 50% of the preparation surface) exhibit a significantly increased risk for requiring a clinical intervention such as re-cementations, significantly affecting the clinical performance of heat-pressed ceramic veneers [142, 143].

Some factors related to the preparation design can positively improve the clinical performance and survival rates of porcelain laminate veneers, with intact enamel bordering tissue, proximal chamfer, and supragingival preparation designs with incisal overlapping [144].

7.13 Final Considerations

Taking into account the aforementioned concepts and the clinical evidences, it can be highlighted that:

- Overall, maximum adhesion among substrates plays a crucial role in fatigue behavior and in clinical performance improvements of glass–ceramic restorations.
- Adhesive cementation plays a reinforcement role in glass–ceramic restorations, increasing the survival probability of the restorations, since the resin cement promotes healing the cracks at the intaglio surface of the restorations.
- In addition to washing the etched surface with air/water spray, the removal of precipitates and salts formed on the surface after hydrofluoric acid etching using an ultrasonic bath with distilled water might optimize the adhesion to glass–ceramics.
- The clinicians should implement previous knowledge of the glass–ceramic material that is being used in order to perform the indicated surface treatment with hydrofluoric acid etching and silanization.
- Finally, ceramic materials and cementing strategies are constantly changing, which demands continuous updating by clinicians.

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New Materials for CAD/CAM Systems: Resin-Based Composites, Polymer-Infiltrated Ceramic Network, Zirconia-Reinforced Lithium Silicate, and High Translucent Zirconia

8

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During the last decade, intense technological advancements in intraoral scanning and processing technologies, enhancements in material properties and the development of new materials [1–6], as well as the consolidation of minimally invasive approaches based on optimized adhesion to tooth substrate and reduced tooth preparations [7–12] have promoted an intense modification in the way restorative treatments are executed.

These developments can be highlighted by the implementation of Computer-Aided Design and Manufacturing (CAD/CAM) processing systems which have expanded material alternatives in comparison to the conventional materials, optimizing the processing time and the cost, resulting in accurate milled restorations (well-fit) with enhanced mechanical properties which mimic the final natural appearance of teeth [13–15]. Therefore, today, for didactic purposes, we may attempt to categorize these new available materials for veneer manufacturing into three major material options for CAD/CAM: resin composites, glass–ceramic materials, and polycrystalline ceramic materials of high translucency [5, 16]. Thus, in this chapter, we aim to discuss the best available evidence regarding the microstructural differences, intrinsic properties, and clinical performance of these different new materials which are currently available.

8.1 Microstructural Differences and Intrinsic Properties

Resin composites consist of a polymeric matrix reinforced by fillers that could be inorganic (ceramics or glass–ceramics or glasses), organic, or composite [17]. Ceramics are defined as crystalline, nonmetallic materials, containing metallic and nonmetallic elements bonded by ionic and/or covalent bonds, while glass shares the same definition but is amorphous [18]. Glass–ceramics are composite-type materials in which the glassy phase acts as the matrix and the ceramic as the reinforcing filler [19]. Polycrystalline ceramics contain no glass; all of the atoms are packed into regular crystalline arrays through which it is much more difficult to propagate a crack (high fracture toughness) than when the atoms are arranged in an irregular network and are less dense, as found in different glasses [20].

The intrinsic properties of materials are usually directly related to their composition and microstructure, more specifically by the strength and type of interaction (bond) between different intrinsic components. Therefore, it is expected that the flexural modulus (E), flexural strength (σ), and hardness of polycrystalline ceramics (E ≅ 200 GPa, σ ≅ 800–1000 MPa, Vickers hardness ≅ 10 GPa—[21, 22]; and manufacturer alleged data) are significantly higher than glass–ceramics (E ≅ 60–100 GPa, σ ≅ 100–200 MPa, Vickers hardness ≅ 4 GPa—[5, 23, 24]), wherein the properties of these materials are higher than those of resin composites (E ≅ 9 to 20 GPa, σ ≅ 100 MPa, Vickers hardness ≅ 0.4 GPa—[5, 17, 25, 26]).

8.2 Clinical Performance

8.2.1 Resin-Based Materials

Conventional resin–composite materials are considered by many dentists as the main material of choice in restorative dentistry [27]. Worldwide manufacturers have been pressuring for the use of new resin-based materials in CAD–CAM technology, whereas many of these new materials are described by the producers only based on in-house laboratory testing and lack objective research and clinical evidence to support their use or their superiority to classical/conventional materials, partly due to their short time on the market [27–29]. Their indication has been alleged to be for manufacturing partial-fixed restorations (inlay, onlays), veneers, and sometimes single crowns (Lava Ultimate was initially indicated for this restorative approach, but the producer removed such an alternative on 12/06/2015 based on a higher than anticipated debonding rate).

It is undeniable that the use of CAD–CAM technology enables great standardization in processing this material and enabling adequate polymerization, packing, and homogeneity, in addition to reducing operator-related variables that potentially result in enhanced mechanical performance [30, 31]. Another argument for supporting the use of these new materials is its ease of fabrication and the possibility of an easier and less visible intraoral repair of minor defects induced by function [5]. Thus, Ruse and Sadoun [5] estimated that a set of CAD/CAM burs, which are relatively expensive (~$20/bur), could be used to mill 5–10 glass–ceramic/ceramic crowns or well over 100 resin-composite crowns, highlighting its cost-attractiveness, additionally enabling the possibility of easier intraoral repair when chipping or small failures occur in comparison to other material possibilities.

The technique to repair resin composites could be accomplished by preconditioning with air abrasion or bur roughening, followed by placement of a resin composite with very similar mechanical and optical properties [32], while hydrofluoric acid (HF) is applied for glass ceramics, which is highly corrosive and toxic [33, 34] [35–38], and translucent polycrystalline ceramics exhibit an even more challenging scenario which is yet to be explored in the literature.

As disadvantages, the use of resin-based materials returns to the discussion regarding their susceptibility to degradation (water sorption/desorption) when exposed to the oral environment and/or the diet, as well as pH variations [39] and their color stability when also exposed to this medium [40, 41].

In regard to reports of clinical longevity/survival of resin-based CAD–CAM milled composites, to the best of these authors' knowledge, only one report to date exists; Vanoorbeek et al. [42] noticed an 87.9% survival rate and a 55.6% success rate considering 59 single crowns (resin composite GC Gradia, GC) over 3 years of follow-up, where debonding, excessive wear, unacceptable color, and marginal opening appeared as complications. Therefore, they concluded that the material presented an unacceptable performance in comparison to conventional ceramic restorations.

Based on the abovementioned, a lack of studies and clinical evidence to support the predictability of using resin-based materials regarding longevity, failure pattern, and potential to esthetically mimic the characteristics of natural dentition with stability is emphasized, in particular as material for veneer restorations.

8.2.2 Polymer-Infiltrated Ceramic Network (PICN)

Another new material that has been introduced recently is PICN (e.g., Vita Enamic—VITA Zahnfabrik, Bad Säckingen, Germany) [43]. Their indication has been alleged to be for manufacturing partial fixed restorations (inlay, onlays), veneers, and single crowns for both anterior and posterior regions. In the beginning, this class of material was classified as a hybrid ceramic; however, it is mainly a composite material, being singularly composed of multiphase structures which are mutually continuous and interconnected [44].

This tridimensional interconnectivity differs from classical composites, as the latter mainly present singular and discreet fibers and/or reinforced laminated particles. The literature shows that the synthetic development of PICN is guided by the attempt to enhance or personalize characteristics as physical properties of constituent phases, fracture toughness [45], flexural strength [46], contact damage tolerance, as well as endurance to clinical adjustments/grinding during CAD/CAM milling or grinding with diamond burs [43, 47]. In this sense, each constituent is specially selected for enabling a determined microstructural characteristic.

As a result, PICN may represent a new material concept as a blend of ceramic characteristics and composite properties [48]. However, what has been reported is an intermediary performance in comparison to the one observed by typical ceramics and composites [48]. Despite the recent introduction to the dental market of such a material, the concept of PICN is not new; Feng et al. [49] previously characterized the performance of such class of material and stated that perhaps the greatest benefit of using this material is that a similar failure pattern that was seen in high brittle ceramics would not be observed, which is its susceptibility for crack initiation and propagation.

Swain et al. [43] observed a decrease in hardness and elastic modulus, although superior fracture strength and toughness were verified for PICN when comparing it to typical glass–ceramics with similar clinical indication (lithium disilicate, leucite, and feldspathic-based glass–ceramics). Kim et al. [50] also observed a decreased wear rate of the antagonist tooth in similar comparisons. In addition to these aspects, the previously reported advantages for resin-based materials in terms of the use of CAD/CAM would also be valid for this class of material (fast processing, reduced cost, low damage to grinding tools, accuracy of final restoration fit), as reported by Swain et al. [43] and Bottino et al. [47]. At the same time, similar disadvantages to resin-based materials may be reported, such as color instability and degradation when subjected to the clinical environment [40, 41].

In terms of adhesion, PICN requires hydrofluoric acid (HF) etching, followed by the application of primers based on MPS silanes (methacryloxypropyltrimethoxysilanes), as the surface treatment which is usually assumed for glass–ceramics. The literature shows adequate performance on bond strength using this approach [51]. Therefore, when considering the potential of intraoral repair, it would perform similarly to glass–ceramics, and in that, a disadvantage in relation to composites exists—the use of a toxic material (HF) under a complex and cautious protocol.

Looking at the clinical longevity/survival of PICN restorations, there are currently three reports which exist to the best of these authors' knowledge: Chirumamilla et al. [52] depicted a complication rate of 4% in 2 years follow-up (a retrospective study of 46 single crowns); Spitznagel et al. [53] observed a 95.6% and 97.4% 3-year survival rate, respectively, in evaluating 58 partial coverage restorations and 45 inlays, wherein fracture was the major complication type; lastly, Lu et al. [54] noticed a 97% survival rate in a follow-up of 3 years considering 47 endocrowns. Thus, taking into account the aforementioned statement for resin-based CAD–CAM materials, research and clinical evidence to support the predictability of using PICN in regard to longevity, failure pattern, and potential to esthetically mimic the characteristics of natural dentition with stability are still lacking, especially as veneer material.

8.2.3 Zirconia-Reinforced Lithium Silicate (ZLS)

Even though this kind of material is somewhat similar to the already-known lithium disilicate glass–ceramics, ZLS glass–ceramics can be considered as a new generation of ceramics, which allegedly combine glass–ceramic esthetic performance and improved mechanical properties due to the presence of metasilicate and zirconia crystals into the glass matrix [55–58]. They are indicated for veneer, posterior and anterior crowns, and implant-supported crowns, as well as for inlay and onlay restorations.

There are currently two different ZLS ceramic materials available for application in restorative dentistry, with both of them essentially being composed of two crystal phases embedded into a glassy matrix. One of the crystalline phases consists of submicrometric lithium metasilicate (Li_2SO_3) crystallites in a round and slightly elongated shape, while the other is a lithium orthophosphate (Li_3PO_4) in a round shape with nanometric size [21].

When compared to the conventional lithium disilicate ceramic (without zirconia reinforcement), ZLS glass–ceramics present a lower percentage of crystal phase content (40–50% in comparison to 70% of a conventional lithium disilicate glass–ceramic) [58, 59]. However, crystals within ZLS materials are smaller, and the glassy matrix is reinforced due to highly dispersed zirconium dioxide (~10% in weight), which is assumed to enhance the strength of the glassy phase [21, 58, 60].

It is important to highlight that the presence of the glassy matrix in their structures enables this class of ceramics (ZLS) to be etched by hydrofluoric acid, even with the presence of zirconium dioxide crystals (etchable material). This allows for the creation of micro-mechanical retention on the cementing surface and resin bond improvement [61].

However, to the best of these authors' knowledge, only one report of clinical performance exists; Saavedra et al. [62] published a case report with a 2-year follow-up showing promising results regarding esthetical potential in mimicking natural dentition characteristics. Thus, research and clinical findings to support the clinical predictability of using ZLS are still lacking. It is also important to consider that in vitro *studies* have been noticing similar performance of ZLS to the already-known lithium disilicate-based ceramics [21, 22, 63]. The performance of this lithium disilicate glass-ceramic was previously discussed in Chap. 9, and the literature supports survival rates of approximately 95% for single crowns for up to 10 years of follow-up [64–66]; thus, the use for manufacturing both crowns and veneers is well elucidated with predictability for success and high longevity for this material, and there is also no indication that ZLS would behave differently, even though it needs to be investigated more over time.

8.2.4 High Translucent Zirconia

High translucent zirconia consists of a third-generation yttrium-stabilized zirconia (YSZ) ceramic, whereby increasing the percentage of yttrium oxide stabilizer (>3 mol%, which was previously used) created a new kind of zirconia polycrystal material that presented up to 53% of cubic phase in its crystalline microstructure (in addition to the tetragonal phase, which composes the previous YSZ generations). Besides microstructural changes, the optical/esthetic properties were improved (translucency and light transmittance), and the mechanical properties were to some extent reduced by eliminating the toughening mechanism based on the t–m phase transformation [67, 68]. Manufacturers have been expanding typical clinical indications of YSZ with these new materials and pointing to its use as veneer, anterior and posterior crowns, as well as partial coverage restorations (inlays and onlays).

There is one case report published suggesting the use of zirconia veneers for anterior teeth as a potential alternative [69], where they successfully mimic the characteristic of natural dentition and presented results from 1 year of follow-up. Hence, as also already mentioned, research and long-term clinical results to support the clinical predictability of high translucent zirconia are still lacking, especially as veneers.

8.3 Adhesion

Proper bond strength is a must for the longevity of restorations, especially for inlays, onlays, and veneers. In these non-retentive restorations, the bonding between tooth and restorative material depends on the implemented adhesive strategy, since the type of preparation does not enable mechanical retention (very low friction effect). Furthermore, despite the laminate having high survival rates, its debonding still occurs clinically [70–73]. According to Morimoto et al. [73], one of the key principles for laminate survival is the bonding. This principle is not only important for the bond strength itself, but also because it reinforces the ceramic and restores strength in the tooth [74]. Thus, the type of surface treatment of the restorative material is imperative for the restoration's longevity.

According to Valandro et al. [75], ceramics can be classified based on the existence of topographical alterations of its surface by hydrofluoric acid (HF) etching. Thus, ceramics with high glass content in their composition, such as feldspar-, leucite-, and lithium disilicate-based ceramics, suffer surface changes as a result of the HF action, thereby resulting in micromechanical retention, and are therefore called acid sensitive. The surfaces of ceramics based on glass-infiltrated alumina or zirconia, densely sintered alumina, and yttria-tetragonal zirconia polycrystal (Y-TZP) do not change with HF etching, do not present micromechanical retention or undercuts thereof, and are referred to as acid resistant.

As a result, the most suitable surface treatment of each new material according to these precepts and classification will be discussed further below.

8.3.1 Resin-Based Materials and Polymer-Infiltrated Ceramic Network (PICN)

In relation to the PICNs, which present mixed ceramic characteristics and composite properties [48], according to the manufacturers, the bonding protocol is classified as a sensitive acid material, since they recommend 5% hydrofluoric acid etching for 60 s, followed by silane application. Scanning electron microscopy characterizations showed the specific microstructure of the surface of etched PICNs characterized by dissolution of the glass–ceramic network and the presence of a typical polymer-based honeycomb structure, including microporosities [76] and microchannels [77]. These topographical characteristics take place because a major leucite-based phase of feldspar origin is present in the ceramic matrix of the PICN [48]. Moreover, the bond is improved through the methoxy groups of silane-containing primer chemically bonding with both the SiO_2 and integrated polymer components of the PICN, polymerizing with the methacrylate groups of the resin composite available in the matrix [78].

Some in vitro studies have investigated alternative ceramic surface treatments. According to Silva et al. [79], surface grinding followed by universal adhesive application promoted higher shear bond strength than the surface treatment recommended by the manufacturer after 48 h and after 6 months of aging. They stated that the alternative treatment appears to be the best method for repairing hybrid ceramics. These authors reported that this treatment creates retentions in the ceramic surface (increase in roughness) and that the interpenetration of the adhesive is optimized in these retentions to form a siloxane bond between the fillers and the polymer matrix. However, the tested surface treatments also did not lead to bond stability after 6 months aging in water, demonstrating that investigations regarding new conditioning methods to promote long-lasting stable adhesion for PICN materials are still necessary.

Another alternative surface treatment that has being explored is the use a self-etching glass–ceramic primer, which results in comparable shear bond strength to the treatment recommended by the manufacturer [77]. According to El-Damanhoury and Gaintantzopoulou [77], the silane system in self-etching glass–ceramic primer (Monobond Etch & Prime—Ivoclar Vivadent—based on trimethoxypropyl methacrylate) leaves a chemically bonded thin layer of silane that remains after a thorough washing with water and drying of the treated surface. Although the action mechanism of self-etching glass-ceramic primer is not very clear, these authors observed (via energy dispersive X-ray spectroscopy elemental analysis) the presence of some fluorine (F) residue on the PICN surface after pretreatment with that primer. Thus, they assume that the presence of F ion residue can be attributed to the material reacting with the glassy part, which could have trapped F ions within the silane layer left on the surface of the PICN restoration.

Regarding the new resin-based materials for CAD–CAM technology, these blocks consist of nanoceramic particles embedded in a highly cured resin matrix [80], and the fillers are classically incorporated by mixing them in a matrix composed of dimethacrylates, such as urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA), which are polymerized under high temperature (>100 °C) [76]. Hence, this material is neither a composite nor a ceramic, but rather a mixture of both [81]. The manufacturer characterizes Lava Ultimate as a "Resin Nano Ceramic" in their technical product profile and recommends air abrasion with aluminum oxide particles (50 μm in size or lower), followed by the application of a silane-based primer as surface treatment. According to Demirtag and Culhaoglu [82], alternative surface treatments such as femtosecond laser irradiation have been studied, and the action mechanism is based on laser irradiation to release filler silica particles as a result of the removal of the resin structure by ablation, increasing the silane effectiveness. Moreover, this type of surface treatment seems to produce homogeneous roughness without causing structural changes or thermal damage on the material surface by avoiding heat transfer on the surface using ultrashort laser pulses [83]. Additionally, in a recent systematic review and meta-analysis, García-Sanz et al. [84] stated that despite the high heterogeneity noticed in included studies, lasers should be recommended as an alternative technique for treating restorative surfaces prior to bonding composites or resin cements as they led to higher bond strengths compared to non-treated surfaces; however, there were no significant differences in comparison with air–particle abrasion methods.

Despite this, according to a review article, the most common surface treatments reported for this kind of material are aluminum oxide air abrasion, silane treatment, and hydrofluoric acid etching [80]. As reported in this review, self-adhesive cements achieve lower bond strengths in comparison to etch-and-rinse systems, and thermocycling has a greater impact on bonding behavior than water storage. Thus, they conclude that the 50 μm alumina air–particle abrasion was the most effective method to roughen the surface, independently of the indirect composite used, and additional silane treatment should be applied to enhance the resin bond to laboratory-processed composites. However, Elsaka [78] showed that despite air abrasion having presented higher roughness values than hydrofluoric acid with and without silane, the bond strength was statistically similar for the two groups. According to this author, the stress concentration at the indirect restorative material/luting agent interface could be increased by airborne-particle abrasion, which creates sharp angles that could hinder complete wetting and produce voids at the interface [85]. Consequently, higher surface roughness will not ensure higher bond strength [86], and the interaction between the achieved topography, roughness, surface wetting, and absence of voids by adequate viscosity of the bonding system seems fundamental to the performance of these systems.

The prolonged air-abrasion effect on the bond durability of dual-cure adhesive resin cement to PICN and resin-based materials has been explored. According to Tekçe et al. [87], the longer the air-abrasion time, the rougher the achieved surface. However, micro-tensile strength values decrease with prolonged air abrasion (over 30 s). As they reported, 60 s of air abrasion disturbs the initial micro-tensile strength values and the adhesion stability of CAD/CAM restoratives to dual-cure adhesive resin cement. Moreover, the bond strength values in such a scenario also significantly decreased after 5000 thermocycles. Therefore, although a rough surface is required to obtain ideal bond strength, excessive air abrasion produces excessive roughness and proved to be deleterious in such an outcome. Hence, it is clinically beneficial to not exceed 30 s of air abrasion for both PICN and resin-based materials (according to that study).

Furthermore, still comparing the performance of resin-based material to PICN regarding bond strength and stability, it is observed that the bond strength for the PICN with dual-curing self-adhesive resin cement system has been statistically higher than that of the resin-based material used with the same cement [78]. This finding can be attributed to the different composition and microstructure between these materials. As reported by Elsaka et al. [78], the PICN microstructure has a significant influence on the mechanical properties such as increased chemical stability, reduced monomer absorption, and greater biocompatibility, different from resin based-materials. These findings corroborate those of Demirtag and Culhaoglu [82], who explored the performance of both materials submitted to different surface treatments (hydrofluoric acid and air abrasion).

8.3.2 Zirconia-Reinforced Lithium Silicate (ZLS)

ZLS microstructure combines the glass–ceramic of metasilicate and zirconia crystals (from 8 to 12% zirconia) embedded into the glass matrix. As a surface treatment, the recommendation is etching with 5% hydrofluoric acid for 20 s, followed by rinsing and silane application for 60 s. Its ceramic matrix is predominantly glass; therefore, this material is considered as acid sensitive and susceptible to hydrofluoric acid etching, being different from polycrystalline ceramics [56, 57, 75, 88]. When a glass–ceramic surface is exposed to HF etching, a selective removal of its vitreous matrix occurs, exposing the crystalline structure [89] and resulting in topography for bond improvements via micromechanical retentions (mechanical bond), thereby increasing the contact area and wettability of the cement [90].

When different acid etching times were considered, it was concluded that etching for 20 or 40 s was equally effective in producing stable resin bonding to ZLS ceramic [91]; however, according to the authors, it is suggested that the usage time should be decreased whenever possible due to the potential risk of using HF (high toxicity of such material), and in accordance with Sato et al. [91], the time recommended by the manufacturer could be reduced without compromising bond performance. Furthermore, the same authors reported that silica coating (air abrasion for 25 s with 2.5 bar pressure at 15 mm distance) was not effective in achieving long-lasting bond strength. According to Kern and Thompson [92], this is attributable to the fact that the irregularities created by the air abrasion are devoid of microretention. Ataol and Ergun [93] also corroborate that the surface treatment of CAD/CAM ZLS by HF etching is more effective than alumina particle air abrasion and Er,Cr:YSGG laser irradiation.

Moreover, according to Monteiro et al. [56], who evaluated the effect of etching time and hydrofluoric acid (HF) concentration on the fatigue failure load and surface characteristics of ZLS glass ceramic cemented to a dentin-analogue material, when the etching time increases, the interaction region increases as well, and the interaction involves the whole surface. They reported that the defects introduced at shorter etching times appear to be in a dimension and format that make it difficult for the cement to fill in the irregularities, making bonding vulnerable to failure. Conforming with these authors, when the etching duration is longer, the surface becomes more homogeneous due to extensive loss of the glassy matrix and pullout of lithium silicate/zirconia grains, facilitating penetration of the resin cement that leads to optimized bonding, finally improving fatigue performance. Thus, they concluded that the pretreatment with 10% HF acid etching for 60 s up to 90 s, followed by an application of an adhesive that contains silane and MDP (methacryloyloxydecyl-dihydrogen-phosphate), promotes the best fatigue performance of ZLS restorations. Additionally, etching with 5% HF acid, independent of time (30, 60, or 90 s), does not change the fatigue behavior. From these observations, it is clinically relevant to perform ZLS surface treatment which is able to optimize the resin bond strength without damaging the fatigue behavior under cyclic loading for the ZLS restorations (the glass–ceramic clinically fails from the defects/flaw located at resin cement–ceramic interface) [56, 57].

8.3.3 High Translucent Zirconia

As this material has a dense polycrystalline nature, it has to be considered an acid-resistant ceramic, and consequently, the surface treatment should be airborne particle abrasion at 0.3–0.4 MPa, followed by primer application (manufacturer's recommendation). At the same time, many studies have evaluated different protocols to improve the resin bond strength to zirconia polycrystal materials, such as air–particle abrasion with aluminum oxide particles [94], tribochemical silica coating and subsequent use of a silane agent [95, 96], application of resin cement containing MDP monomer [97], plasma processing [98], selective infiltration-etching method [99], glaze-on technique [100], and heated silane [101].

Nowadays, the concept of achieving high adhesion between restorative materials and tooth substrate and its importance on the longevity and reinforcement of such restorations is undeniable [56, 57, 102–106]. Resin bonding supports ceramic restorations, and it is necessary for optimizing the performance of onlays, laminate veneers, and metal-free fixed dental prostheses. Thus, to achieve high and long-lasting resin bonding to zirconia, Blatz et al. [107] recommend a three-step approach, which consists of air–particle abrasion at the bonding surface with aluminum oxide, applying special zirconia primer, and finally using dual-cure or self-cure composite resin cement. Based on the results of a systematic review, increased adhesion can be expected after physicochemical conditioning of zirconia and after the use of MDP-based resin cements, which tend to present higher results than those of other cement types when tested using macro- and micro-tensile tests [108].

Phosphate monomers (such as MDP) are components of some resin cements, primers, and adhesives and act as a bifunctional molecule in which one end connects with the ceramic's metal oxides (such as aluminum and zirconium) while the other end copolymerizes with the resin cement matrix [94]. Furthermore, it has been found that MDP monomers promote a water-resistant chemical bond to densely sintered zirconia ceramics [109]. A meta-analysis considering bonding effectiveness to zirconia ceramics also showed that the combination of mechanical and chemical surface pretreatments contributed to the durability of the bond of composite cements to zirconia ceramics; however, the cement choice appeared less critical as long as a composite cement was used for adhesive luting of zirconia ceramics [110].

It also has to be emphasized that there is substantial in vitro data supporting the tribochemical silica-coating treatment to bond conventional 3Y-TZP ceramics leading to similar bond results to the one observed with air abrasion of aluminum oxide followed by MDP-based primers [85, 94, 96, 110]. Thus, it seems that the main guideline is to execute a surface pretreatment to enhance micromechanical interlocking (air abrasion with aluminum oxide or silica-coated aluminum oxide particles), followed by the specific primer to enhance chemical bonding (MDP-based primer or silane, respectively) between Y-TZP ceramics and resin cement [108, 110–113]. Even though these observations have not yet inspected translucent zirconia to the best of authors' knowledge, we expect that the adhesion process and findings will be similar to already-known zirconia polycrystals.

Another current undeniable presupposition is that enhanced adhesion between restorative material and base substrate (tooth or post and core) plays an important role for fatigue improvements in zirconia-based restorations [102–104, 106, 112]. Therefore, as resin cement presents superior properties in all considered aspects, the idea of not using them seems unfounded. So, even for polycrystalline zirconia materials, it is recommended to follow strict cementing protocols to obtain maximum mechanical performance under cyclic loading, minimizing the fatigue effect on restorative setup and any potential subcritical crack growth mechanism.

Despite all the aforementioned presuppositions, it is important to emphasize that recent studies evaluating surface treatments of highly translucent zirconia are still scarce (they mainly consider older generations of zirconia ceramics), and according to Inokoshi et al. [114], air abrasion with aluminum oxide particles did not significantly increase the surface roughness of some highly translucent Y-PSZ zirconia ceramics (except for Katana UTML, Kuraray Noritake), which may point to different performances of distinct translucent zirconia with different compositions and/or manufacturers. Furthermore, it depicted microstructural alterations throughout the air-abrasion protocol in some ceramic brands (e.g., phase transformation and residual stress introduction). Thus, more in vitro studies are extremely encouraged to clarify this subject, as well as long-term clinical studies.

8.4 Scanning Electron Microscopy Observations of Resin-Based Materials, PICN, ZLS, and Translucent Zirconia

In this section, we describe the topography depicted on each respective class of material inspected under scanning electron microscopy (FEI Inspect F50; FEI) before and after surface treatments from the perspective of adhesion enhancement, taking into consideration each manufacturer's guidelines. To this aim, we selected specific materials that were directly linked to each class of new material discussed in this chapter. The materials used are shown in Table 8.1 and Fig. 8.1, and its topography is in Fig. 8.2.

In the resin-based material, a smooth and homogenous surface with tiny micropores is observed (Fig. 8.2a, e). Under higher magnifications, it is possible to observe that this material has large clusters of filler particles that are roughly a micron in size and are made up of much smaller discrete particles. However, the specimen surface treated by air abrasion shows well-defined micro-sized elevated and depressed areas with crevices and pits, which possibly resulted from the high impact of blasting particles on the material surface (Fig. 8.2i, m). The topographical pattern can also be observed in previously published literature [76, 115].

A surface with irregular micropores is observed in the PICN material, with two continuous interpenetrating networks, namely, the polymer phase (dark gray) and the ceramic phase (light gray), which are evident (Fig. 8.2b, f). In relation to PICN etched by the hydrofluoric acid, it shows a lattice of exposed polymer, since the ceramic phase was partially dissolved and there are many micropores (dark gray), which is suitable for micromechanical bonding (Fig. 8.2j, n). The topographical pattern can also be observed in previously published literature [76].

The untreated ceramic block of zirconia-reinforced lithium silicate shows a smooth surface pattern, presenting scratches from the cut procedure (Fig. 8.2c, g). However, the etched ceramic surface shows strong surface alterations (increase in roughness and surface area) due to the selective HF etching, promoting dissolution of the glassy phase and traces of lithium crystals being removed, revealing the lithium silicate/zirconia grains (Fig. 8.2k, o). It is possible to observe rod-like crystals after etching in higher magnifications. This topographical pattern can also be seen in previously published literature [118].

Ultra-translucent multilayered zirconia presents a polycrystalline-grained structure having no glassy phase (Fig. 8.2d, h) and grain sizes that can reach almost 5 μm

Table 8.1 Materials description

Material	Manufacturer	Clinical indication[a]	Composition[a]	Flexural strength (MPa)	Vickers hardness (VH)	Elastic modulus (GPa)	Poisson's ratio	Fracture toughness KIc (MPa m$^{1/2}$)
Nano-particulate pre-polymerized resin composite (RC)	Lava Ultimate/3M ESPE	Veneers; inlays; onlays	Silica nanomers (20 nm), zirconia nanomers (4–11 nm), nanocluster particles (0.6–10 nm), silane coupling agent, and resin matrix of Bis-GMA, Bis-EMA, UDMA, and TEGDMA	248.4[b]	96 ± 6[c]	16.0[b]	0.36[d]	±2.0[a]
Polymer-infiltrated reinforced-glass network (PICN)	Enamic/VITA Zahnfabrik	Veneers; inlays; onlays; anterior and posterior crowns	Ceramic: silicon dioxide, 58–63%; aluminum oxide, 20–23%; sodium oxide, 9–11%; potassium oxide, 4–6%; boron trioxide, 0.5–2%; zirconia and calcium oxide. Polymer part (25%): UDMA and TEGDMA	202.1[b]	200 ± 5[c]	21.5[b]	0.23[e]	0.86 ± 0.27[f]
Pre-sintered lithium silicate/ phosphate (LSP) glass–ceramic (ZLS)	Suprinity/VITA Zahnfabrik	Veneers; inlays; onlays; anterior and posterior crowns	Zirconia-reinforced lithium silicate ceramic, zirconium oxide, 8–12%; silicon dioxide, 56–64%; lithium oxide, 15–21%; other oxides >10%	230[g]	632 ± 17[c]	±106[d]	0.23[f]	1.25 ± 0.79[f]
Ultra-translucent multilayered zirconia (UTML)	Katana UTML/ Kuraray Noritake	Anterior crowns; veneers; inlays; onlays and posterior single crowns	Zirconium oxide, yttrium oxide, and pigments	500-600[h]	[i]	200–210[h]	[i]	2.2–2.7[h]

[a]Clinical indication as given by the manufacturer
[b]Lawson et al. [115]
[c]Ludovichetti et al. [117]
[d]Belli et al. [21]
[e]Della Bona et al. [48]
[f]Ramos et al. [118]
[g]Furtado de Mendonça [116]
[h]Zhang and Lawn [68]
[i]Not found in the literature

Fig. 8.1 On the left, examples of CAD/CAM block trademarks: base-resin material (Lava Ultimate), polymer-infiltrated ceramic network (Vita Enamic), and zirconia-reinforced lithium silicate (Vita Suprinity). On the right, an example of CAD/CAM disc of ultra-translucent multilayered zirconia (Katana Zirconia)

in length [119]. However, the abraded ceramic surface shows an increase in roughness and surface area due to micro-sized elevated and depressed areas with crevices and pits, owing to the high impact of the particles on the ceramic surface (Fig. 8.2l, p). These topographical changes have also been reported in previously published literature [119].

8.5 Wear Behavior

Ceramic materials have been widely used in restorative dentistry; however, there are concerns regarding their clinical performance due to their brittle nature that may lead to catastrophic failure of the restorations and their abrasive character when sliding against antagonist natural teeth, which may result in excessive enamel wear [120, 121]. An atypical loss of dental material may have effects on the chewing ability and dental sensitivity and at the esthetic level [122]. However, the multifactorial nature of wear [123] makes it important to understand the wear potential of the materials based on the composition and microstructural aspects [21] that will determine their properties [124].

According to Ludovichetti et al. [117], who evaluated the wear resistance and abrasiveness of CAD-CAM materials in a two-body wear test setup together with bovine enamel, nanofilled composite resin and polymer-infiltrated ceramic network were the most antagonist-friendly materials when sliding against enamel. They also reported that zirconia only caused damage to enamel substrate, whereas the lithium disilicate and the zirconia-reinforced lithium silicate caused high wear rates of the antagonist (considering both enamel and all previous restorative materials, i.e., nanofilled composite resin, polymer-infiltrated ceramic network, lithium disilicate, zirconia-reinforced lithium silicate, and zirconia). The same authors stated that hardness should be considered in the selection of materials, especially in patients with bruxism (the higher the hardness, the higher the wear rate). Furthermore, Ludovichetti et al. [117] asserted that roughness and the friction coefficient of some materials might change during the wear process. Despite that, Pereira et al. [125]

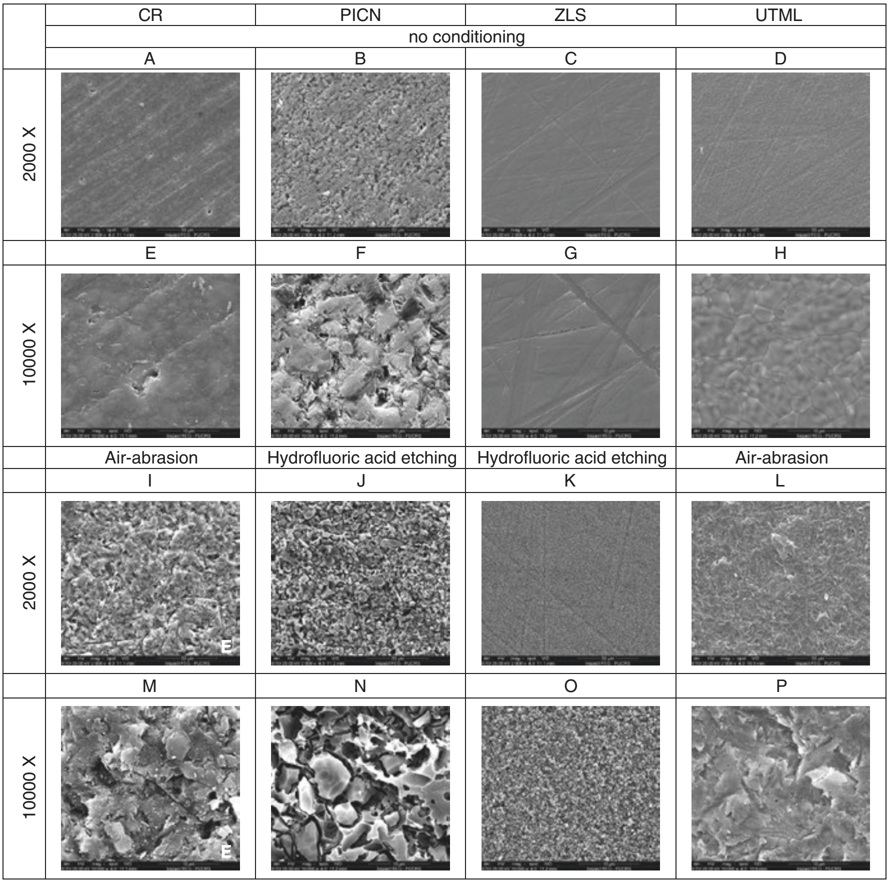

Fig. 8.2 Micrographic images depicting the surface topography prior to (**a**–**h**) and after (**i**–**p**) specific surface treatments to enhance adhesion following manufacturer's guidelines. *CR* (composite resin)—air abrasion with 45 μm aluminum oxide powders, under pressure of 2.8 bars at a distance of 1 cm, by motion for 10 s, *PICN* (polymer-infiltrated reinforced-glass network)—hydrofluoric acid etching 5% (IPS ceramic etching) for 60 s, *ZLS* (zirconia-reinforced lithium silicate)—hydrofluoric acid etching 5% (IPS ceramic etching) for 20 s, *UTML* (ultra-translucent multi-layered zirconia)—air abrasion with 45 μm with aluminum oxide powders (same aforementioned parameters)

using a three-body wear test showed adequate performance of zirconia-based substrates against enamel and composite resin material.

However, Santos et al. [122] compared the wear performance of a polymer-infiltrated ceramic (PICN), zirconia, leucite, and veneered zirconia tested against natural teeth. They observed that zirconia presented the most suitable tribological behavior, since it led to the lowest wear on both occlusal surfaces, while PICN was the prosthetic material that presented the highest wear rate. Regarding the cusp wear, the highest values were found for both leucite and veneered zirconia.

These authors stated that no direct relation could be established between wettability, initial roughness, and hardness of the prosthetic materials with the wear of the tribological systems, while microstructure and toughness revealed to be critical parameters.

These results corroborate the systematic review article published by Hmaidouch and Weigl [126], who addressed some of the material factors related to the wear of opposing enamel and ceramic. They stated that scientific studies have not demonstrated a strong correlation between the hardness of ceramic and the wear rate of human enamel. Thus, the wear process appears to be more closely related to the ceramic microstructure, the roughness of contacting surfaces, and environmental influences (food bolus and pH of the medium, among others) [126, 127]. Furthermore, the main recommendation was to guarantee perfectly polished surfaces of all restorations after any occlusal adjustments [126], strongly emphasizing that maintaining a smooth ceramic surface during clinical use is key to avoid microcracking initiation or progression and for minimizing the abrasion of the opposing teeth.

It is additionally important to remember that irrespective of epidemiological concerns or even etiological factors, tooth wear at an individual level may become severe, and a restorative treatment needs to be considered in many clinical situations because severe tooth wear may result in loss of vertical dimension of occlusion, tooth sensitivity, decreased oral health related to the quality of life, and esthetic complaints [128]. In those cases, selection of the restorative strategy should target evidence-based treatment protocols [129] and be “additive” rather than “subtractive” wherever possible, as the latter involves removing more tooth tissue. In order to protect tooth structure and the pulp, minimum-intervention approaches involving direct, indirect, or hybrid techniques should be favored over approaches comprising very invasive, traditional indirect restorations, which require extensive preparations that can sacrifice sound tooth tissue [130].

8.6 Final Considerations

- Glass–ceramic and porcelain laminate veneers have high survival rates, being that the main types of failures are fracture/chipping, debonding, secondary caries, severe marginal discoloration, and endodontic problems [73].
- One of the main factors affecting the fracture and fatigue behavior of ceramic crowns is the quality of their bonding interfaces, since their bulk fracture originates from the intaglio surface of the restorations [108, 110, 131]. Hence, the pre-cementing treatments of tooth and ceramic play a decisive role for the long-term clinical success of all-ceramic restorations [67].
- The best surface treatment for bond improvements of the polymer-infiltrated ceramic network (PICN) and composite resin-based materials (CR) is hydrofluoric acid etching and alumina particle air abrasion, respectively [76].
- Regarding the new glass–ceramic materials such as zirconia-reinforced lithium silicate (ZLS), hydrofluoric acid etching and silane application are recommended

as the surface treatment, which promotes more stable and durable bond strength with the resin cements [91].

– In terms of optimum adhesion, polycrystalline ceramics should be treated with tribochemical silica-coating and the use of MDP-based primer application [110].
– Studies show that the internal surfaces of the ceramic restorations are the origin of mechanical failures (cracks and fractures) [68]; therefore, the sudden increase of roughness owing to aggressive procedures on the internal surface of the restorations might increase the risk of failure of the restorations [132].
– In order to avoid microcracking initiation/propagation and to minimize the abrasion of the opposing teeth, polishing the surfaces of all restorations after any occlusal adjustments is imperative [126].

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The Artificial Intelligence-Based 3D Smile Design: REBEL

9

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When it comes to maximum aesthetic results with minimally invasive approaches, porcelain laminate veneers have become the aesthetic alternative of choice [1, 2]. Among indirect techniques, porcelain laminate veneers represent a well-documented, effective and predictable treatment option [3–8].

An indirect technique may be considered the first treatment choice when an adequate amount of residual sound tissue exists. Achieving optimal and predictable results with the use of veneers cannot be taken for granted [9, 10]. Success comes from correct planning and accuracy in performing every single step of the treatment (Fig. 9.1).

Smiles can be transformed painlessly, conservatively and quickly with dramatic, long-lasting results with the successful use of the porcelain laminate veneers [11, 12].

Porcelain veneers are now the restorative choice for aesthetics in numerous clinical circumstances that would have resulted in the use of full crowns in the past. Tissue response is excellent, and the finished surface is very similar to the natural tooth. Veneers exhibit natural fluorescence and absorb, reflect and transmit light exactly as does the natural tooth structure. Patients are highly enthusiastic about these restorations that represent a conservative treatment that enhances patient self-image.

Innovative preparation designs for porcelain laminate veneers are much less invasive than conventional complete-coverage crown preparations. It has been

Fig. 9.1 A well-designed and treatment-planned case always comes out successful

quantified, with a gravimetric analysis, the amount of tooth structure removed during these preparations: Porcelain laminate veneers required approximately one-quarter to one-half the amount of tooth reduction of conventional complete coverage crowns [13–15].

And this will be even less if we can create an additive approach on the new smile design and make the preparation of the natural teeth through the aesthetic pre-evaluative temporaries (APT) [16, 17].

Several porcelain materials can be used for the fabrication of veneers, and they can be classified into five groups: castable glass–ceramic; heat-pressed ceramic; computer-aided manufacturing (CAD/CAM) processed factory produced ingots; feldspathic porcelain baked in the traditional water-slurry method; and feldspathic porcelain over foil matrix with refractory die technique. Each system has its own advantages and disadvantages (Fig. 9.2).

The finalization was obtained by means of state-of-the-art adhesive techniques and ceramic laminate veneers. The correct use of modern materials, in combination with rigorous adhesive procedures [18–22], allows for a minimally invasive and highly aesthetic treatment, with adequate function and a perfect integration that is in harmony with the patient's face [23, 24].

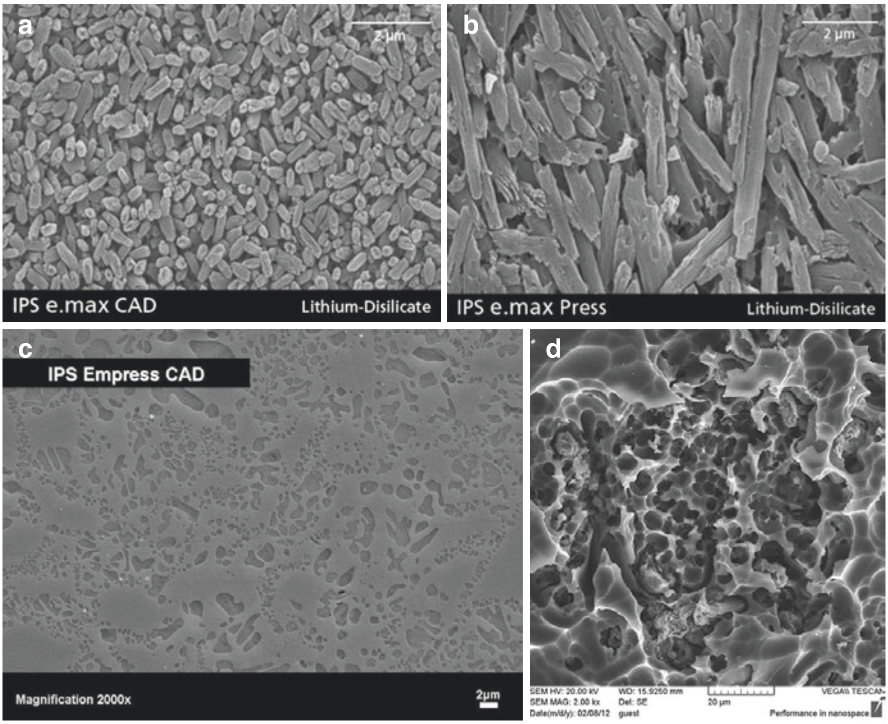

Fig. 9.2 There are differences between the types, properties, microstructures and handling of porcelain materials

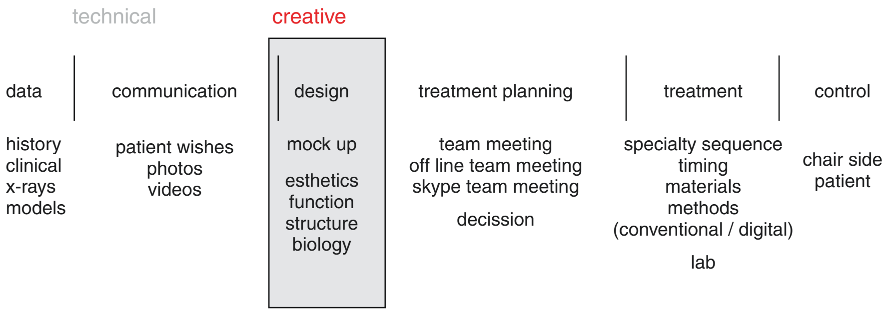

Fig. 9.3 The most creative part of the workflow is the design part. This is the heart of any aesthetic treatment that will differentiate a more committed dentist from an average one. The final aesthetic smile design and treatment planning should as well be based on this mock-up, that should fulfil the expectations of the patient

9.1 The Workflow

Regardless of the complexity of any dental procedure, there should be a workflow of which either the dentist or the whole team need to follow and work together. Basically a workflow for an aesthetic case starts with the collection of the data, history of the patient, clinical findings, making X-rays, models, photos and maybe videos. Then one of the most important parts of the whole journey is to start communicating with the patient regarding their expectations from this aesthetic treatment.

The treatment planning then should base on final expectations of the patient. And the treatment should be sequenced and executed accordingly.

The most **creative** part of the workflow is the **design** part; however, at this stage, verbal communication will never be enough. Any aesthetic procedure is very subjective, and without materializing the aesthetic smile design, it will not be possible for the dentist to explain what he/she would want to deliver to the patient at the end of the treatment.

Therefore, the final design should somehow be created even before the treatment plan is done and shared with the patient (Fig. 9.3).

9.2 Visualizing the Final Result at the Beginning/The Mock-Up

Visualization of the new smile design will create a great impact on the patients understanding about the rest of the treatment. It is much more powerful than just verbally explaining what will be done. Prior to initiating any treatment, it is necessary to visualize the desired outcomes. It then becomes possible to formulate the steps required to achieve this result. In restorative dentistry, the mock-up is a diagnostic technique that allows for the intra-oral try-in of a prosthetic rehabilitation [16, 25]. Mock-ups facilitate significant improvement in communication with patients by showing them the potential final outcome of the treatment and allowing an easy comparison of the pre- and post-operative situations and permit the clinician to check the functional aspects [25].

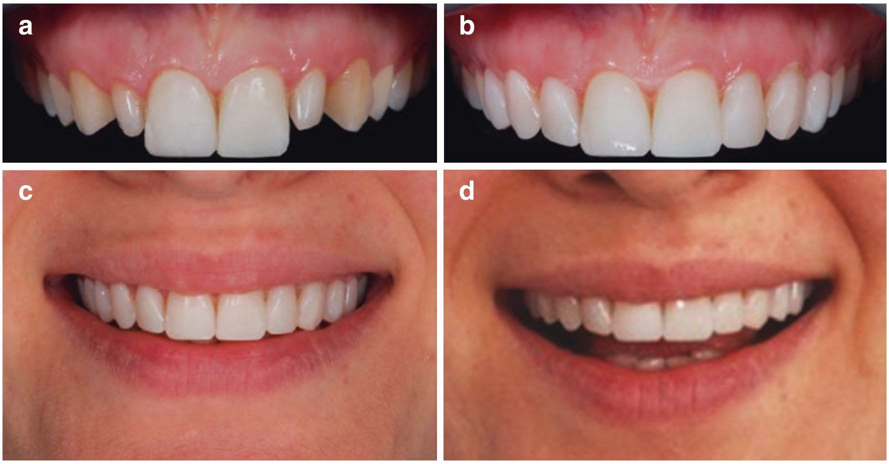

Fig. 9.4 Either a direct mock-up or a wax-up should be placed into the patient's mouth in order to visualize the final design before even the case is treatment planned. (**a**) Direct mock-up should first start by placing the composite over the two centrals, defining the incisal edge position, (**b**) and gradually continued over the laterals, canines and premolars, (**c**) and evaluated with the lips and (**d**) the face

There are different ways to make the mock-up. It can be directly created in the patients' mouth or indirectly either through a wax-up or by digital ways.

The direct mock-up is the fastest way of starting the communication with the patient. A composite can be placed on the teeth with free hand carving without the need of any bonding material over the existing teeth. Ideally, the first step to execute the direct mock-up should be to start morphing the composite on the two maxillary centrals. Technically, it will be the ideal if the final incisal edge position of the centrals is decided just after the composites on two centrals are placed, before further adding the composites on the remaining teeth (Fig. 9.4a–d).

This step is extremely important, since the design of a smile and the following treatment planning would purely be based on the incisal edge location of the two maxillary central incisors. And this should be done by sitting the patient upright on the dental chair and when the dentist and the patient are standing face to face to each other. There will be a lot of factors that will be influential on the decision making of this procedure, such as the relationship of the centrals primarily to the upper lip line, then the lower lip line, their proportions, age and sex of the patient. Upon this decision, then the mock-up can be done on the rest of the teeth.

9.3 The Aesthetic Pre-evaluative Temporaries (APT)

Once this preliminary design on the direct mock-up is approved by the dentist and the patient, the case can now be sent to the laboratory, for a wax-up. When the wax-up is sent back to the dental office, a silicone impression is made from the wax-up. This silicone impression is filled with a flowable resin and placed in the mouth before the patient is anaesthetized, and the teeth are prepped. This is named as the aesthetic pre-evaluative temporaries (APT) (Fig. 9.5a–d).

Fig. 9.5 (**a**, **b**) Initial situation. (**c**) Over the natural teeth, a direct mock-up is created. (**d**) This mock-up design is converted to a delicate wax-up in the laboratory. In order to copy this wax-up, a silicone impression is made through the wax-up model and transferred into the mouth with the help of a bis-acryl resin provisional material, i.e. Luxatemp. This is named as the APT (aesthetic pre-evaluative temporaries) by the author

The dentist can benefit from the application of the APT at this stage in two extremely important ways. The first benefit is to be able to visualize the final aesthetic outcome, check the function and phonetics and get the approval of the patient. This will be very realistic, since the APT is being tested in 3D in the patient's mouth and the lips have not been anaesthetized yet.

9.4 Tooth Preparation Through the APT

The second amazing benefit is the tooth preparation technique. Tooth preparation is an important step because it tries to consider obtaining an adequate thickness of ceramic and tooth structure wear. This can be done with almost a 100% precision with the prep through the aesthetic pre-evaluative temporary (APT) technique, which takes the final volume of the restoration into consideration. Using the depth cutter through the very solid reference, which will be the facial contour of the APT, will guide the dentist to prepare the exact amount of teeth, being thoroughly minimally invasive and yet creating the maximum amount of volume for the porcelain laminate veneer to be fabricated [16].

The tooth structure will undergo only the minimal necessary preparation or even no preparation in certain areas using depth cutter burs through the APT restoration according to the pre-established goals. Use of the APT technique, step by step, may guide the clinician from the time of diagnosis, communication and preparation through the final result, making the treatment predictable (Fig. 9.6a, b).

9.5 Finalizing the Case

After the tooth preparation, impression making and the provisionalization [16], the case will be sent to the laboratory, and the porcelain laminate veneers will be produced. These PLVs will then be bonded on the patient's teeth [26].

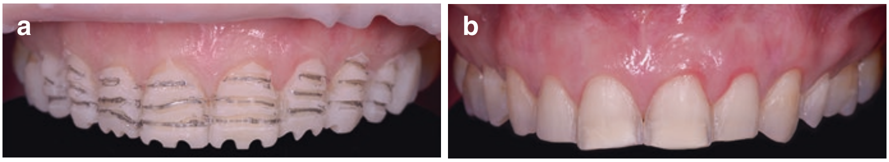

Fig. 9.6 Preparation through the APT. During the beginning of the preparation, since the APT will be left on the tooth as a very solid reference for the depth cutter, the dentist will always be very precise with his/her preparations. (**a**) The depth cutter will be used to create the horizontal depths, and a fissure diamond bur will be used for the vertical incisal reduction. The groves are painted with a pencil in order facilitate the final preparation. (**b**) Then the remaining parts of the APT are removed, and the tooth surfaces are prepared until the pencil lines disappear, and the margins are refined. The final minimally invasive preparations

Fig. 9.7 (**a**, **b**) Even though a new smile design is created by using all the necessary aesthetic rules and looks very nice in an intra-orally taken photo, its harmony with the facial appearance of the patient may not be the ideal or may not arouse the pleasant feelings that the patient should have had experienced at the end of the treatment, and the patient can have a feeling like the smile does not belong to her

9.6 Morphopsychology

Aesthetics had become one of the most important outcomes of daily dental treatments. Regardless of the complexity of the cases, the patients are seeking for the better-looking smiles.

However, often, the final aesthetic results may fail to meet the patient's expectations due to disharmony between the smile design and the patient's identity [16].

The patient's demands and the level of information has driven the profession to a certain questioning respecting the customization of the new smile design, according to the individual psychological characteristics of each patient, that if ignored, may lead to aesthetic dissatisfaction, even though all the aesthetic principles and rules which tend to establish standards were incorporated.

Even though the new created smile design may look picture perfect when we take pictures of it with the lips retracted, the patient may feel that the restored teeth do not really "belong" to him or her [27] (Fig. 9.7a, b). Without the proper knowledge, the origin of this disharmony can be difficult to identify. In earlier times, the idea of a smile design was to align teeth in a perfect manner, keep them as bright as possible and wish for a rock-solid structure. Today's world requires a novel approach that places the patient's needs in the centre. Sometimes, patients may recognize what is lacking in their smile, but in most cases, they could not verbalize their needs simply because they do not know how to. Also, there are certain restrictions and technical limitations from which the dentists suffer such as not being able to visualize the final result in detail before starting the procedure. Sometimes, everything looks just fine and functional, but it just does not "feel right" [28].

9.7 Patient's Personal Identity

Incorporating into the smile design elements that visually translate each patient's personal identity may help the dentists to do restorations that correspond not only to the aesthetic but also to the psychological features of the created image which affects the emotions, behaviour and confidence of the patient. On the other hand, these factors affect the way the patients react to the definite treatment positively.

At the end of the treatments, the patients need to feel happy. If one can trigger these senses with a new smile design, then both the dentist and the patient will be feeling very different than receiving a standard nicely aligned teeth.

The growth of personalization in all areas is being rightly welcomed as a liberation from more than a century of globalized repetition and imitation, in other words brand images that look almost exactly like each other. What everyone really wants is diversity and differentiation, something that has often been easier to achieve for smaller, individual concerns who invest in tailor-made solutions to help them stand out in the crowd. Senses like touching, smelling and tasting are all individual personalized feelings that every other person experiences in a different way (Fig. 9.8).

Fig. 9.8 Senses like touching, smelling, tasting and hearing are all individual personalized feelings that differ from one person to another

9.8 The Fifth Dimension of the Smile

The smile design in dentistry so far till the recent years has been based on four dimensions: biology, structure, function and aesthetics. And the aesthetic parameters were basically dependent on the age, gender and sex.

The reality is that in neither of these parameters personality of the patient was considered. However, perfect smile design should reflect the patient's personality, adding the fifth dimension of a smile!

The aim of this chapter is to reflect the results of our researches that we have been working on in the past 11 years evaluating the new smile designs that we had been working on which created amazing differences in the acceptance of our patients, just because their personalities are reflected into it by means of applying the visual language into the designs. It is about the fifth dimension of a smile which also incorporates the personality and the emotional needs of a patient which is quite different than the traditional approaches. Translation of these feelings and reflecting the personality into the new smile design can happen by using the visual language.

9.9 Archetypical Symbols

It goes all the way back to Carl Jung (1875–1961), who was a Swiss psychiatrist and psychotherapist who founded analytical psychology, and his widely accepted studies about the "symbols"—that talks the same language—for most of the people around the world, regardless of their geographic locations, cultures, religions, lifestyles, etc. [29]. In the last years of Jung's life, he observed that certain symbols and images have been used in all cultures with the same meaning. That is about some universal symbols in all cultures, from all times, regardless of their backgrounds, ethnical belongings, religions, geographic locations and cultures, always used with the same meaning.

Vertical lines represent strength and power, horizontal lines represent stability, inclined lines represent dynamism, and rounded lines represent suavity and delicacy (Fig. 9.9a–d).

9.10 Visual Language

Each type of line or shape has a specific emotional meaning.

Lines represent the most basic elements of visual language. **Horizontal** lines, because they conform to gravity, express stability, passivity and calmness, while **vertical** lines represent the movement of the point against gravity, expressing strength and power, just as **inclined** lines arouse the sensation of instability, tendency to movement and dynamism. **Curved** lines are associated with delicacy, sensuality and feminine gender [30].

The combination of lines generates the most basic forms, transferring to them their own expressions. Thus, the vertical rectangle expresses strength by the

Fig. 9.9 Some universal symbols in all cultures, from all times, regardless of their backgrounds, ethnical belongings, religions, geographic locations and cultures, always used with the same meaning (**a**) Vertical lines representing strength and power, (**b**) horizontal lines representing stability, (**c**) inclined lines representing dynamism and (**d**) rounded lines representing suavity and delicacy

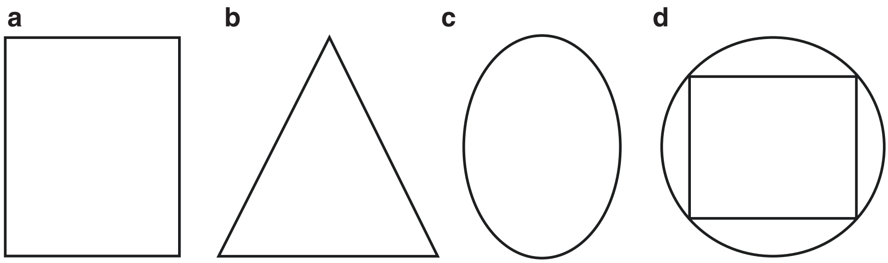

Fig. 9.10 (**a**) Vertical rectangle expresses strength by the predominance of the vertical element on the horizontal, (**b**) the triangle dynamism, (**c**) the oval delicacy, (**d**) the square/rounded circle stability and immobility by the balance between its vertical element and the horizontal one

predominance of the vertical element on the horizontal, the triangle dynamism, the oval delicacy, the square stability and immobility by the balance between its vertical element and the horizontal one (Fig. 9.10a–d). These basic shapes can be observed in the facial contour as well as in the shapes of the incisors and three-dimensional configuration of the dental arrangement, thus the incisal silhouette.

9.11 Human Temperaments

According to Hippocrates (460–370 BC), who is considered the father of Western medicine, each human being is an odd mixture of characteristics of four distinct temperamental types, in which each person can identify one or two more predominant temperaments. Below are the main behavioural psycho-characteristics of each temperament:

- **Choleric (strong):** dominant, determined, objective, explosive, intense, leader, passionate
- **Sanguine (dynamic):** extroverted, communicative, enthusiastic, dynamic, surrounding
- **Melancholic (delicate):** introverted, organized, perfectionist, artistic, abstractive, timid
- **Phlegmatic (calm):** diplomatic, pacific, mystic, spiritualized, conformist, discreet, tending to submission

9.12 Visagism

The word visage is derived from French, meaning face, and the term "visagism" describes the study of the face as to its constituent traits, the aesthetic relation among its elements and its visual expression. The visagism concept was defined by the plastic artist Philip Hallawell as the art of creating a customized personal image that expresses a person's sense of identity [31].

His work had as its main focus the painting of human figures, and he studied the visual language on face to create paintings with more realistic expressions. He gave a great boost to the development of visagism, with the association of visual expression of the facial traits, given by lines, shapes and colours, to the archetype theory coined by Carl Jung.

Such association suggests that the **facial traits are unconsciously noticed by the observer generating sensations which influence the way a person is perceived,** or being quick the observation of a face, which creates a remarkable first impression [32].

9.13 Visual Identity of the Smile (VIS)

This idea is the basis of the fifth dimension. Every human being is unique and special, and their smile reflects their personalities. Shape, texture, colour and combination of teeth convey direct messages, and when it comes to creating new smile designs, dentists must consider the “unity of the whole” idea, which is about bringing the biology, structure, function and aesthetics, together with a fifth element, the **personality**. The personality is literally the quintessential part here because the former is traditionally laid to balance it like a keystone.

In our research, we also realize the same effects while we are designing the new smiles. Using the visual language created by lines and circles, we tried to deliver a new smile design to the person which will be accompanied with his personality. A calm person would not like to have a smile design with an aggressive look, for example dominant centrals straight and sharp canines, but instead a design with more rounded and softer designed tooth shapes.

The visual language knowledge applied to the main expressive elements of smile design such as dental shapes, incisal edge, interdental ratio or dominance and 3D positioning of the teeth in the arch determined four smile design types with primary expression:

- **Strong:** composed mainly of rectangular dental shapes, strong dominance of centrals and canines on lateral incisors (radial symmetry), as well as plane incisal edge and rectilinear 3D dental positioning on the arch on an occlusal view.
- **Dynamic:** triangular or trapezoidal dental shapes, standard dominance, inclined incisal edge and angled 3D dental positioning on the arch.
- **Delicate:** oval dental shapes, medium dominance, curved incisal edge, and standard 3D dental positioning.
- **Calm or stable:** smoothly rounded square dental shapes, weak dominance (current symmetry), horizontal incisal edge and 3D rectilinear or standard dental positioning on the arch (Fig. 9.11).

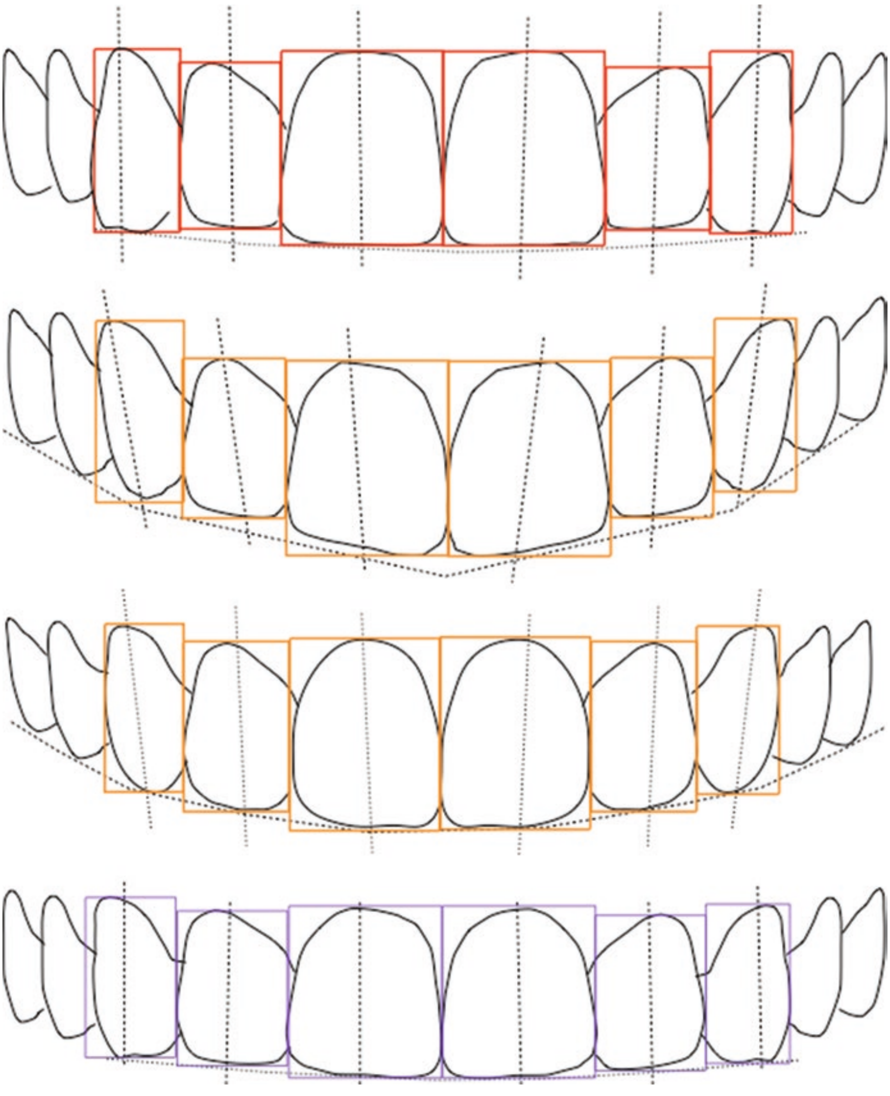

Fig. 9.11 The visual language knowledge applied to the main expressive elements of smile design such as dental shapes, incisal edge, interdental ratio or dominance and 3D positioning of the teeth in the arch determined four smile design types with primary expression, from top to bottom: strong, dynamic, delicate and calm

9.14 The New Concept

Complex cases with high aesthetic needs represent a challenge for clinicians. An interdisciplinary approach is vital to achieve the planned result. New technological devices are needed to facilitate the collaboration between the clinical team members and to develop a fluent and effective diagnostic and therapeutic pathway [33].

Through the large number of smile design's elements, as incisal edge, dominance, dental axis and shapes as sub-elements, such as morphological details of each tooth, it is possible to establish, based on the dental scientific literature, which ones should be determined by the facial typology and which could visually represent the unique personality of each patient, beyond their personal preferences and expression's will.

Thus, for a standard practice, reproducible and accessible to all professionals, a concept for smile design customization was elaborated by Paolucci et al. [29, 34, 35].

It came from the association of different knowledge as aesthetic and functional dental fundamentals, artistic visual language, facial recognition and still personality typology, being denominated "Visual Identity of the Smile" (VIS). For the objective application of this concept, a software was developed, which is called **REBEL**.

This holds true when the dentist first evaluates a new patient with aesthetic concerns; many critical factors may be overlooked. The VERBAL information exchange should be translated into a VISUAL perception in order to get the patient and the dentist understands what exactly the final expectations should be at the end of the treatment. The basic means of this communication starts with a 3D preview of the design in the patient's mouth (APT) even before the rest of the treatment is planned. At the end of the day no matter what clinical difficulties a dentist would face, how technically these problems would be solved, if the patient would not like the final aesthetic outcome, the treatment will be considered as a failure.

9.15 The REBEL

The fifth dimension including the personality traits on top of the previous aesthetic rules makes a world of a difference when properly introduced to the algorithm. It's an algorithm which REBEL is built on. The computational mind of REBEL is now fuelled not only by the biological, structural, functional and aesthetic parameters but also the variables related with the personality. This chunk of information is gathered from two sources: the Dellinger and Eysenck Personality Test and Controlled Interviews with the patients, and then simply fed to the algorithm by the dentist [36].

REBEL software is able to perform facial reading, personality assessment and personal preference evaluation of each patient and convert that information into mathematical language. Through pre-programmed algorithms, initially, a two-dimensional smile design is created. The software is capable of transforming automatically this 2D smile design into a 3D customized model. The model generation is performed by custom 3D library, developed specifically for REBEL Simplicity. Every model is personalized according to the proposed teeth configuration.

9.16 The Virtual Lab

The REBEL system is actually a virtual lab that converts the 2D design into 3D and creates a digital wax-up immediately. The 2D is created by relating the facial perception and the personality of the patient to the smile design by applying algorithms for computing the optimal combination of the incisal silhouette, tooth axis, dominance of the centrals and the combination of individual tooth shapes out of thousands of possibilities. It may sound complicated; however, it is the simplest way of getting one of the best 3D digital wax-ups possible.

REBEL has a very sophisticated artificial intelligence-based software behind; however, it provides a great simplicity to the end users, the dentists and dental technicians.

9.17 The Ideal Treatment

The ideal treatment can be mono-professional approach or better an interdisciplinary approach. The best aesthetic results largely depend on the ability of the members of the interdisciplinary team to work together [30]. Efficient communication between team members can present a challenge due to the requirement for continuous communication between the different specialists. Prosthodontist, orthodontist, periodontist and dental technician need to work together because understanding the various phases of the treatment is fundamental to achieving the desired result [37].

Today, the use of new technologies such as REBEL can improve the communication process between specialists. The previsualization of the final result can be a motivational key, not only to start the treatment but also to keep the patient involved throughout the process.

The aim of this chapter is to present a clinical case demonstrating an accurate operative protocol for the realization of porcelain laminate veneers with an interdisciplinary approach on the basis of the most recent clinical and scientific evidence.

3D real pre is going to be prepared through the rebel software. This will then be converted to a clinical previsualization by 365 means of a mock-up or aesthetic pre-evaluative temporaries (APTs), based on a 366 diagnostic wax-up. With the use of the prep through the APT technique, will end up with the most Minimally invasive preparation, driven by both the mock-up and 367 the silicone keys made from the 3D printed digital wax-up. After the tooth preparation and impression, the porcelain veneers will be manufactured and bonded under rubber-dam isolation.

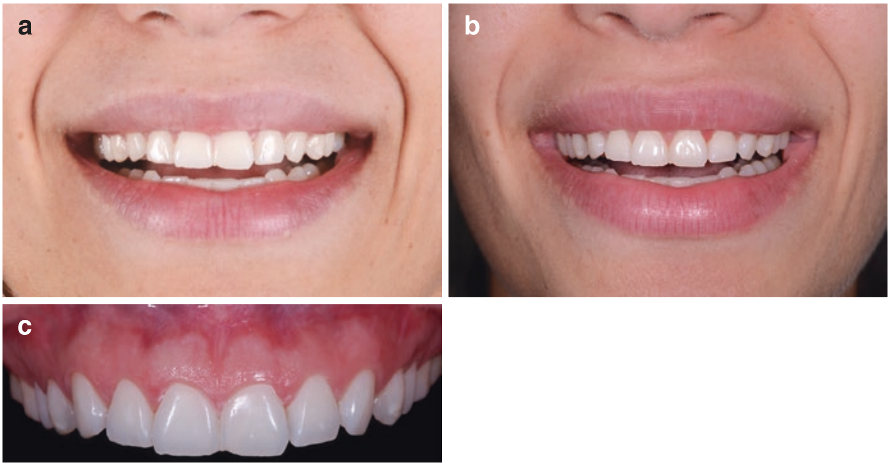

Fig. 9.12 Her chief complaints are the small size of her teeth, chipping at the incisal edges and irregularities at the incisal silhouette

Fig. 9.13 (**a**–**f**) The patient has a very stable bite, no TMJ problems and needs no alterations in her bite

9.18 The Case

A patient feel discomfort with the look of her smile. Her chief complaints are the small size of her teeth, chipping at the incisal edges and irregularities at the incisal silhouette. Aesthetic analysis, based on fundamental objective and subjective aesthetic criteria, highlighted disharmony and a lack of balance of dento-labial, dental layout. From a periodontal perspective, the patient showed good oral hygiene habits (Fig. 9.12).

She was not happy with the white calcification spots on her teeth. The teeth suffered from a loss of buccal volume and surface texture; their colour was characterized by low value and moderate chromacity. She wanted to have brighter looking teeth, compared to her existing colour, but never the whitest colour (Fig. 9.13a–f).

9.19 Aesthetic Analysis and REBEL

REBEL is a recent digital previsualization technique that allows the clinician to efficiently design the new smile, improve the communication between the dental team members involved in the treatment, obtain better communication and achieve better patient motivation and visualizing the final aesthetic result even before case has started. Within the same token, REBEL will enhance the predictability of the whole treatment which will guide the actual clinical treatment. This approach allows for the sharing of the treatment plan among team members and for creating a 3D visual perception of the case in the patient's mouth. It means that the digital project will be tested and approved even before starting the actual treatment. And accordingly, it will allow the dentist to present the treatment solutions.

9.20 The REBEL Workflow

Probably, REBEL has one of the simplistic steps for transferring all the necessary information to the REBEL digital laboratory. These are the three mandatory simple steps to be followed:

1. Single mock-up on a central to be digitally scanned
2. A full-face photography protocol
3. A simple questionnaire

9.20.1 The Single Central Mock-Up and Intra-oral Digital Scanning

A composite mock-up is placed on one (or two) of the centrals, in order to identify the incisal edge position vertically and the position of the facial surface bucco-lingually (Fig. 9.14a, b). This will be no different than making any direct mock-up; however, the greatest advantage of creating this mock-up for REBEL is that the dentist should not worry about the perfect design of this mock-up. It means that he/she does not need to try to choose the shape of the tooth (square, triangular, rounded, etc.), the angulation of their axis, surface texture, etc. These details of the new smile design will be given by the **REBEL artificial intelligence-based software** according to the facial perception and the personality of the patient. Therefore, this will allow any dentist at any level to start working with mock-ups and end up with high level wax-ups.

If the dentist does not want to make any mock-up, then he/she can as well write down the additional length that would need to be added on the centrals vertically and the volume on the facial side (i.e. 0.3 mm thicker facially). In that case, the dentist can easily relate the existing length of the teeth to the upper lip position with the help of a periodontal probe. This information should be written down (the additional length that needed to be added on the centrals vertically and the volume on

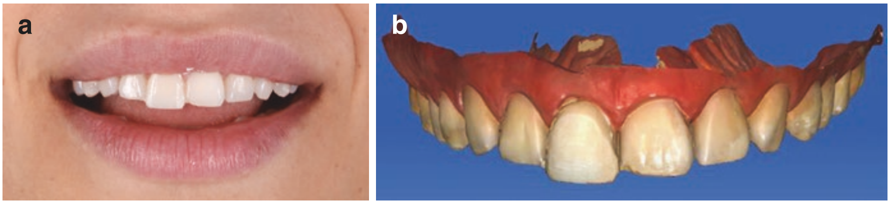

Fig. 9.14 (**a**, **b**) Treatment of every aesthetic case should start by defining the incisal edge position of the maxillary central incisors. A composite mock-up on one (or two) of the central incisors identifies the incisal edge position (vertically) and the position of the facial surface (bucco-lingually). This simple mock-up is digitally scanned together with the full maxillary arch

the facial side (i.e. 0.3 mm thicker facially)) and added to the file that will be sent to REBEL.

9.20.1.1 Intra-oral Digital Scanning

Once the mock up on the central(s) are completed, then this should be digitally scanned. (Fig. 9.14b) It can be scanned with any intra oral scanner that can create a STL file. Most of the intra oral scanners already convert the 3D scanning in to an STL file automatically.

9.20.1.2 Analog Impression

If the dentist does not have an intra-oral scanner in the dental practice, the following can easily be done; an analog impression of the upper jaw (preferably with the direct mock-up done on the centrals) is made; then this analog impression can be sent to the nearest dental lab which has lab scanner (each lab which has CAD/CAM machine has a digital scanner), and the dental technician can digitalize this impression for the dentist and will upload the "STL" file into REBEL to complete your order through the provided link.

9.20.2 The Full-Face Photography Protocol

The software needs to have a five full-face photography protocol in order to get the facial recognition of the patient and relate the 3D intra-oral digital scan into the facial features. The mandatory five full-face pictures are the following (Fig. 9.15a, b1–b5).

9.20.2.1 Full-Face Rest Position

This photo is for the automatic facial recognition part of the software, and part of the new REBEL smile design will be based on this facial perception of the patient. Technically, it is very important that the forehead and the ears of the patient are visible. If the patient has long hair, please keep it away from the face. It is crucial to keep the head upright (NOT tilted to the right, left or up and down), preferably position the eyes parallel to the horizon, and keep the lips apart.

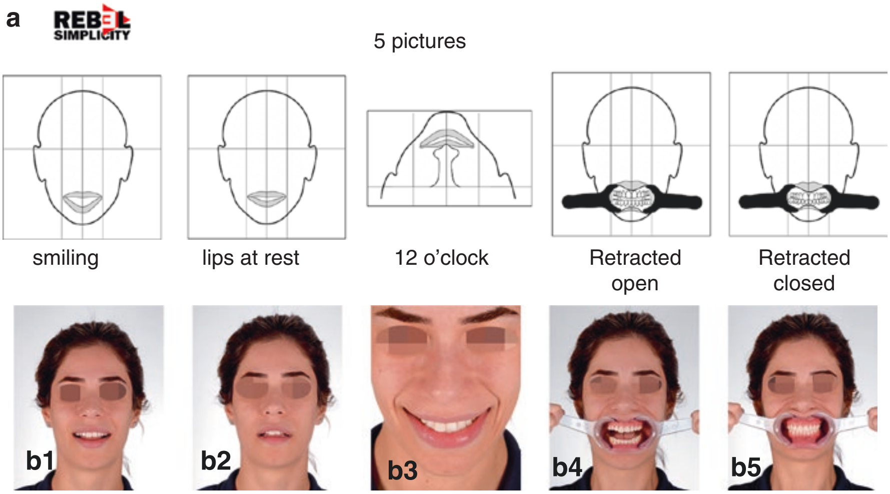

Fig. 9.15 (**a**) The full-face photography protocol. (**b1**, **b2**, **b3**, **b4**, **b5**); Five mandatory photos need to be taken: (**1** smiling; (**2**) lips at rest; (**3**) 12 o'clock position; (**4**) retracted mouth open; (**5**) retracted mouth closed

The software automatically checks the required full pace picture, and if it is not according to the rules, the dentist will receive an immediate message to replace it.

9.20.2.2 Full-Face Smiling

Keep the patient in the same position with the eyes open and parallel to the horizon and keep the head upright (NOT tilted to the right, left, up or down). This time ask the patient to keep the lips apart with a soft smile (if possible, show the incisal edges of the maxillary incisors).

9.20.2.3 Face 12 O' Clock Position

There are two simple ways of taking this specific photo.

First and easy choice will be to keep the patient in the same position and ask him/her to bend the face 45° forward while having a full smile and take the photo that will show the relationship to the upper centrals and the displayed arch position to the lower lip line.

Or the dentist can lay down the patient into a supine position on the dental chair and moves him/herself to 12 o'clock position and ask for the full smile and take a photo from 45°.

9.20.2.4 Full-Face Retracted Close Mouth

The patient should be asked to hold the full mouth retractors, again keeping the position of the eyes parallel to the horizon, keeping the head upright (NOT tilted to the right, left or up and down) and keeping the teeth closed and the occlusal plane parallel to the horizon.

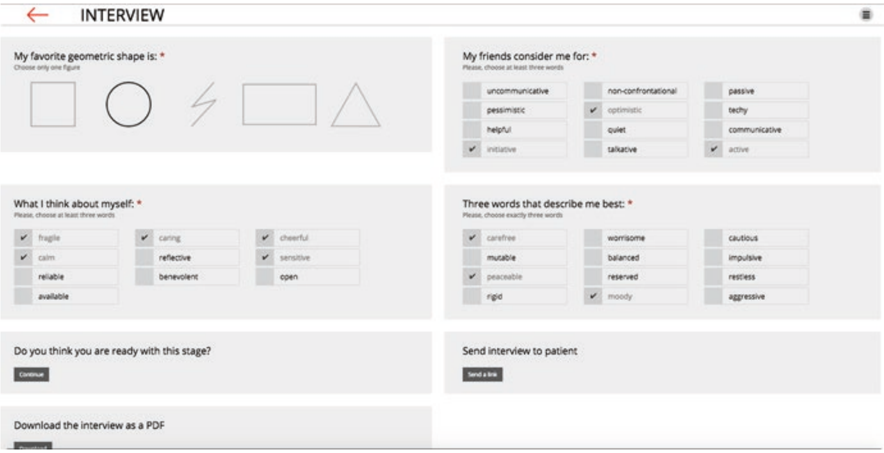

Fig. 9.16 Based on the data from the interview, the software algorithm automatically calculates the temperament (personality), the way the patient wants to be perceived. The temperament is a combination of strong, dynamic, delicate and calm

9.20.2.5 Full-Face Retracted Open Mouth

The same protocol above should be repeated, however this time with the teeth (upper jaw and lower jaw) separated.

9.20.3 Questionnaire

Then the interview that will indicate the character and the personality of the patient will be completed again in less than a minute through a questionnaire in the software and give you the primary and the complimentary character of the patient.

The temperamental type of each individual is defined by a unique combination of diverse characteristics of the four main temperaments, and therefore, for a precise and practical evaluation of it, it is necessary to apply a specific questionnaire (Fig. 9.16).

The optimal tooth shape is determined with the help of the interview. The questionnaire is based on popular psychological tests for personal self-assessment. The first question is an adapted test by Dellinger, and the other three questions concern personality traits based on the theory and questionnaire by Eysenck [38].

The questionnaire is checked by a computer algorithm to classify the patients' personalities. Based on the data from the interview, a software algorithm automatically calculates the temperament, as perceived by the patient. The temperament is a combination of "strong, dynamic, delicate and calm." After this procedure is done, the dentist and/or the technician will have the full idea of the facial perception and the personality of the patient.

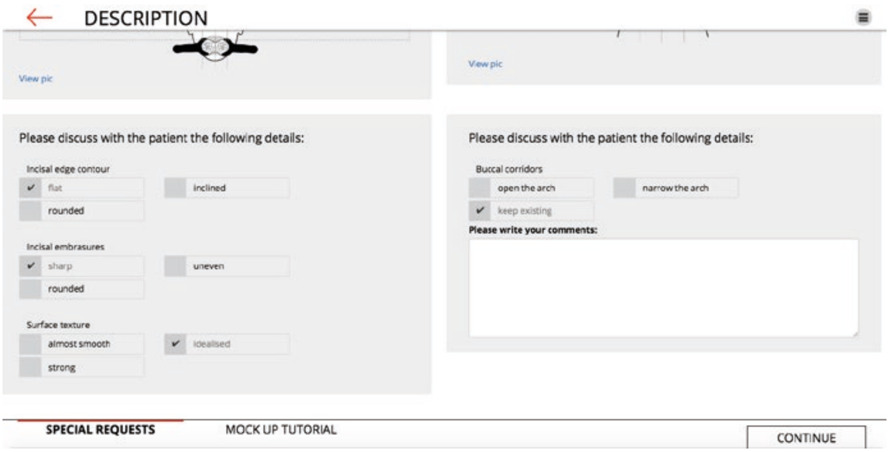

Fig. 9.17 REBEL digital lab allows the dentist to provide additional information regarding details such as the final design of the incisal embrasures, surface texture and expected appearance of the buccal corridors, which will then be calculated and designed by the REBEL software

As the dentist is about to send all these three mandatory files, he/she will also be asked to inform the REBEL digital laboratory with the description of the clinical case regarding any specific designs, such as the buccal corridors, perfect imperfections, the intensity of the surface texture, etc., or choose some of the optional features provided if needed (Fig. 9.17).

9.21 REBEL Digital Laboratory

It has a very sophisticated simplicity, in the way that there is a very complex software behind, which enables the dentist to do the most simplistic but the most predictable and personalized 3D wax-up.

The next step is to convert the two-dimensional (2D) digital project into a 3D mock-up. The REBEL system is actually a digital lab that converts the 2D design into 3D and creates a digital wax-up immediately. The 2D is created by the VisagiSMile concept that relates the facial perception and the personality of the patient to the smile design by applying algorithms for computing the optimal combination of the **incisal silhouette, tooth axis, dominance of the centrals and the combination of individual tooth shapes** out of thousands of possibilities (Fig. 9.18). It may sound complicated; however, it is the simplest way of getting one of the worlds' most realistic 3D digital wax-ups possible.

Once all this information is sent to the REBEL digital laboratory, the software will immediately create the new REBEL smile design by first converting it to the 2D VisagiSMile format and into the 3D REBEL design. While doing this, the artificial intelligence-based REBEL software will decide on the main elements of the new

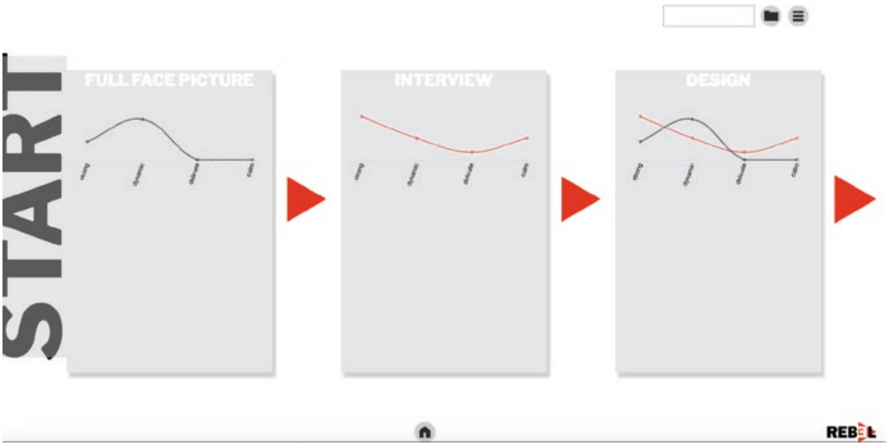

Fig. 9.18 The outcomes of the *facial recognition and the personality* test both correspond to a blend of *strong/dynamic* design. REBEL is now ready to convert these mathematical readings into a visual 3D digital wax-up

smile design, such as the incisal silhouette, the dominance of the centrals, the tooth axis and the arch form and in addition choose the ideal individual tooth shape that would be most natural for that specific patient relative to their facial perception and the personality that they wanted to be perceived.

REBEL has a very large digital tooth library, composed of the ideal forms of natural teeth and wax-up designs of the top dental technicians (Fig. 9.19).

Even though these individual teeth shapes of digital library are great, the amazing part of the design procedure is that the software selects the two main shapes (i.e. from rectangular, triangular, ovoid, square) that will be matching with patient's facial perception and personality, and depending on the percentages, it blends and moulds the selected two main shapes into the ideal forms. For example, if the overall perception of the face and personality is a combination of 70% dynamic and 30% delicate, it selects the ideal triangular and ovoid shapes and blends them into each other with a combination of these percentages, main silhouette of the teeth being triangular but with the saddle appearance of ovoid as well.

Once this design is automatically placed over the digitally scanned original upper jaw of the patient and rendered, an immediate STL file of this new REBEL digital wax-up is formed.

9.22 Back to Chair Side/3D Printing

This STL file is then sent to the dentist via email, ready to be 3D printed. After the STL file is 3D printed, the dentist can easily transfer this design into the patient's mouth by making a silicone impression of the digital wax-up. The harder this

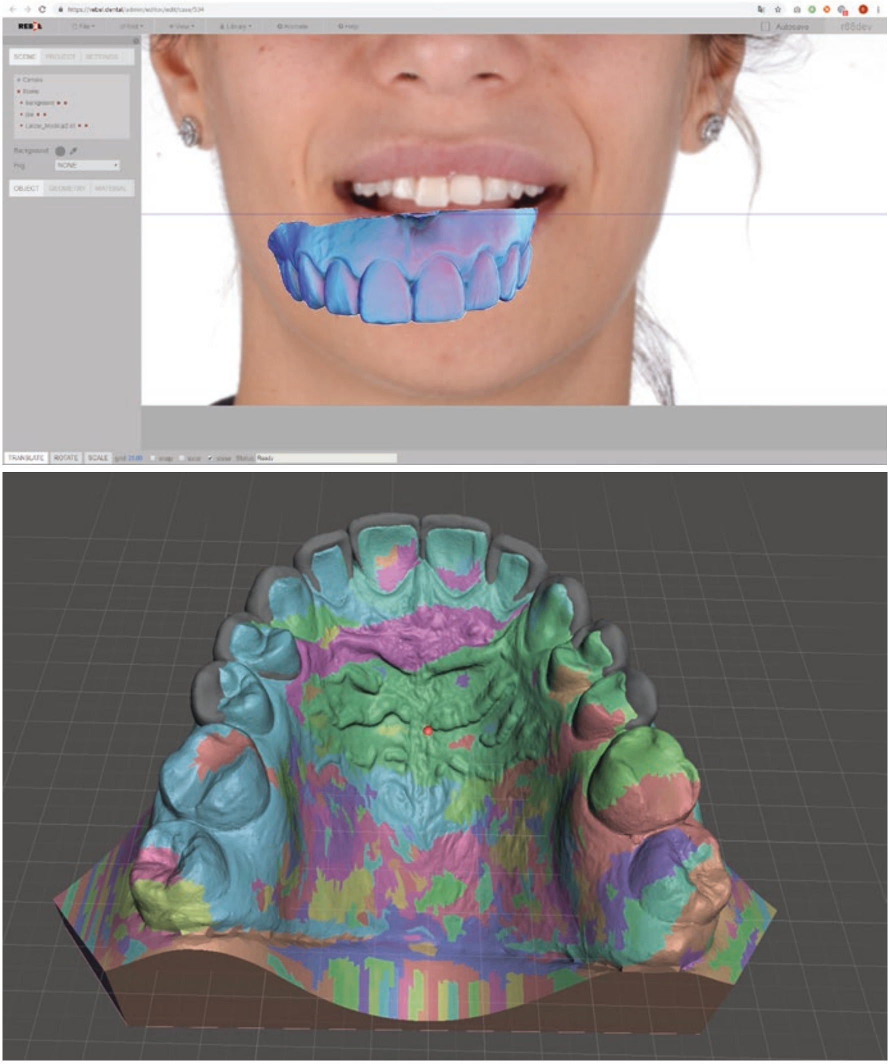

Fig. 9.19 Since the size of the frontal facial aspect of teeth on the photos does not correspond to the actual size of the teeth in the mouth, a smile design can lead to errors in the information provided to the laboratory and to final restorations of inadequate volume and dimensions. A mathematical model allows the parameters measured in 2D to be recalculated and determines the real 3D dimensions of the teeth to provide accurate parameters for the digital wax-up. The digital planning software that REBEL uses provides dentists and technicians with a 2D preview of the final design that relates the facial perception and the personality of the patient within a second. The REBEL Simplicity software is also capable of recalculating and recreating personalized 3D models of the teeth by morphing the individual tooth shapes from its 3D library. Every model is generated according to the proposed 2D teeth configuration. Users can visualize the 3D model in their browsers and can also download the models for use in a dental laboratory

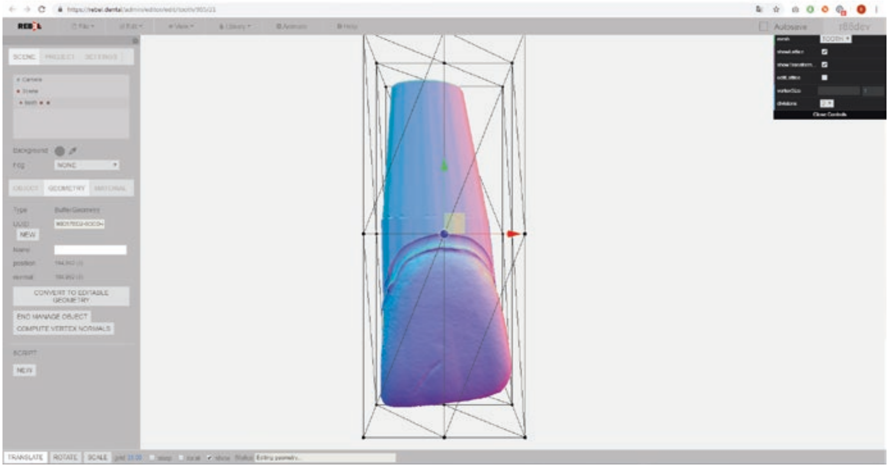

Fig. 9.19 (continued)

silicone transfer impression, the more precise this transfer will be, in order to duplicate all the details such as the line angles that give the ideal shape of the teeth and surface texture (Fig. 9.20).

This transfer should be done prior to everything. The dentist should evaluate the new design well before starting the tooth preparation, as the APT (or as the final mock-up). This way not only the ideal 3D smile design but a great 3D communication chance will be given to the dentist and the patient at this moment. And the final aesthetic design should be approved at this period (Fig. 9.21a–c). REBEL also has another feature, i.e. designing the smile in a respective way. That means if some of the original teeth positions are remaining outside of the final smile design arch position such as rotated or facially protruded teeth, it will create its design regardless of these teeth.

This will create two major advantages:

- The first one is that the dentist will be able to place the silicone impression and thus create the APT in the patient's mouth, without the need of cutting (aesthetic pre-recontouring (APR)) the protruded parts of the original teeth.
- And the second advantage is that it will allow both the dentist and the patient to realize the final new smile design relative to their original teeth through this APT. This will be a great tool for sharing this information and create a platform to both parties regarding the treatment planning. The dentist can now solidly debate with the patient, for example, the need of an adjunctional ortho treatment in order better position these teeth for minimally invasive approaches instead of an extensive tooth preparation of these teeth remaining outside of the new smile design.

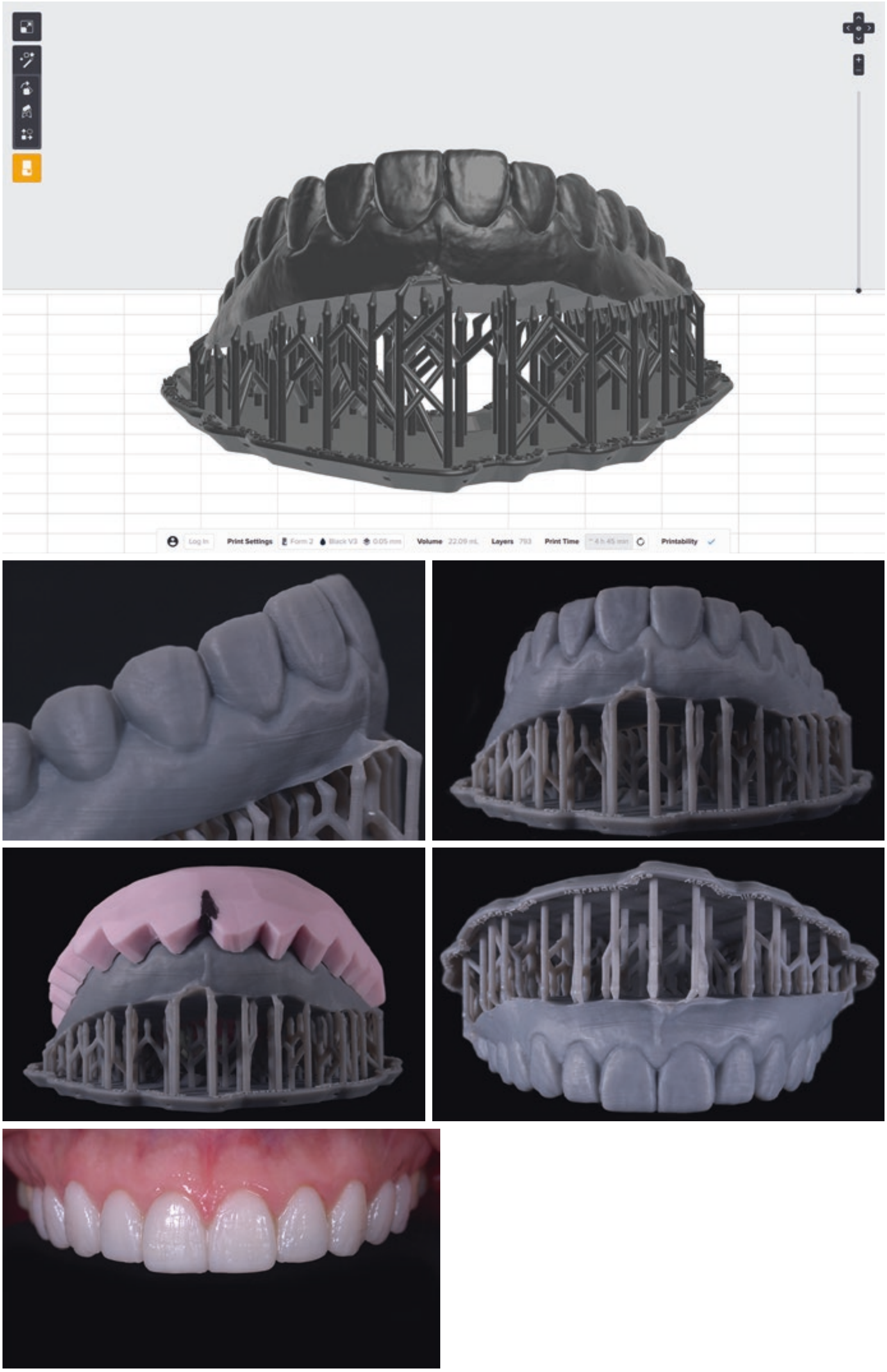

Fig. 9.20 After the STL file is received from the REBEL digital lab via email, it can be 3D printed (Form 2, Formlabs). When the 3D printed model is created, the dentist can easily transfer this design to the patient's mouth by making a silicone impression of the digital wax-up and using a provisional material of choice (i.e. Luxatemp, DMG)

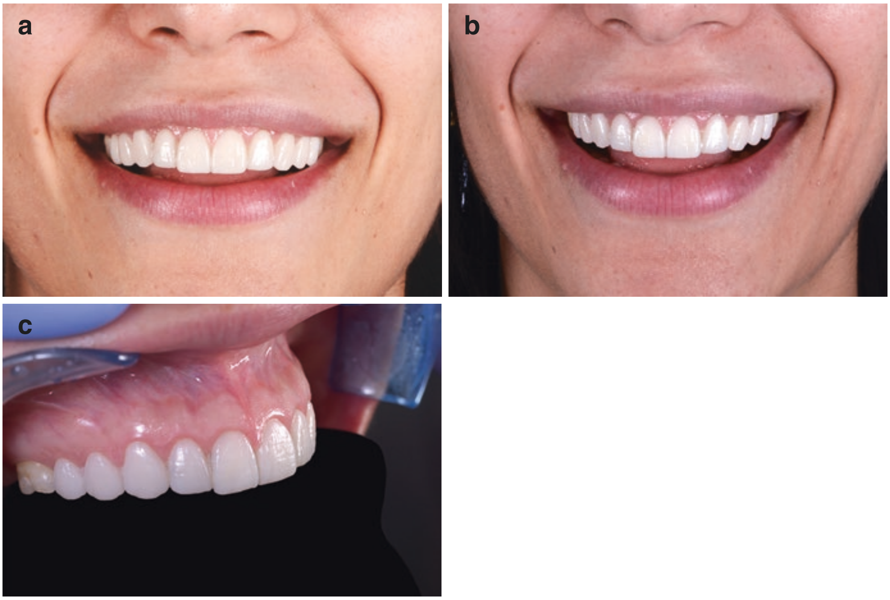

Fig. 9.21 (**a**–**c**) The visualization of the APT in the mouth and its relation to the facial appearance. REBEL design according to the facial perception and personality of the patient, the design is created with the rectangular shape of the individual tooth shapes, straight tooth axis, dominant centrals and flat to triangular incisal silhouette

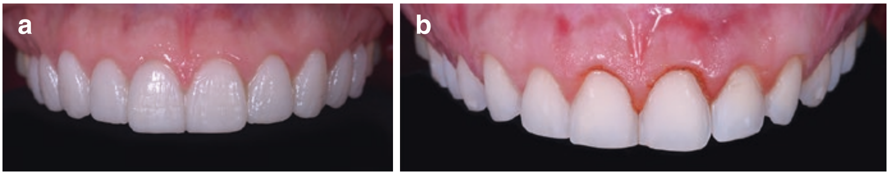

Fig. 9.22 (**a**, **b**) After the approval of the aesthetic outcome of the APT (from the REBEL 3D digital wax-up), the dentist can start preparing the teeth through the APT for the most aesthetic and minimally invasive preparations (note the minor soft tissue touch-up correction on the centrals, to define the zenith points)

9.23 Tooth Preparation Through the APT

Once the final design is approved by the dentist and the patient, the dentist can anaesthetize the patient and start preparing the teeth through the APT (Fig. 9.22a, b).

9.24 Finalizing the Case

As soon as the teeth are prepared, it is then the choice of the dentist to further continue the case digitally by making an intra-oral digital scan or continue with the conventional analog way.

Fig. 9.23 (**a**–**c**) The final result: monolithic e.max porcelain laminate veneers with a minor cutback technique applied over the incisal edges in place. The smile flows with the facial appearance and the personality of the patient. She is extremely happy with the new smile design, expressing her feelings by saying that "even though a major change had been done with my smile, no body hardly ever understand that I had been treated with veneers"

In the same way, the lab can produce these veneers digitally by milling or using pressable ceramics or utilizing feldspathic veneers. In this case, the material of choice is the e.max pressable ceramics, with a one-third incisal cut back and feldspathic porcelain applied on top with the micro-layering technique (Fig. 9.23a–c).

9.25 Conclusion

The combination of the basic rules of aesthetics together with the reflection of the facial analysis and the personality of the patient on the "new smile design" creates more natural and personalized smiles (Fig. 9.18).

This principle presumes the harmony between the smile design and the patient's personality. However, in the dental practice, its application has been limited due to the lack of an objective method for assessing personality and incorporating their meaning into the smile design.

Current aesthetic software VisagiSMile/REBEL can help the clinicians to provide new smile design that affects patient's emotions, sense of identity, behaviour and self-esteem. Combining the modern digital technologies with the classic treatment rules can be used to achieve predictable aesthetic results.

The VisagiSMile/REBEL concept which can be applied very easily and fast can help the dentist\ceramist to achieve this goal in its most simplistic, practical and personalized way.

The author's clinical experience shows a minimum of 80% success in the acceptance of the final smile design.

And finally before any further investigation and research is done, if the result by applying this technique does not satisfy the patient due to the subjectivity of the matter, the dentist can always make minor alterations in order to adopt this design according to the patient's desires.

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10 Contact Lens Veneers with Pressed Ceramic

Ivan Ronald Huanca and Anabella Oquendo

Contents

10.1 Introduction

Prior to the advent of adhesive dentistry, for decades, dentists sacrificed healthy dental structures to suit the materials available at that time. Amalgam restorations required a retentive preparation, and the metallo-ceramic crowns need a mandatory complete preparation of the entire tooth for retention. With the advent of adhesive dentistry [1, 2], a new horizon in dental preparations was created. As an example, today we treat carious disease strictly where there is affected tissue, just as prosthetic crowns have in many cases been replaced by veneers. This is how the concept of minimally invasive dentistry emerged, which seeks to preserve dental tissues as much as possible by reconstitution, repair, or restoration of the dental organ. The current concept requires the material to adapt to the preparation, and the preparation

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no longer must adapt to the material [3, 4]. Based on this principle, the preparations for ceramic veneers have followed the same path reaching the point that in some cases there is no preparation, which has led to the creation of ceramic veneers with a thickness reaching from 0.1 to 0. 3 mm (contact lens).

The main characteristic to name a case as contact lenses [5–7] is in the final thickness of the ceramic that ends below 0.3 mm [6]. Basically two methods can be used, the feldspathic ceramics on refractory or on platinum sheets and the injected ceramics reinforced by lithium disilicate. Another way would be to use the CAD/CAM systems, but the high cost of the materials (CAD blocks) involved makes this procedure less utilized. The feldspathic ceramics have excellent optical characteristics and good adhesion to the tooth structure, but the fracture index in the preparation and cementation phase is greater when compared to the ceramics such as lithium disilicate. Another positive point of the pressed systems is the reduction in fractures when there is increased occlusal contact (bruxers).

This article describes a technique to more accurately perform contact lens cases using vitreous disilicate glass ceramics (CVDL).

10.2 Case Report

The patient, a 29-year-old female, sought assistance in the clinic dissatisfied with her smile (Fig. 10.3). The patient previously had an esthetic treatment completed with composite resins and a history of fractures and recurrent staining and showed interest in having the same work replaced with ceramics.

10.3 Initial Focus

First, radiographs were taken to evaluate the periodontal condition. We verified her periodontal status was good, no endodontic treatment was required, and there is absence of caries. Four veneers of composite resin had been used to restore the four anterior teeth and in addition fill small cavities and slightly increase the incisal edge. A photographic protocol was developed to evaluate esthetic principles related to hard and soft tissues, consisting of facial photography (Fig. 10.1), photos of the lip at rest (Fig. 10.2), smile (Fig. 10.3), right lateral smile and left lateral smile (Figs. 10.4a and 10.4b), and photos with retraction (Figs. 10.5a, 10.5b, 10.5c, 10.5d) [8]. Examination of the photographs demonstrated a favorable incisal edge rest position, which is usually from 2 to 4 mm for women [9]. There was a normal gingival architecture, with existing papillae, central incisors zenith oriented distally [10], absence of black triangles, and correct gingival margin position which eliminated any need for gingivoplasty [11]. The shape and dimensions of the dentition were proportional, and the dental coloration was pleasant, which ruled out the treatment with whitening. In order to balance the difference of inclination of the left canine in relation to the right side, contact lens veneers for 7–11 were indicated.

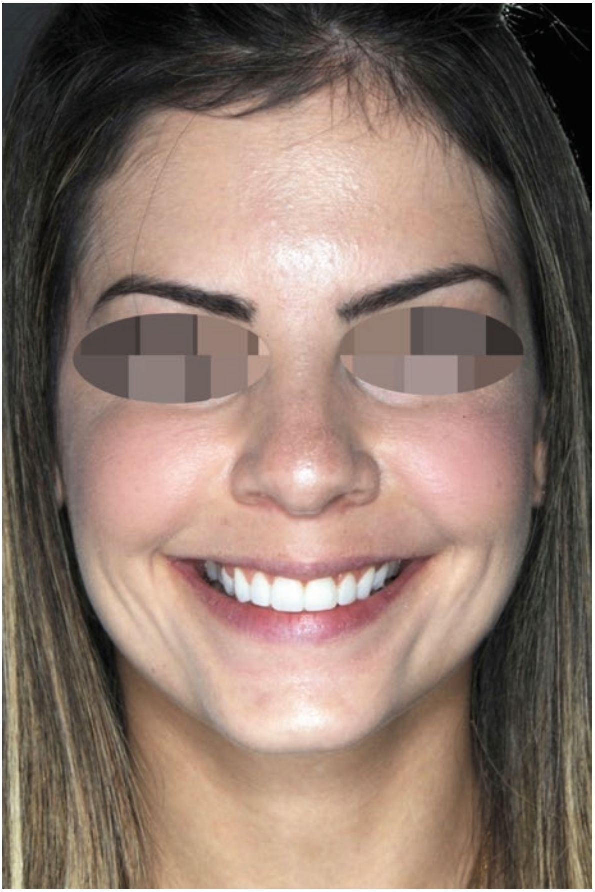


Fig. 10.1 Full face

Fig. 10.2 Lip at rest

Fig. 10.3 Smile

Fig. 10.4a Right lateral smile

Fig. 10.4b Left lateral smile

Fig. 10.5a Retracted teeth in occlusion

Fig. 10.5b Retracted right lateral view

Fig. 10.5c Retracted anterior view

Fig. 10.5d Retracted left lateral view

10.4 Phase 1 Clinical Procedures

Initially impressions were taken with high-quality materials of addition or condensation silicones, to produce an accurate model of the patient's arch. Next, a type IV gypsum model was produced to perform the diagnostic waxing (Fig. 10.6). In this phase knowledge of dental anatomy, esthetic principles, and perception of the patient's personality define the final aspect of the work. The smile desired by the patient must be guided by the professional, who becomes a modifier between what the patient wants and what can be accomplished. Next a mock-up trial (Fig. 10.7) was done, to enable the patient to visualize how their expectations coincide with a prospective new smile. A silicone copy of the wax-up is fabricated and filled with bis-acryl resin of teeth to be modified and inserted into the patient's mouth. After polymerizing the acrylic, the silicone is removed. The resin remains intimately attached to the involved teeth, making it possible to visualize the esthetic potential of the work by the patient and professional. After deciding that the potential esthetic treatment would satisfy the patient's expectation, the preparations were initiated. The preparations can be made in two ways, by using silicone guides made on the diagnostic waxing or depth cuts with the mock-up in position or both simultaneously [12].

The two techniques produced suitable preparations for making the contact lens restorations.

Once the preparation is finished, an impression with addition silicone must be made using the double-cord technique [13]. In this procedure either the two-step or single-step impression technique can be chosen, depending on the experience of the professional with one or another technique. After the impression is obtained, a detailed inspection must be made, as any possible defects in the impression can lead to inadequate laboratory work and consequently clinical deficiencies. If tears, drags, pulls, bubbles, or lack of accuracy is seen when the two-step technique is used, a new impression must be made [14]. After the impression is obtained, a bite registration

Fig. 10.6 Diagnostic waxing

Fig. 10.7 Mock-up

and impression of the antagonist are made. In a similar manner to the mock-up, but with an application of phosphoric acid (spot etch) on the prepared teeth, the provisional is made with bis-acryl. After instructions are provided regarding the maintenance of the provisionals and surrounding soft tissues, the patient can be released.

10.5 Laboratory Procedures Using Ink and Glue

Initially a meticulous inspection is made to evaluate if there is a defect in the impression that could create inaccuracies in the working model. Once the optimum quality of the impression is verified, the preparation of the models begins. Two models will be necessary, a die model and a rigid model, both made with type IV stone following the manufacturer's recommendations. The die-cut model (has no finishing line and preparation supragingival) is duly isolated, and the waxing is carried out guided by the previous planning (Fig. 10.8). For this technique, the use of a wax with a color different from that of the model is essential to locate where the work restorations are very thin, as this would make the pressing of the ceramic difficult. In these places, the wax must be thickened to a thickness of approximately 0.3 mm to guarantee adequate pressing of the ceramic.

Once the waxing is finished, they are sprued, invested, pressed using the selected ingots, and finally divested of the restorations from the ring. All these procedures must be done according to the manufacturer's guidelines. Once the restorations were adapted to each die (Figs. 10.9a, 10.9b, and 10.9c), a dark-colored permanent

Fig. 10.8 The use of wax other than plaster color is essential for fabrication thicknesses less than 3 mm which should be thickened to ensure the injection of the ceramic. Finish and texture will be made in the ceramic

Fig. 10.9a Wax pattern ready to inject individual die

Fig. 10.9b Individual die

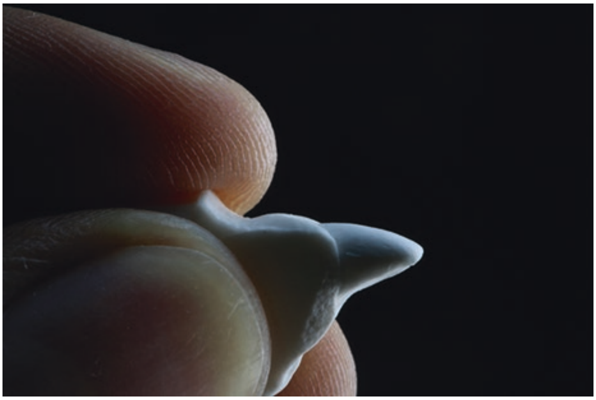
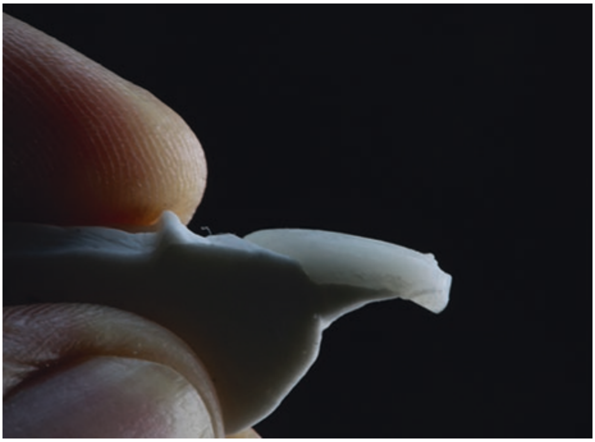


Fig. 10.9c Individual die



marker is painted on the inside of the ceramic (Fig. 10.10a–d). This will help to visualize the minimum thickness that we want to reach, especially in cervical and proximal regions when there is no finish line. It also facilitates the handling of the ceramic pieces because they are very thin structures (0.1–0.2 mm).

Once the paintings are done, we place the pieces on the dies with a glue based on water (white glue) (Figs. 10.11a, 10.11b, 10.11c, 10.11d, and 10.11e). This union initiates a foundation on the plaster die and makes possible the manipulation of the ceramic to finish and polish, imitating what happens with the ceramics on refractory, without the fear that the ceramic restoration will break or initiate cracks.

Ink and glue can also be used for restorations produced by the CAD/CAM system independent of the material to be used. At the end of the finishing and polishing processes (Figs. 10.12a and 10.12b), we submerge the dies in a container with hot water. The stone model quickly absorbs the hot water that will facilitate the removal

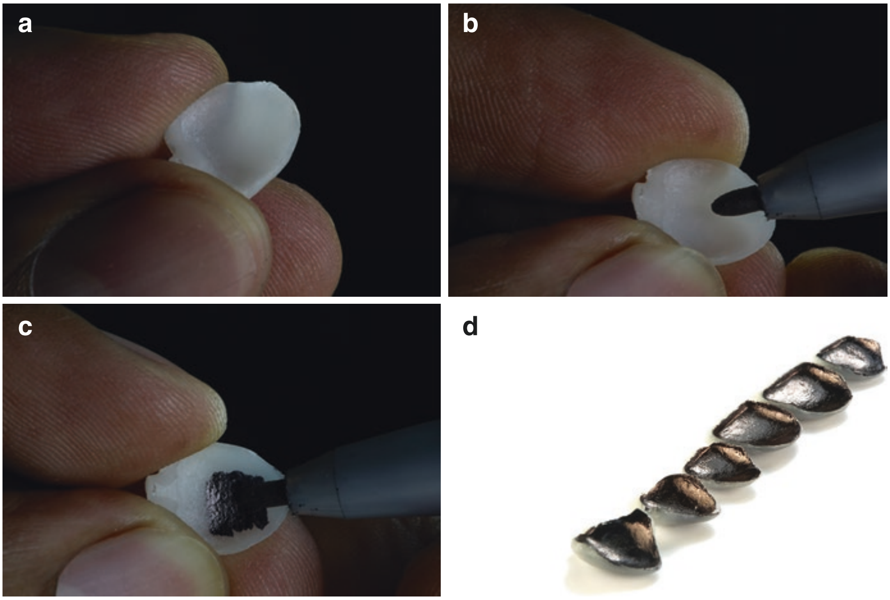


Fig. 10.10 (**a**–**d**) With the permanent markers the restorations are painted on the inside

Fig. 10.11a Permanent markers

Fig. 10.11b White glue

Fig. 10.11c Injected veneer, faithfully adapted to the die and internally painted with the overhead marker

of the restorations with thicknesses 0.1–0.2 (Fig. 10.13a). With the contact lens restorations removed, we submerge the pieces again in another container now with monomer (acrylic liquid) or acetone, to remove the ink (Fig. 10.14). The finished restorations will be tried on the rigid model observing points of contact and occlusion. With the pieces adapted to the rigid model, we finished the restorations by applying tints and final glaze (Figs. 10.15a, b and 10.15c).

Fig. 10.11d Placing white glue on the inside, the glue has the consistency of a resinous cement

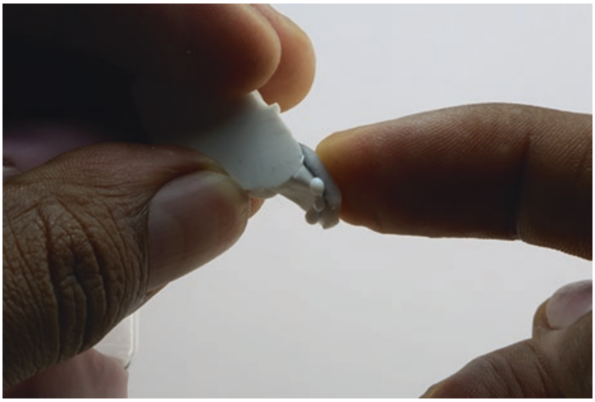


Fig. 10.11e Glue the veneer on the plaster cast, imitating a foundation to the tooth

For restorations in lithium disilicate, if cracks occur during the finishing and polishing phases, it can be repaired by making a new crystallization, whose program is as follows:

– Initial temperature of 450° with vacuum
– Cooking speed of 60° per minute
– Final temperature of 900°/1 min without vacuum.

10.6 Phase 2 Clinical Procedures [15]

Once the laboratory work is received, the restorations are first tested using try-in paste with the color like the adhesive cement. With contact lens cases, the color of the cement should approximate the teeth. Because it is a minimal thickness ceramic restoration, there is no way to alter the color of the shade by increasing or decreasing

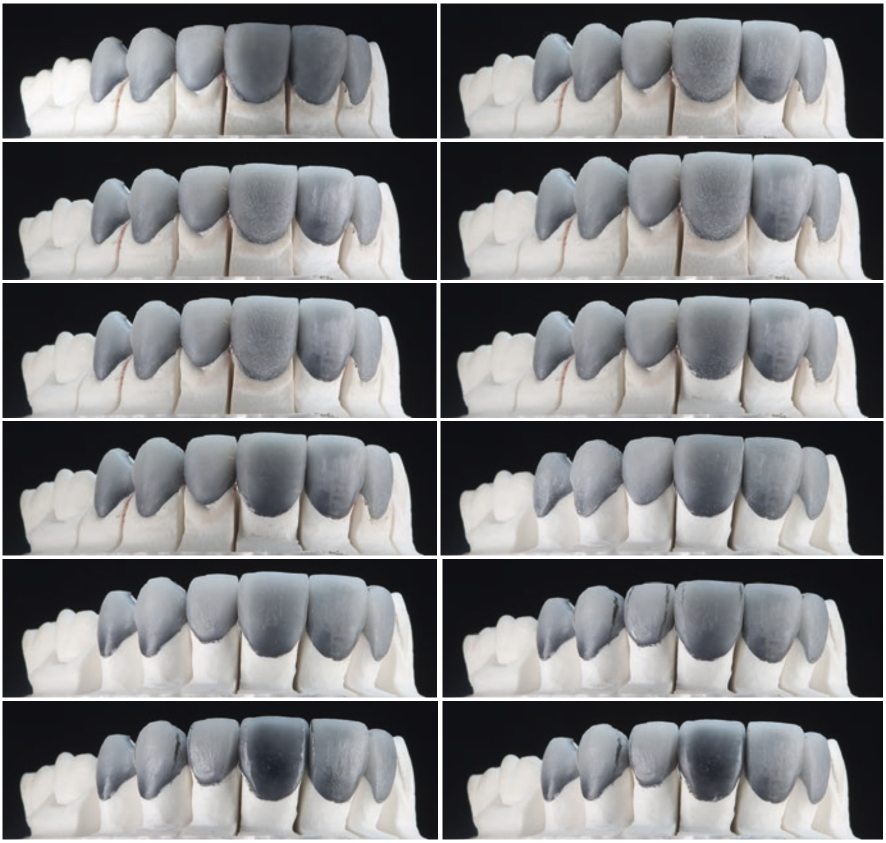


Fig. 10.12a The restorations are adhered to the plaster dies imitating a foundation

the chroma of the cement. With the restorations in position, we checked the adaptation, contact points, and esthetics (Figs. 10.16a, 10.16b, and 10.16c). The work is evaluated by the patient and by the professional, and if it meets their expectations, they proceed with final cementation. The patient was anesthetized, and the use of a modified absolute isolation is necessary for the control of the moisture, labial lip retraction, and protection of the patient. Prior to isolation a dental cleaning is done with Robinson's brush and pumice.

The insertion of the restorations can be made together or individually depending on the experience and preference of the operator. Following the try-in, the ceramic is prepared with 10% hydrofluoric acid for 20 s, followed by the removal of the acid with a water jet for 20 s. Phosphoric acid is applied on the tooth with a light scrubbing with microbrush for 20 s and removal with water spray for 20 s. Then silane is applied following the manufacturer's recommendations on the veneers.

Fig. 10.12b The knowledge of the dental morphology is very important for the final finish of the ceramic, with a minimum thickness of 0.3 mm or less

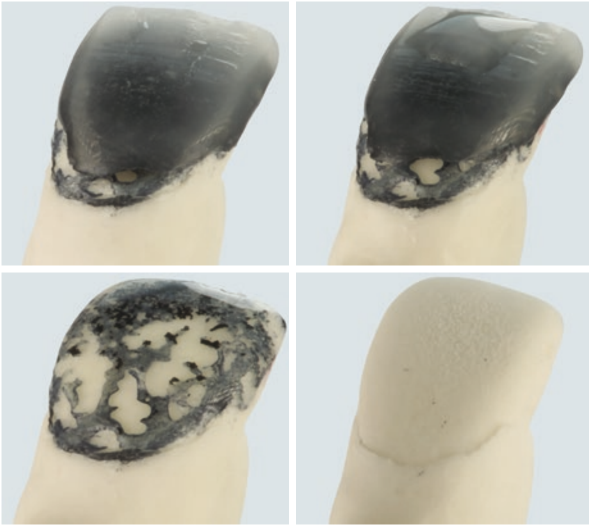


Fig. 10.13 The finishing procedures. The restorations are removed from the dies with the help of hot water, leaving it submerged in a container for 5 min

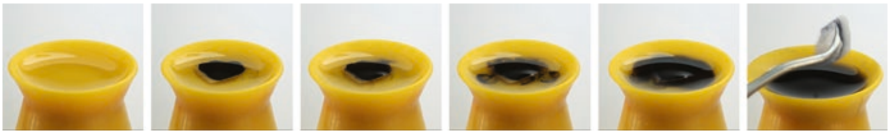


Fig. 10.14 The restorations are submerged in monomer or acetone

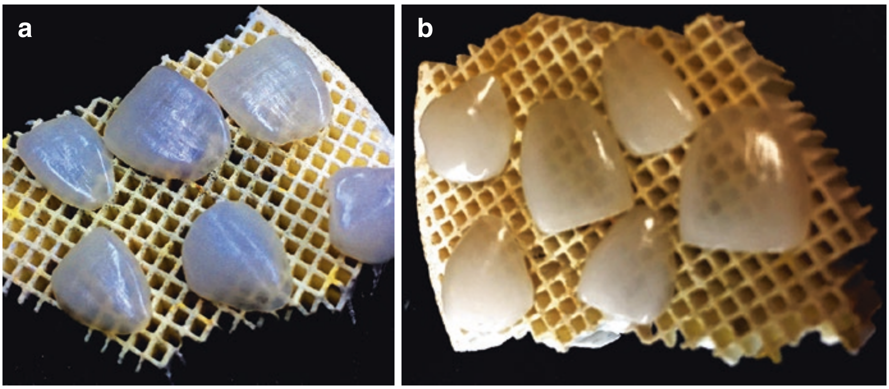


Fig. 10.15a,b Makeup procedures and final glaze

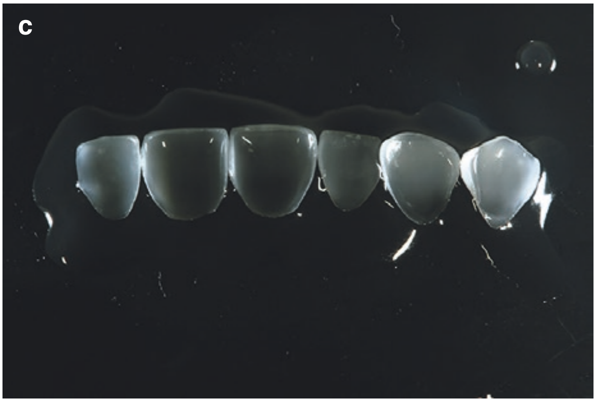


Fig. 10.15c Finished restorations

Fig. 10.16a Dry restoration test

Fig. 10.16b Very thin cervical contour reaching 0.1 mm

Fig. 10.16c Observe the thin thickness of the restoration

With the ceramics ready for cementation, we start the dental conditioning that must be done according to the adhesive system that is going to be used. In this case, a conventional three-step adhesive system (Optibond™ FL, Kerr, Orange, CA). Teflon tape is placed on adjacent teeth for separation followed by the application of phosphoric acid for 30 s on the enamel region. There was no dentin exposure. The teeth were dried, and application of adhesive is applied without polymerization.

When the teeth are ready, we return to the silanized ceramics and apply adhesive in the restoration without polymerization. The cement is inserted in the restoration, and then they are inserted into its position on the tooth. Then excess cement is removed with an instrument of preference, proximal removal with dental floss, and finalization with photo polymerization. The same process is followed for each tooth. At the end of the procedure, dental floss and scalpel blade are used to verify all excess cement was removed. With the contact lens restorations cemented, adjust the occlusion and check the excursions.

Final photographs are taken (Figs. 10.17a, 10.17b, 10.17c, 10.17d, and 10.17e).

10.7 Conclusion

The use of ink and glue is an effective way to fabricate contact lens-type restorations, which can be used in the conventional way by waxing and pressing ceramics or by making the ceramic using any CAD/CAM system. The result of this procedure was ceramics as thin as using ceramics on refractory. Greater safety was verified in the clinical part in the face of fitting and cementation. On the other hand, in the laboratory, it was verified the ease of finishing and polishing the lithium disilicate ceramics independent of the dies that were made either analog or digital. It also allowed the fabrication of extremely thin restorations when compared to ceramics on refractory dies.

Fig. 10.17a Full face photograph

Fig. 10.17b Resting lip position

Fig. 10.17c Final photo of the smile

Fig. 10.17d Right lateral view of smile

Fig. 10.17e Left lateral view of smile

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Minimally Invasive CAD/CAM Veneers

11

Stefano Patroni

Contents

11.1 Introduction

Thanks to the increasing awareness in Western world population about the etiologic factors causing dental diseases, dental caries incidence is fortunately declining [1].

Conversely the incidence of erosive pathologies such as tooth wear is, without any doubt, increasing every day [2]; this clinical phenomenon is particularly evident in children and adolescents [3, 4] achieving a prevalence up to 30% [5, 6].

Severe tooth wear, on the other hand, has been reported having a prevalence ranging from 3% in a 20-year-old population, 15% in 70-year-old patients [7], and up to 25% in a 15-year-old adolescents' population [8] (Fig. 11.1).

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The wear etiology is usually multifactorial and recognizes as possible causes erosion, abrasion (Fig. 11.2), abfraction and attrition (Fig. 11.3), factors which are frequently combined [9–11].

On the other hand, some other pathologies like the general (Fig. 11.4) or localized microdontia (Figs. 11.5, 11.6, 11.7, 11.8a, b) and congenital agenesis involve tooth substance lack or teeth absence congenitally determined.

In the first case, it is necessary to increase the tooth size and reshape the correct tooth form; in the latter, there is the need to adjunct absent teeth (e.g., by means of a Maryland bridge in childhood and an implant-supported crown in adulthood)

Fig. 11.1 An example of serious erosive pathology in a 16-year-old young patient: the enamel has quite completely disappeared on the central and lateral incisors

Fig. 11.2 One more example of tooth wear: it is evident the enamel and dentin loss in the cervical area (non-carious cervical lesions) combined with gingival recessions

Fig. 11.3 A clinical example of severe tooth wear caused by attrition. The occlusal surfaces are severely compromised due to the parafunctional patient habits

Fig. 11.4 A case of general congenital microdontia. The “early” increase of the tooth size reshaping the correct tooth form before the orthodontic treatment with the veneers will make their alignment faster, easier, and more predictable

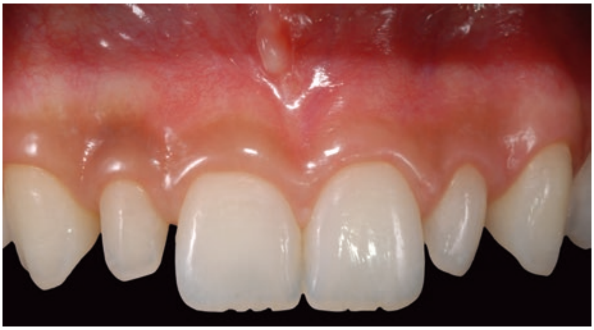


Fig. 11.5 One of the main indications for laminate veneers: the conoid teeth morphologic modification. This is the pre-restorative view at the end of the orthodontic treatment

Fig. 11.6 The rubber dam is in place and the field insulated: all is ready to adhesively lute the no-prep ceramic laminate veneers

Fig. 11.7 The final result achieved “only” by adding a “new ceramic skin”

Fig. 11.8 (**a**, **b**) The initial smile (left) and the final result (right)

Fig. 11.9 A case of congenital agenesis (missing maxillary right lateral, tooth 12) combined with lateral microdontia on the opposing side (second quadrant tooth 22). After the orthodontic treatment, it is possible to bond a Maryland bridge to replace the tooth 12 and a ceramic laminate veneer on the tooth 22 to reestablish the ideal shape

(Figs. 11.9 and 11.10) or, when the treatment plan forecasts the spaces closure, substituting the laterals with the canines and the canines with the first premolars to correct the tooth shape and dimensions in the attempt of solving the residual spacing problems (Figs. 11.64, 11.65, 11.66, 11.67, 11.68, 11.69, 11.70, 11.71, 11.72, and 11.73).

With this in mind, it is mandatory to carry out the restorative procedures following the most conservative possible way avoiding unnecessary further sound tooth substance removal, respecting what the European Expert Consensus stated about

Fig. 11.10 The case at 2 months' follow-up. The Maryland bridge (tooth 12) and the ceramic laminate veneer (tooth 22) have been adhesively luted and the soft tissues surgically modified. The edentulous ridge (tooth 12) was thickened with a connective tissue graft, and the marginal periodontal tissues were apically shifted with a crown lengthening flap combined with osseous surgery: this last to uncover the anatomical crown recreating the zenith on the gingival margins of the central incisors

the management of severe tooth wear in 2017: "…there is a shift in restorative treatment protocols for the management of tooth wear towards minimum-intervention approaches" [11].

11.2 Tooth Preservation and Biomimetic

In microdontia, as in erosive cases, reintegration of the already-absent or lost enamel by adding the artificial one without any further sacrifice represents a "must" to be followed in the attempt to preserve at its best mechanical tooth strength [12, 13] fulfilling the biomimetic principle [14, 15].

As a matter of fact, every unnecessary enamel removal implies an increase of coronal flexibility and strains as in the case of conventional prosthetic preparations.

For these reasons, all the partial bonded restorations and the no-prep additive techniques [16–19] are actually more and more indicated both in solving eroded and worn dentition and also in cases of young teenagers suffering from dimension anomalies [20] and realized in place of the complete conventional crowns; in this "adhesive world," the veneering anterior bonded restorations play a role of paramount importance.

11.3 The Digital Evolution and the CAD/CAM Techniques

As already mentioned, one of the possible ways to be followed in realizing the veneers is represented by the CAD/CAM path (CAD means computer-aided design and CAM means computer-aided manufacturing).

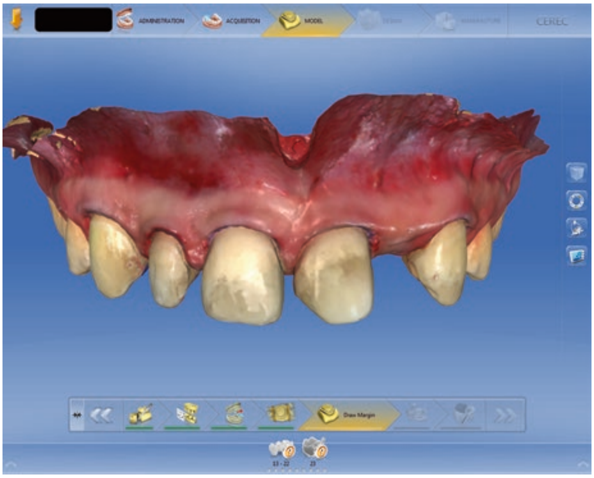


Fig. 11.11 An example of digital impression

The first step in realizing an indirect restoration is represented by the impression: the scanner is able, in many situations, to replace the intraoral conventional impression usually performed using an elastomeric material (silicon or polyether) ensuring an optimal precision of the poured cast.

The digital impression transforms the dental arches in a file on the computer screen ready to be processed, converting an object into a digital image (Fig. 11.11).

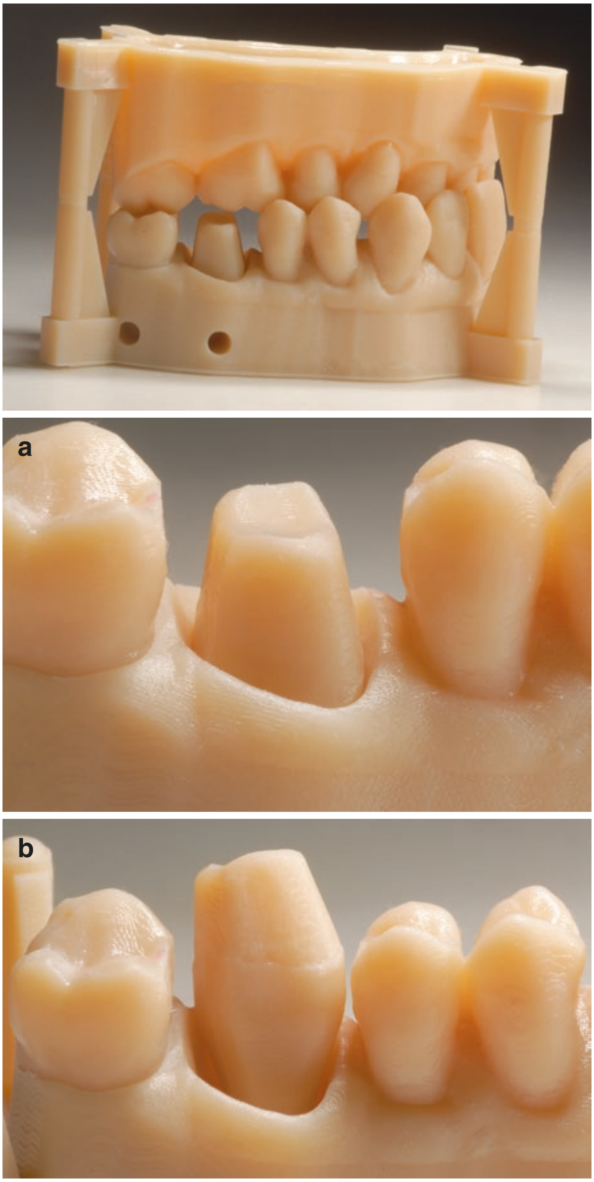
There are two possible ways to follow in taking a digital impression: **extra-orally** and **intra-orally**.

In the first case, the dentist takes a conventional impression, and in the lab, the technician, once poured a stone model, takes an optical impression by means of a scanner of this in order to start the digital work.

In the second case, conversely, the dentist takes straightway intra-orally the scan, alias the digital/optical impression, in place of using the silicons or polyether materials; in this last situation, the analogical model of the dental arches does not exist, and all the procedures are mostly performed in a virtual world. Sometime it is suitable for the dental technician to handle and finish the restoration positioned on the model; in the case of intraoral scan, there is no model, and so it would be appropriate to print, with a digital 3D printer, a resin model on which it is possible to position the restoration in order to finalize the work (Figs. 11.12-13a-13b).

11.4 The Rationale of the CAD/CAM Choice and Possible Indications

There are two main reasons and advantages, among others, in following a CAD/CAM path especially using an intraoral scanner: first of all is the access to new materials with improved characteristics that are mainly processed in a digital way.



Figs. 11.12-13a-13b Some examples of 3D printed models starting from an intraoral digital impression. It is possible to place the opposing arches in maximal intercuspation and to realize the removable dies (13a–13b)

The second reason is that, with an intraoral optical impression, it is possible to realize and finish in a “single appointment” an indirect restoration; this is usually called the “chair-side” approach. This kind of procedure can be finalized either by the dentist (**“chair-side”**) or by the cooperation of the technician in the dental office (the so-called **assisted chair-side**). It is easy to understand that, with the small

Fig. 11.14 The digital impression on the inLab software; it is obvious that there is a learning period to be considered to use the scanner and the program to design the restorations

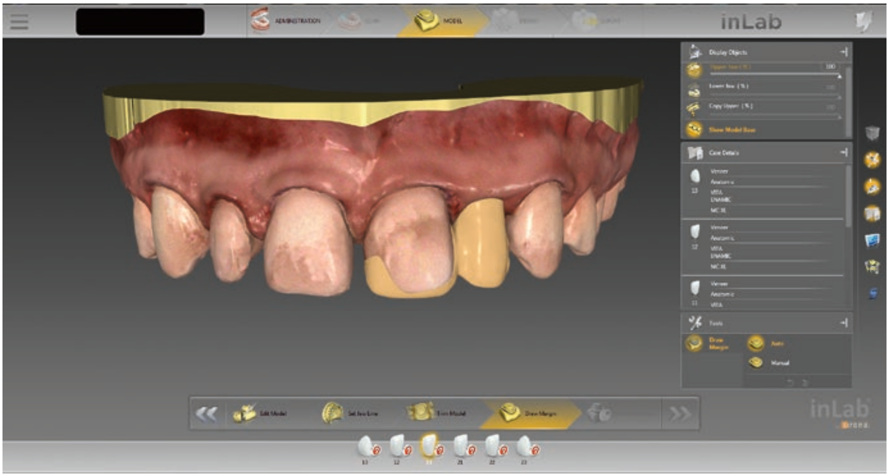


Fig. 11.15 In this clinical case, for example, a Maryland framework project is represented: on the buccal side, it is present the space for a composite CAD/CAM veneer to be luted

amount of time usually at disposal to the patients, the opportunity to finish in only one appointment an indirect restoration represents a great and innovative alternative.

There are obviously some negative aspects to consider in relation to this procedure. The first one is the cost of the device that is not negligible and needs to be used and time to be financially amortized in relation to the dental office budget.

The other one concern the learning curve needed to learn to use both the scanner and the program to design the restorations (Figs. 11.14, 11.15, 11.16, 11.17, 11.18, 11.19, and 11.20).

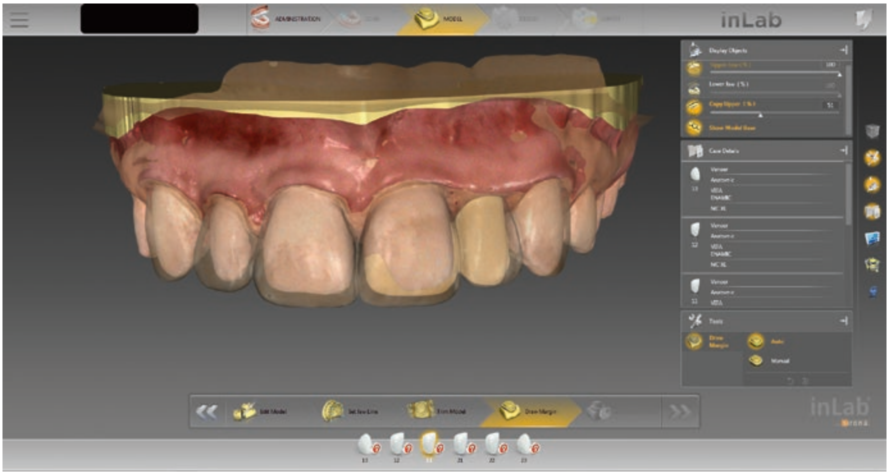


Fig. 11.16 The six anterior CAD/CAM veneers project: on the buccal side, it is evident the superimposed wax-up. To obtain a good and harmonious result, it is foreseen to carry out six veneers made with the same material. One of them will be luted on the zirconia Maryland bridge

Fig. 11.17 The copy lines (white) are drawn on the wax-up digital impression and matched with the abutment teeth

Without any doubt, the chair-side digital workflow actually represents a very good treatment option, especially in the molar and premolar area [21] taking progressively the place of various intraoral and extraoral techniques [22–24]: the long-term success rate is very high ranging from 84.4% [25] to 89% [26] until 95.5% [27] and reaching 96.5% [28].

Fig. 11.18 The achieved final result after a "manual" correction of the initial proposed restoration. The tooth 21 has been made transparent, and it is possible to see the underlying palatal Maryland bridge supporting the missing lateral (tooth 22)

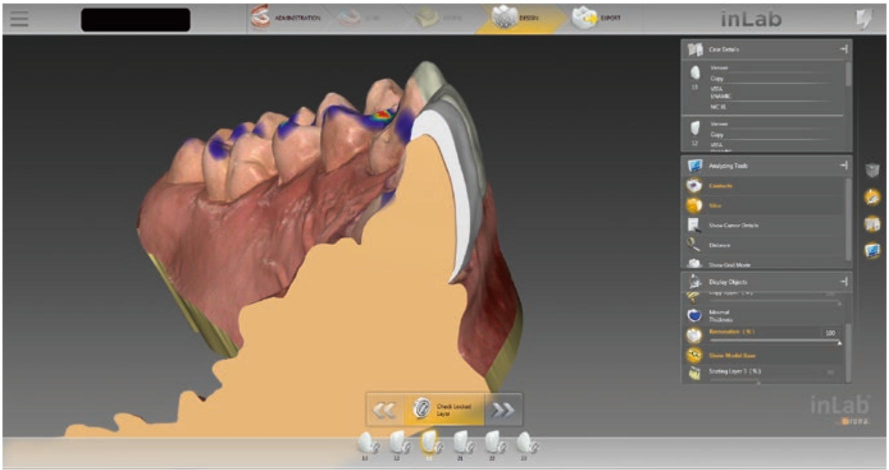


Fig. 11.19 The buccolingual section of a veneer

Nevertheless, recently, more and more clinical interest is upraising in the anterior CAD/CAM veneers as a possible chair-side alternative approach to the conventional porcelain laminate veneers [29–32].

In realizing the CAD/CAM restorations, both in the anterior and in the posterior area, we can choose between two main categories of materials: the ceramic and the polymers blocks.

Fig. 11.20 The final result before the individual milling phase

The use of ceramic ingots in comparison to the CAD/CAM polymers means more time and a less efficient milling, more possible marginal chipping, more difficult to handle, easier to fracture, and more final thickness [30, 33–40].

The CAD/CAM resin matrix ceramic materials represent a good alternative and can have, in our opinion, a specific indication, especially in the anterior area in treating tooth dimension anomalies and congenital agenesis-related problems in young patients.

Moreover, the porcelain analogical realized laminate veneers are indicated too in that particular case, but they are, on average, rather expensive.

The CAD/CAM indirect veneers represent, in our opinion, the first "ideal" option especially for teenagers before or after a scheduled ortho treatment in comparison to both the direct composites for the best and easier predictable results and to the classical porcelain laminate veneers for the reduced costs.

Nevertheless, the accuracy in handling and the delicate luting technique are the same to be followed by the dentist as in case of the conventional one laminate.

We consider this restoration as **"ad interim"** in view of the definitive solution to be carried out once the patient reaches adulthood and the end of the growth achieved together with the marginal periodontal tissue stability [29].

11.5 Step-by-Step Procedures

11.5.1 Setup and DSD

The treatment of young patients with general microdontia and/or congenital agenesis frequently needs an interdisciplinary approach involving from the beginning the orthodontist and the restorative dentist.

In planning the orthodontic treatment, it is immediately taken into consideration the ideal alignment and position of the reshaped teeth; these dimensionally impaired teeth are restored and placed to their adequate position and correct size.

The cooperation between the orthodontist and the restorative dentist is easier following the digital preview that makes possible the following three main steps:

- First of all, the case study starts with a three-dimensional (3D) virtual digital setup that pre-visualizes the final result (Figs. 11.21, 11.22a, and 11.22b).
- In the second step, the digital scans of the arches at the beginning or during the treatment and in the previewed final position are superimposed making a 3D check possible (Fig. 11.23).
- CAD/CAM realization of the restorations that creates the shape of the final teeth is already established in the virtual setup.

Three are available options to manage cases of general microdontia with spaces to close in one or both arches and congenital single (e.g., missing maxillary laterals) or multiple agenesis:

- To restore the "small teeth" to the ideal dimensions in a wrong position before every ortho procedure (Fig. 11.4) and then to carry out the orthodontic treatment straight to the end bonding the brackets to the laminates.
- To restore the "small teeth" to the ideal dimensions during the ortho procedure once they have achieved a position near to the ideal just before the end of the ortho therapy (Fig. 11.21).
- To restore the "small teeth" to the ideal dimensions at the end of the ortho treatment (Figs. 11.64, 11.65, 11.66, 11.67, 11.68, 11.69, 11.70, 11.71, 11.72, and 11.73).

In the first two cases, the correct sized teeth make faster, easier, and more predictable their alignment and the whole orthodontic treatment.

Fig. 11.21 A clinical case of a young patient with microdontia during the orthodontic treatment

Fig. 11.22 (**a**, **b**) The orthodontic upper jaw setup: the initial situation (**a**) above and the six anteriors new sized teeth before the orthodontic treatment below (**b**) (Courtesy of orthodontist Dott. Cocconi Renato)

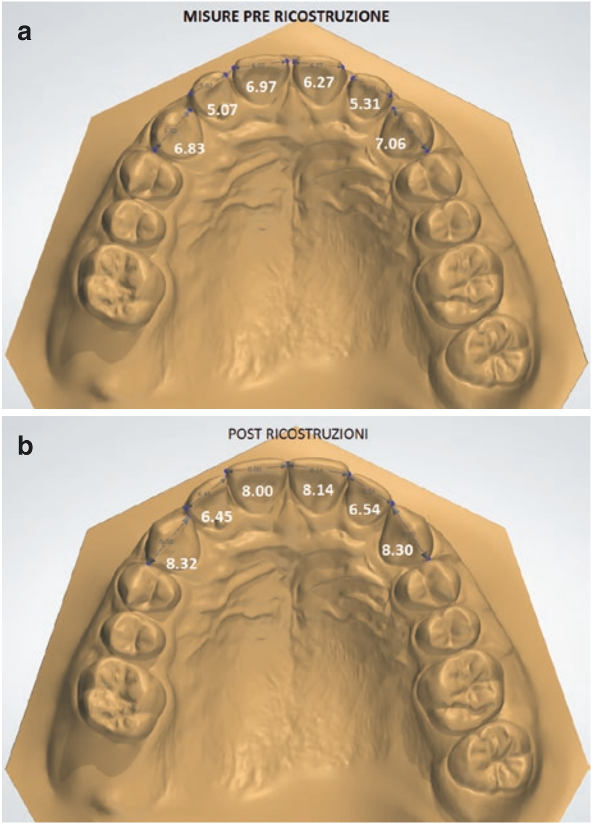
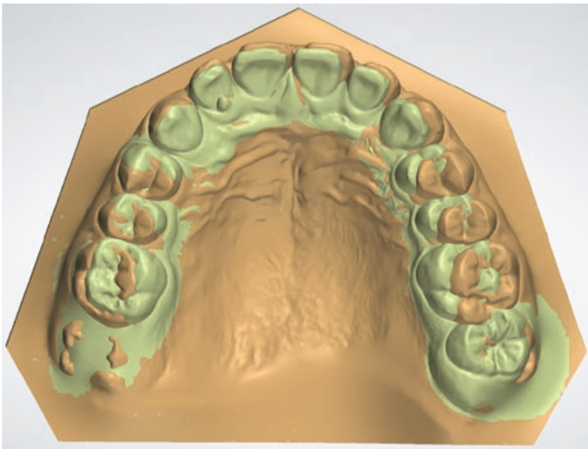


Fig. 11.23 The pre-orthodontic setup of the upper jaw with the final teeth position (green) superimposed to the initial situation (brown) (Courtesy of orthodontist Dott. Cocconi Renato)



Reshaping the genetically impaired anterior teeth, closing the abnormal spaces, and replacing the congenitally absent teeth, the orthodontist and the restorative dentist together ensure an optimal esthetics and, probably, a more stable result creating the interproximal contacts.

Treating young teenager, it is fundamental to improve as much as possible the esthetic appearance given the vulnerability from a social and psychological point of view during this delicate life moment.

When the teeth are almost or already in the final desired position, before the restorations (cases 2 and 3 listed above), it is very useful to make a Digital Smile Design in order to visualize on the computer screen the final result allowing a simpler path to follow with the further lab wax-up realization and clinical mock-up try-in.

In reality this last procedure is followed in every case during the diagnostic preliminary phase before any ortho movement to proceed with a DSD that cooperates and drives the digital setup particularly if the teeth dimensions are to be corrected. Moreover, before the refinement orthodontic phase, a further DSD will be recommended pre-visualizing the ultimate final result as cited before.

The diagnostic DSD begins with a set of full-face high-definition photographs taken in some standard preestablished positions: with the lips at rest, with a wide smile, and with a moderate, teeth apart, smile [41–43] (Figs. 11.24, 11.25, 11.26, 11.27, 11.28, 11.29, 11.30, 11.31, and 11.32).

This important phase allows to check, only by taking some pictures, the possible result and to show this to the patient having his opinion and his approval; in case of unsatisfactory result or/and patient disagreement, we can obviously choose to drive a new DSD with the suggested corrections.

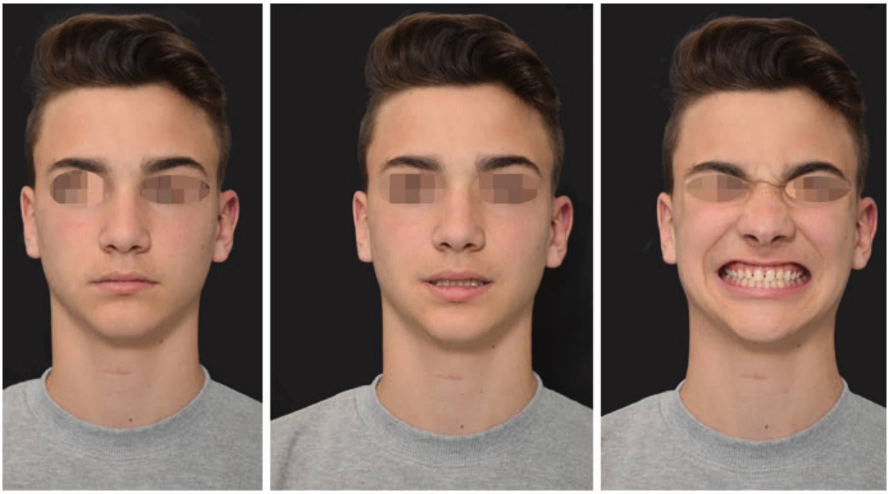


Fig. 11.24 The three main frontal pictures needed to realize a Digital Smile Design (DSD): serious, moderate smile and wide smile

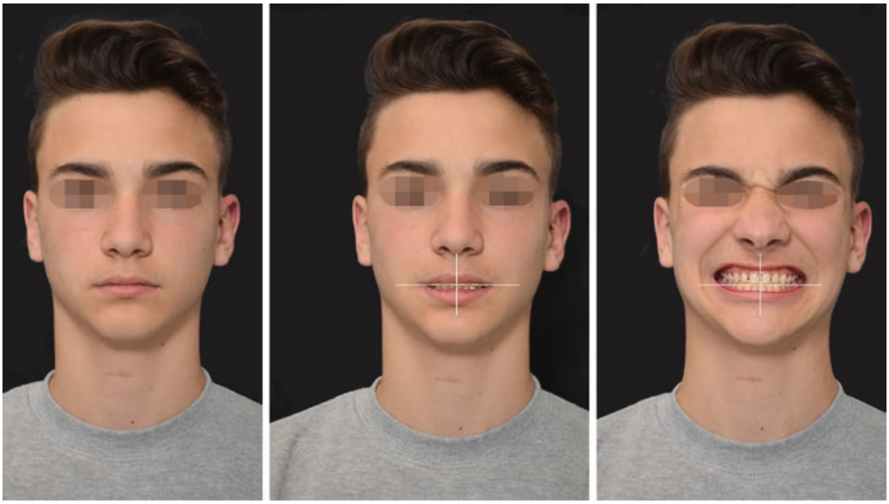


Fig. 11.25 The superimposition of the “cross” (identifying the horizontal and vertical reference planes) and the lip in the different positions (moderate and wide smile)

Fig. 11.26 First of all a virtual ruler is “calibrated” measuring the intraoral mesio-distal teeth dimensions in comparison to the size of the same teeth reproduced in the photograph. The actual teeth outline is designed and transferred the lip position lines previously recorded

Fig. 11.27 The width–height actual proportion of the central incisors is measured and the tooth inscribed in a corresponding rectangle

Fig. 11.28 A rectangle with the "ideal" width-height ratio is placed over the central incisors to compare the initial dimensions to the "ideal" ones

Fig. 11.29 The new "ideal" teeth shapes are drawn following the same procedure for the whole upper jaw

Fig. 11.30 If necessary also the gingival scallop is reshaped according to the superimposed lip lines to obtain a "natural" teeth display

Thanks to the digital preview, it is possible to mimic a modification of the gingival scaffold if necessary like in cases of gingival scallop disharmony (recessions, altered passive eruption of the gingival margins, etc.) or gummy smile showing the final result of the periodontal surgery [44] (Figs. 11.55, 11.56, 11.57, 11.58, 11.59, 11.60, 11.61, 11.62).

However, we are convinced that this approach does not replace the analogical way but somewhat represents the preliminary stage in order to address with more accuracy the mandatory wax-up and the following mock-up [45, 46].

Fig. 11.31 The final teeth outline (yellow) compared to the initial one (white). This step allows to measure in millimeters the differences existing from the beginning and the final foreseen result

Fig. 11.32 The new sized virtual teeth inserted in the whole face: the initial wide smile (left) and the corresponding virtual designed (right)

Actually, there are many possible options to follow in realizing both the wax-up and the resulting mock-up more or less conventionally or digitally realized as listed below:

- Fully analogical: pictures and models + DSD and wax-up + mock-up printed by means of silicon index.
- Mixed: pictures, DSD, intraoral scan, printed models, handmade wax-up realized on the printed models (Fig. 11.63), and mock-up printed intra-orally by means of a silicon index.

- Digital: pictures, DSD, intraoral scan, digital project/digital wax-up, and printed model of the digital wax-up, silicon index realized on this model, and mock-up printed intra-orally by means of this last.
- Digital: pictures, DSD, intraoral scan, digital project/digital wax-up, and 3D printed indirect mock-up to be positioned in the mouth.

Nowadays the most followed alternative is the fully analogical one but, in the near future, with the technological improvements, the others, second and third especially, will be probably followed more frequently than today.

Traditionally the wax-up is realized by the technician on the poured plaster casts following the average teeth proportions [47], and it is three-dimensionally inserted in the gingival scaffold, in the lip frame, and finally in the whole patient face.

It is well-known that the teeth dimensions as length and width primarily vary depending on the patient sex: the width/length proportions play an important role indeed and are reestablished, thanks to the wax-up.

Creating the new harmonious teeth shape has to take in great consideration their positioning in relation to the face horizontal and vertical esthetic reference lines on the basis of the information suggested by the DSD shared with the patient.

To obtain a good project integration on the whole facial frame, the marks graved on the model surface, representing the facial landmarks, are of paramount importance as, principally, the vertical midline (middle face line) and the horizontal (interpupillary and commissural lines) (Figs. 11.33 and 11.34); about this there is also a tool (Ditramax) [48] that carries out this task easily establishing on the patient and in transferring, to the stone cast, the frontal and sagittal reference lines.

Similar to the DSD, the wax-up can modify the gingival scallop overlapping the marginal tissues on the stone if suitable in cases of inappropriate gingival positions as in the gummy smile cases, for example.

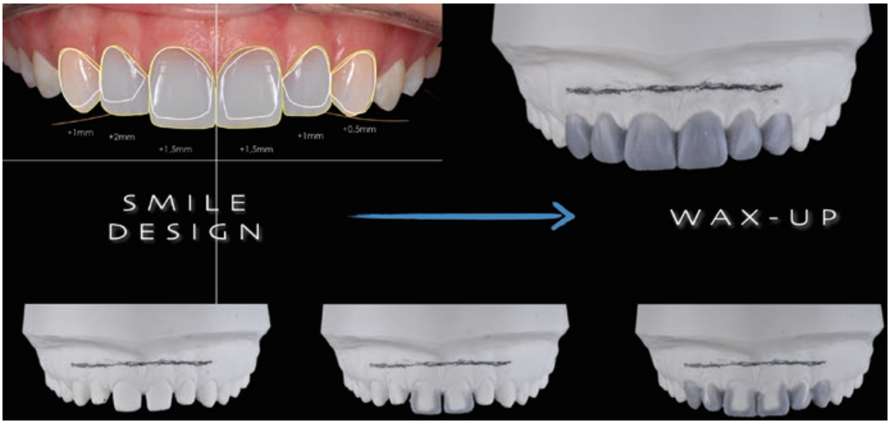


Fig. 11.33 The differences measured in the teeth shape and size obtained, thanks to the DSD, can easily drive the following wax-up

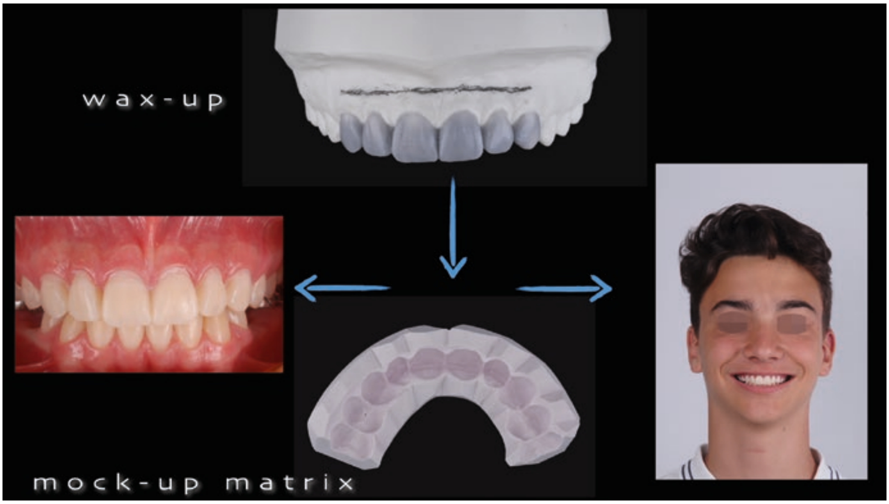


Fig. 11.34 The intraoral printed mock-up obtained, thanks to the silicon matrix derived from the wax-up

This procedure will allow to mimic the results of a periodontal surgical repositioning with the following intraoral mock-up (Figs. 11.55 and 11.56).

Once completed, it is created a silicon matrix of the wax-up (Figs. 11.34 and 11.63); thanks to this silicon key, it is possible to mold directly in the patient mouth an acrylic template using a self-curing resin (Protemp 4 3 M ESPE Temporization Material, Germany): **the intraoral mock-up** [49–51] (Figs. 11.33, 11.34, 11.35a, 11.35b, 11.35c, 11.56, 11.65, 11.66a, 11.66b).

It is very important that the silicon matrix is realized using a rigid material with a Shore A hardness of 80–85 (Platinum 85, Zhermack) in order to make easy his intraoral handling avoiding any possible distortions.

To improve the detail reproduction, it is recommended to place the silicon matrix under 2 atm pressure during its setup [52].

In an attempt to ensure a stable and correct intraoral positioning, the silicon matrix should overlap almost two distal unwaxed teeth: this will allow the realization of an undistorted resin mock-up.

Once hardened, the resin excess is removed either with a bur or with a blade: in case of a weekly try-in, the facial enamel is spot etched for few seconds (10–15 s) and placed a thin layer of bonding light cured after the complete resin setting to secure a better mock-up retention.

It is of course possible to improve the result, as usually the restorative dentist do with the temporaries, performing some small modifications of the molded mock-up intra-orally; in this case it is strongly suitable to take its impression, no matter if

Fig. 11.35 **(a–c)** The face's photographs of the printed mock-up. The diagnostic phase is completed with the clinical try-in of the foreseen result

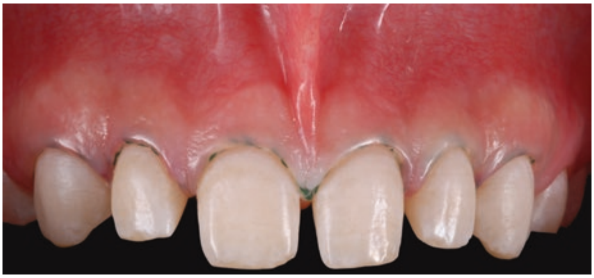


Fig. 11.36 In this particular clinical case, no tooth preparation is needed. The digital impression is taken with a scanner of the natural healthy teeth once a retraction cord is inserted into the sulcus

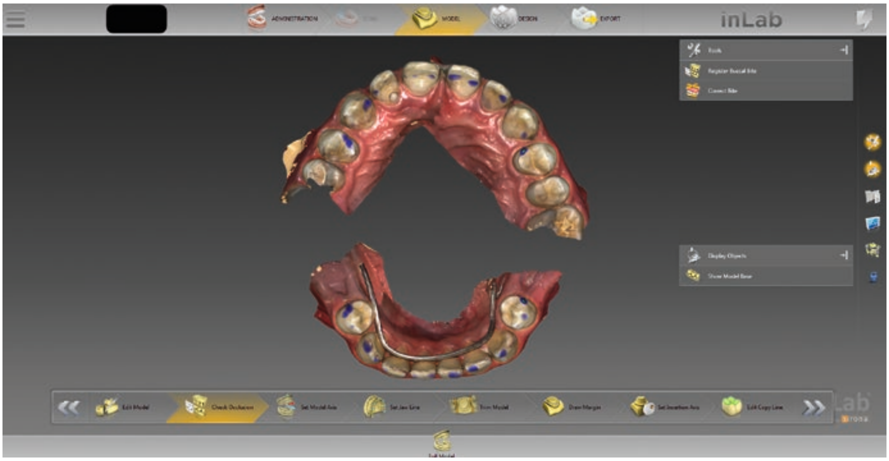


Fig. 11.37 Once the digital impression is taken, it is possible to check on the screen the occlusal contacts of the opposing teeth

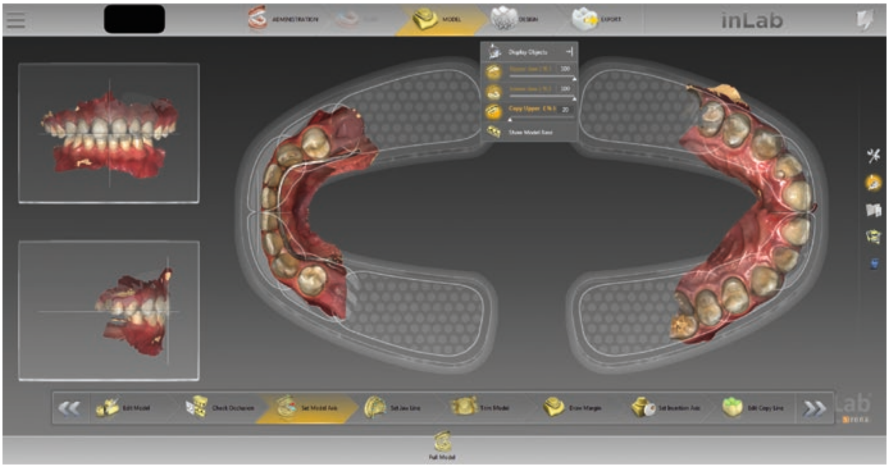


Fig. 11.38 First of all it is necessary to set the model axis inscribing in a virtual template the corresponding arches

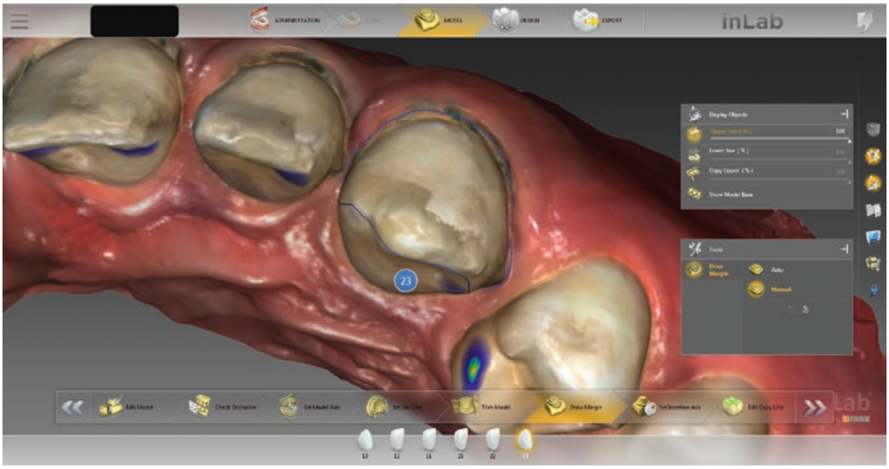


Fig. 11.39 The virtual "margin" (blue line) is drawn on the abutment teeth. In this "no-prep" case, no margin exists at all! The designer has to establish where to place the end of the restorations on the sound hard tissues

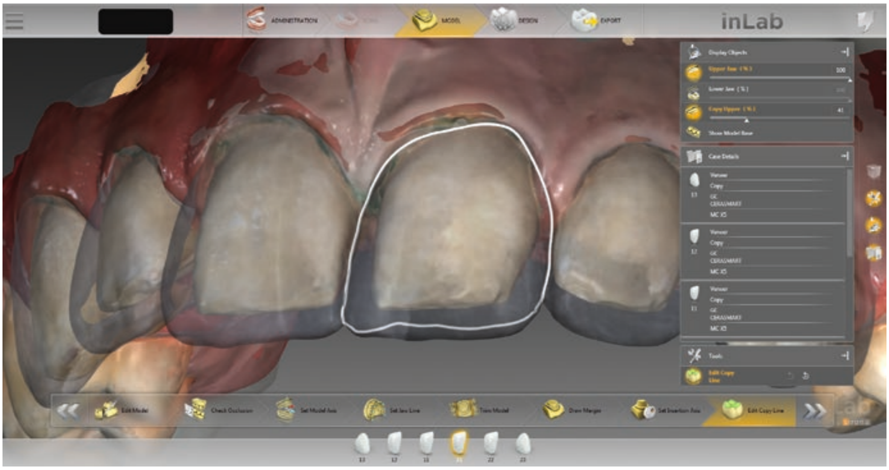


Fig. 11.40 The copy lines (white) are drawn on the wax-up digital impression matched to the abutment teeth. Making the wax-up (gray in the picture) partially transparent, it is possible to see the underlying matched abutments

digital or conventional, to transfer to the technician this valuable information in view of the final veneers.

The mock-up is obviously tested intra-orally as it concerns the phonetics and the esthetic points of view [53, 54].

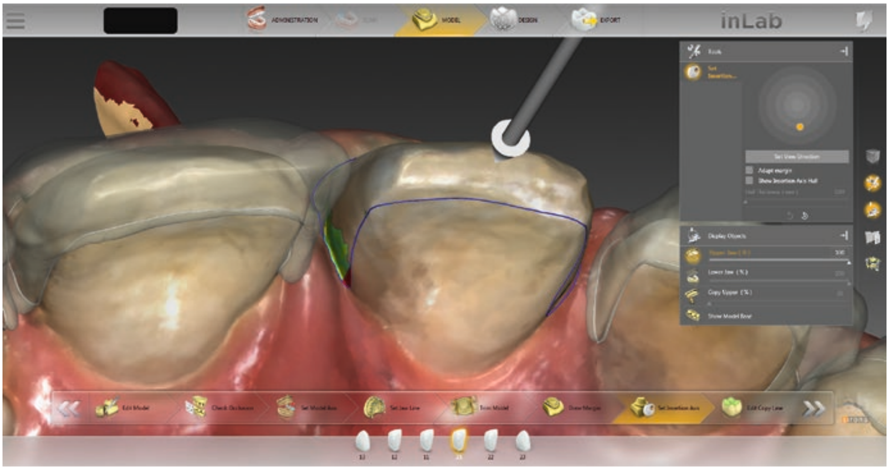


Fig. 11.41 In the following step, the insertion axis of every restorations is set. This last greatly depends on the presence of possible undercuts (green areas)

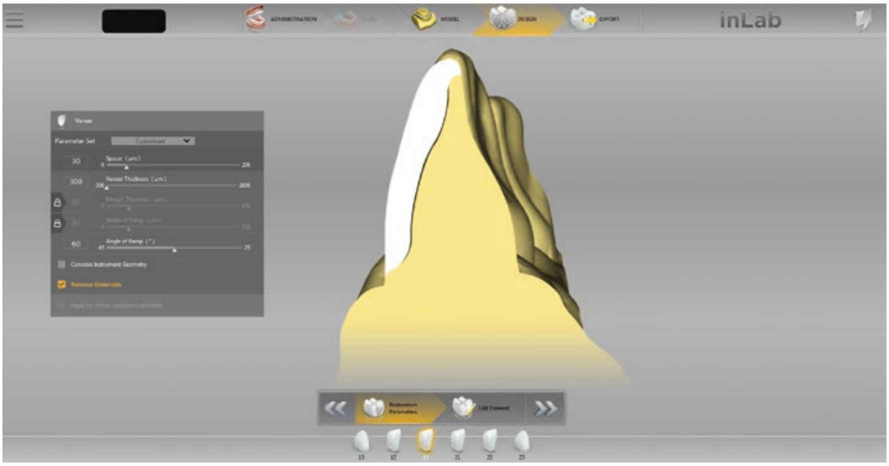


Fig. 11.42 The restoration parameters as the virtual spacer, the veneer and the margin thickness, the interproximal contact strength etc. are set

Also the gingival display is considered with great attention in view of an eventual periodontal surgical phase to attain the best teeth dimensions in accordance with the average width/length ratio [44, 47, 52].

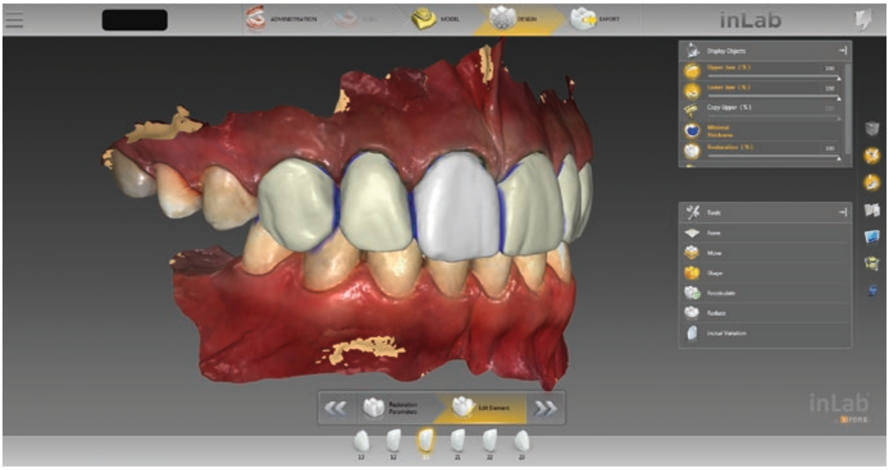


Fig. 11.43 The restorations are proposed from the software respecting all the parameters previously set, according to the drawn margins and the copied wax-up acting as a reference

Fig. 11.44 It is possible to make the restorations, one by one, more or less transparent and therefore to see the underlying abutments. The interproximal red spots means too strong interproximal contacts not in accordance with the parameters previously set

11.6 The Mock-Up-Driven Preparation

In order to respect, as much as possible, the sound tissues but, at the same time, to create the correct space for the adhesive restoration, it is mandatory to use the mock-up as a guide for the minimally invasive prosthetic preparation, making calibrated depth cuts directly on the added resin [45, 46, 55, 56].

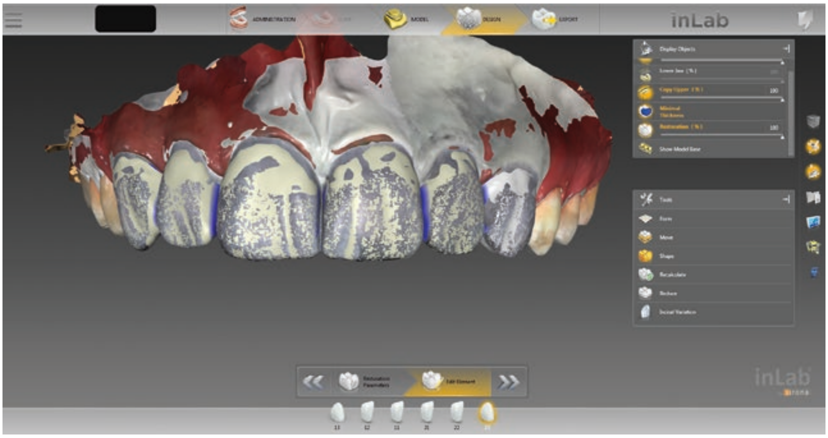


Fig. 11.45 The gray areas represent the wax-up superimposed to the restorations proposed by the software. Many are the tools that can be used to change this project improving the final result

Fig. 11.46-47 The achieved final result after a "manual" correction of the initial designed restoration

Fig. 11.48 The six additive CAD/CAM milled veneers realized with a resin matrix ceramic material (Cerasmart GC): a chair-side path assisted by the technician was chosen. We are ready for the luting step

Fig. 11.49 The "abutments" (i.e., the natural untouched "small" teeth) ready for the luting step

Fig. 11.50 Since the a-prismatic enamel (no bur was used) is still present, it is mandatory to sandblast it for 5 s. with an aluminum oxide 50 μm powder before its etching. The rubber dam is used on every single tooth and kept in place with the fingers to avoid any possible marginal tissue damage

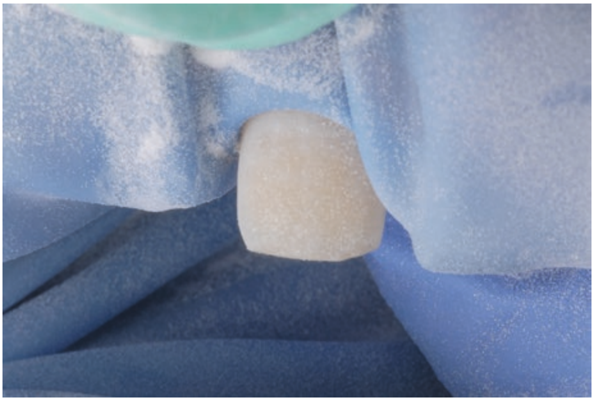


Fig. 11.51 The "abutments" after the sandblasting and immediately before the field insulation: notice the two small buccal spots on the upper right lateral and cuspid not well treated. It is necessary a quick correction

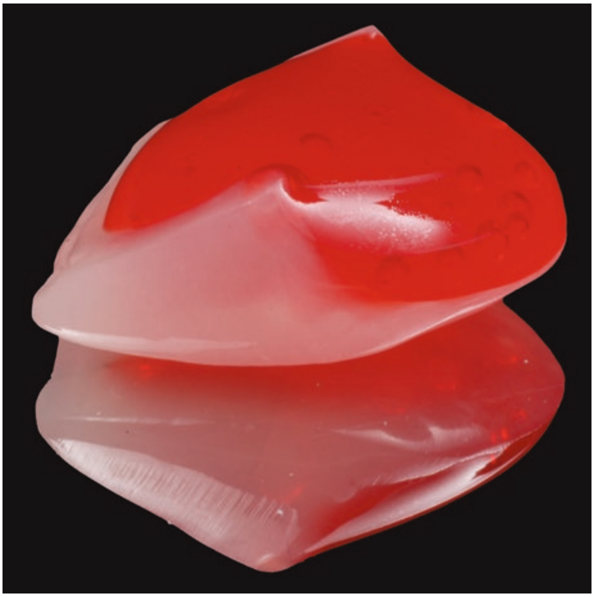


Fig. 11.52 The restoration's intaglio surface etching with a 5% hydrofluoric acid for 60 s

Fig. 11.53 The veneers are luted in place; the patient can be finally orthodontically treated cementing the brackets on their buccal surface

Fig. 11.54 The patient with the brackets cemented on the laminate veneers; the orthodontic phase can be carried out faster and easier (Courtesy of orthodontist Dott. Cocconi Renato)

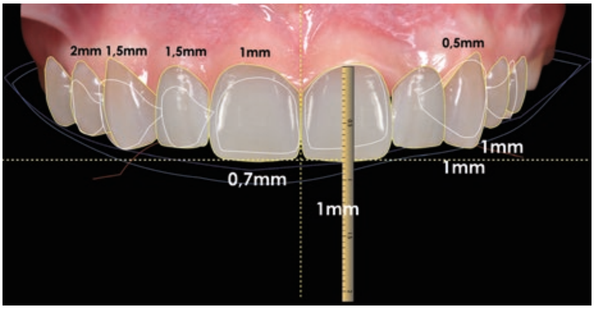


Fig. 11.55 A further clinical case. The new “ideal” teeth outline (yellow) superimposed to the actual one; it is evident the microdontia and the gingival scallop to be corrected

Fig. 11.56 The printed mock-up overlaps the marginal periodontal tissues guiding the surgery

Fig. 11.57 The upper jaw before the surgery. The gingival scallop has to be modified

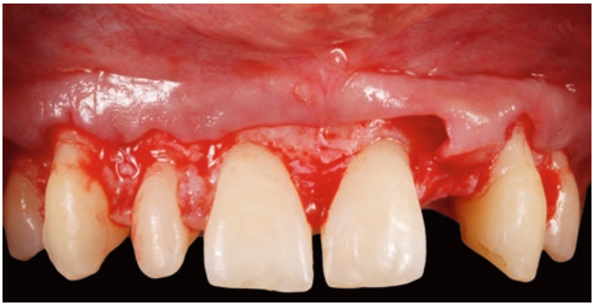


Fig. 11.58 The full-partial thickness flap raised

Fig. 11.59 The mattress sutures at the end of the surgery

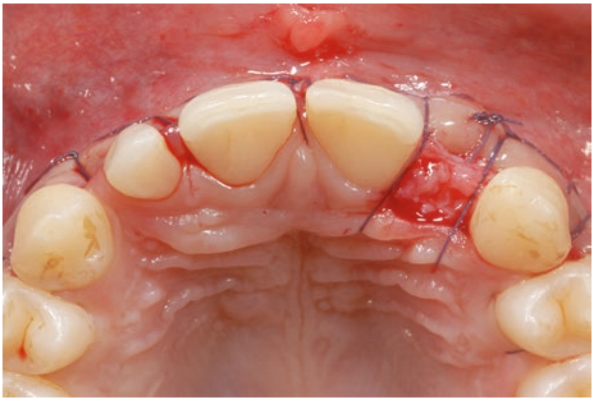


Fig. 11.60 The edentulous ridge thickened, thanks to a connective tissue graft inserted buccally

The extent of tooth reduction (TR) is represented by the difference between the extra added volume (EV) and the laminate veneer thickness (LT): TR = EV − LT.10 [57].

The tooth preparation is carefully guided by calibrated horizontal depth grooves: a straight one in the middle crown third and a scalloped one in the cervical one. We usually perform the depth grooves by using two different round diamond burs, assuring a 0.3–0.5 mm space in the cervical third and a 0.5–0.7 mm space in the middle third.

In the incisal margin, the minimal recommended clearance to be created is 1.5 mm [45, 58].

Figs. 11.61-62 The 3 months' healing follow-up

Fig. 11.63 The silicon index on the wax-up realized on the 3D printed models: we are now ready to mold intra-orally the mock-up

Every attention must be taken to avoid any dentinal exposure keeping the preparation inside the enamel thickness!

It is well-known how thin the enamel is at the level of the dentin–enamel junction [59]; every attempt is performed to preserve this thin enamel layer in order to achieve the best adhesive result and to assure a high fracture toughness [60].

Especially when there are residual spaces and/or microdontia, it is necessary to wrap with the laminates the mesio-distal tooth surfaces.

Fig. 11.64 One more clinical case. The frontal view of a young patient at the end of the orthodontic treatment (upper lateral agenesis); the two upper cuspids are positioned in place of the laterals and the two upper premolars in place of the cuspids

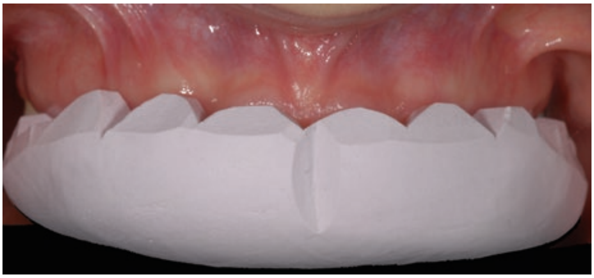


Fig. 11.65 The wax-up (guided by the DSD) impression made by a stiff silicon material to be placed in the mouth as mold for the mock-up resin

Fig. 11.66 (**a**, **b**) The wide smile with the printed mock-up

Fig. 11.67 The teeth after the bleaching right before a minimally invasive surgical phase

Fig. 11.68 Based on the DSD and the following mock-up, a flap was raised in the cuspid area to shift apically the gingival scallop after a minimal amount of bone surgery

If, in this particular case, interproximal undercuts are present, interfering with the laminate insertion (also in case of horizontal insertion path) during the luting, we are given two possible solutions:

- Undercut removal.
- Undercut filling (before or after the veneer cementation).

The first, more aggressive, option can be followed in case of limited undercuts; in that case, it is important to foresee the end of the preparation with the enamel still present.

The second, more conservative, option consists in the filling of the undercuts with composite recreating a "new artificial apically positioned dentin–enamel junction" modifying the interproximal tooth shape from a triangular one in a squarer form, in a similar way as proposed in view of closing multiple diastema [61–66].

This procedure can be carried out either before the tooth preparation or after the veneer cementation; in this latter case, the cemented veneer could act as "guide" in the composite buildup, being the palatal side of more difficult access.

In the first case, when the procedure has been carried out before the tooth preparation, conversely, the newly created composite emergence profile has to be prepared by the bur likewise the natural enamel before taking the impression, making a new artificial margin (composed by the buildup restoration) in the horizontal (bucco-lingual) dimension similar to that proposed by Dietschi and Spreafico with the so-called deep margin elevation in the vertical one (apico-coronal) direction [67, 68].

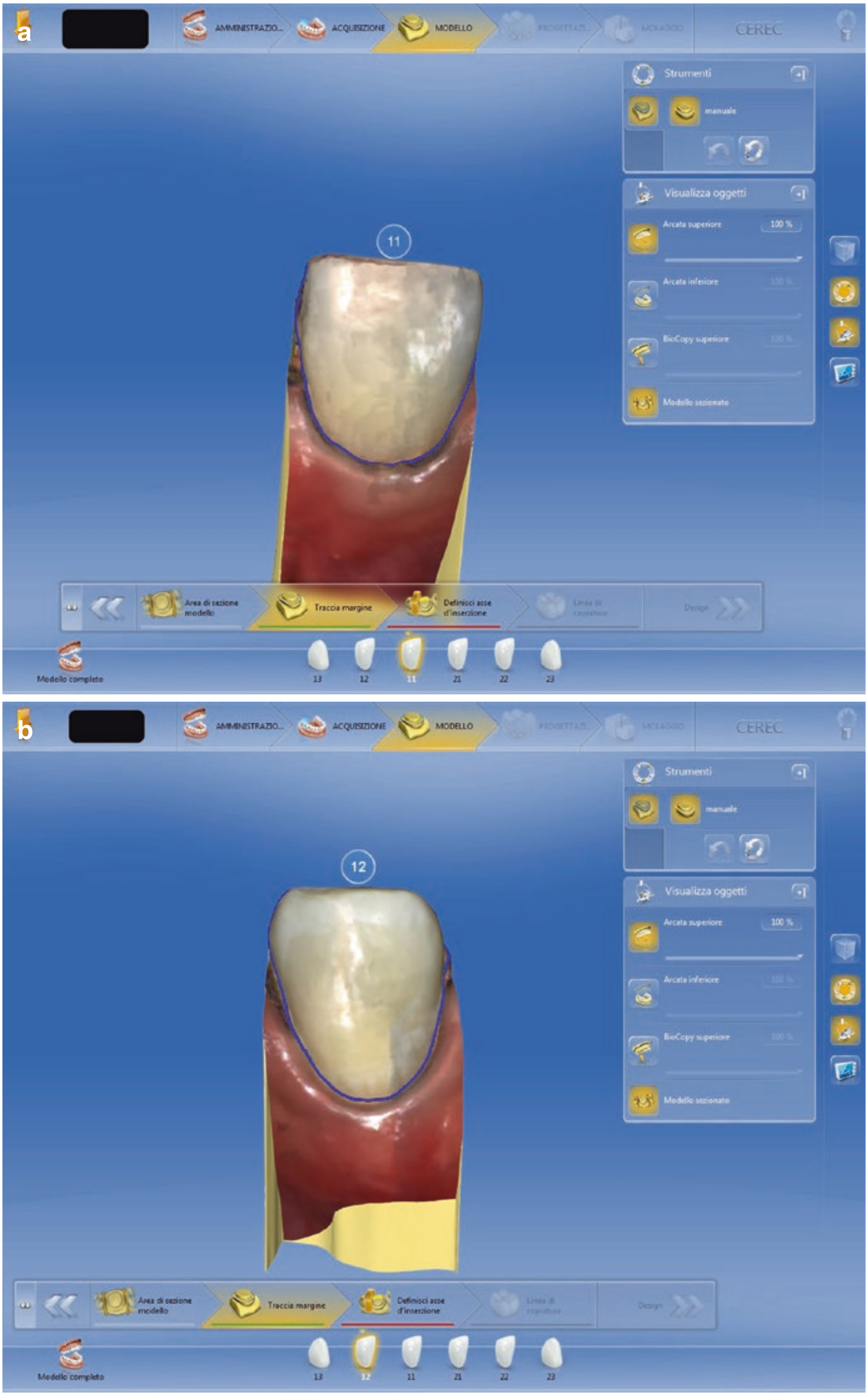


Fig. 11.69 (**a**–**f**) Screenshots from Cerec SW 4.4.4. The finishing lines

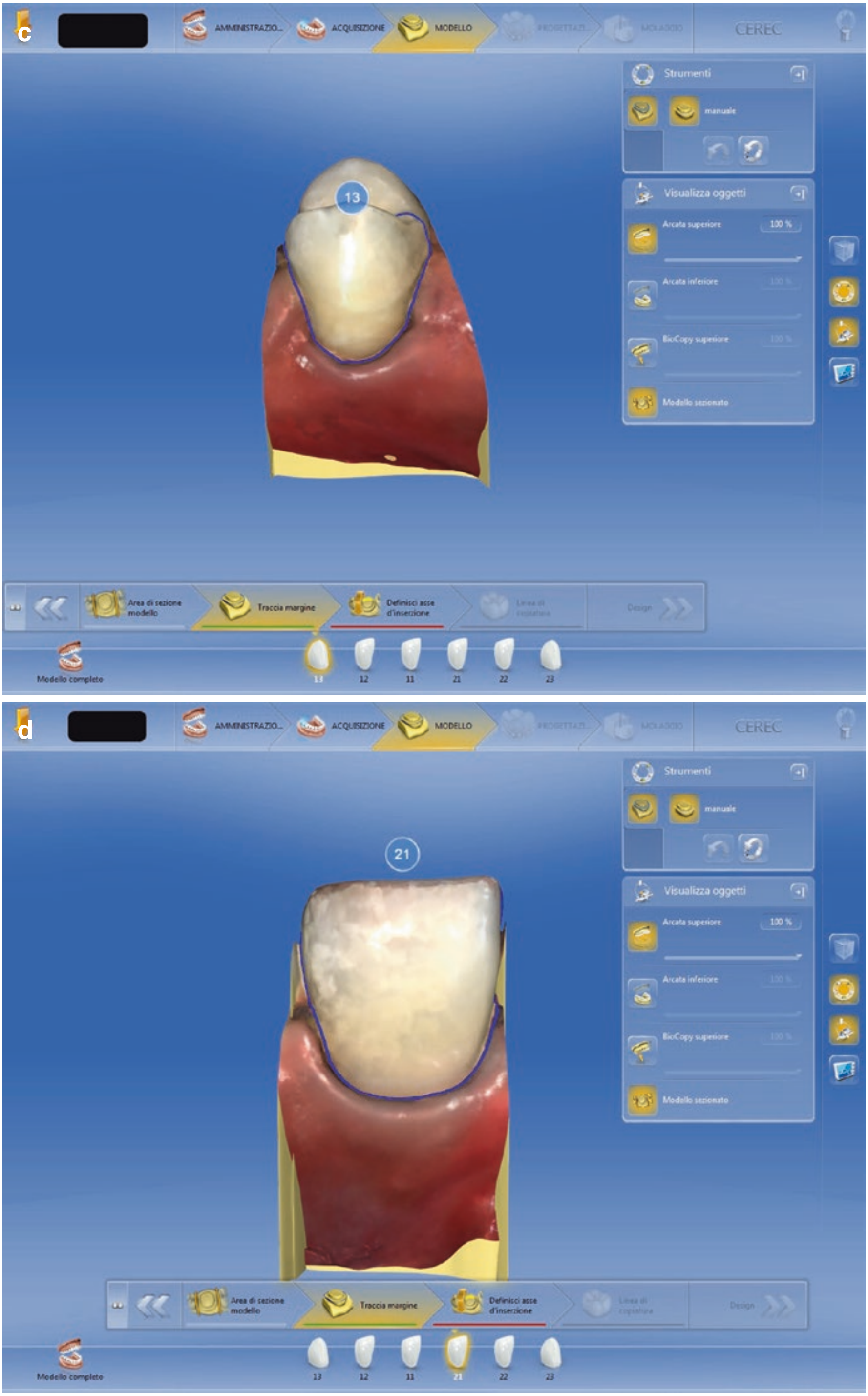


Fig. 11.69 (continued)

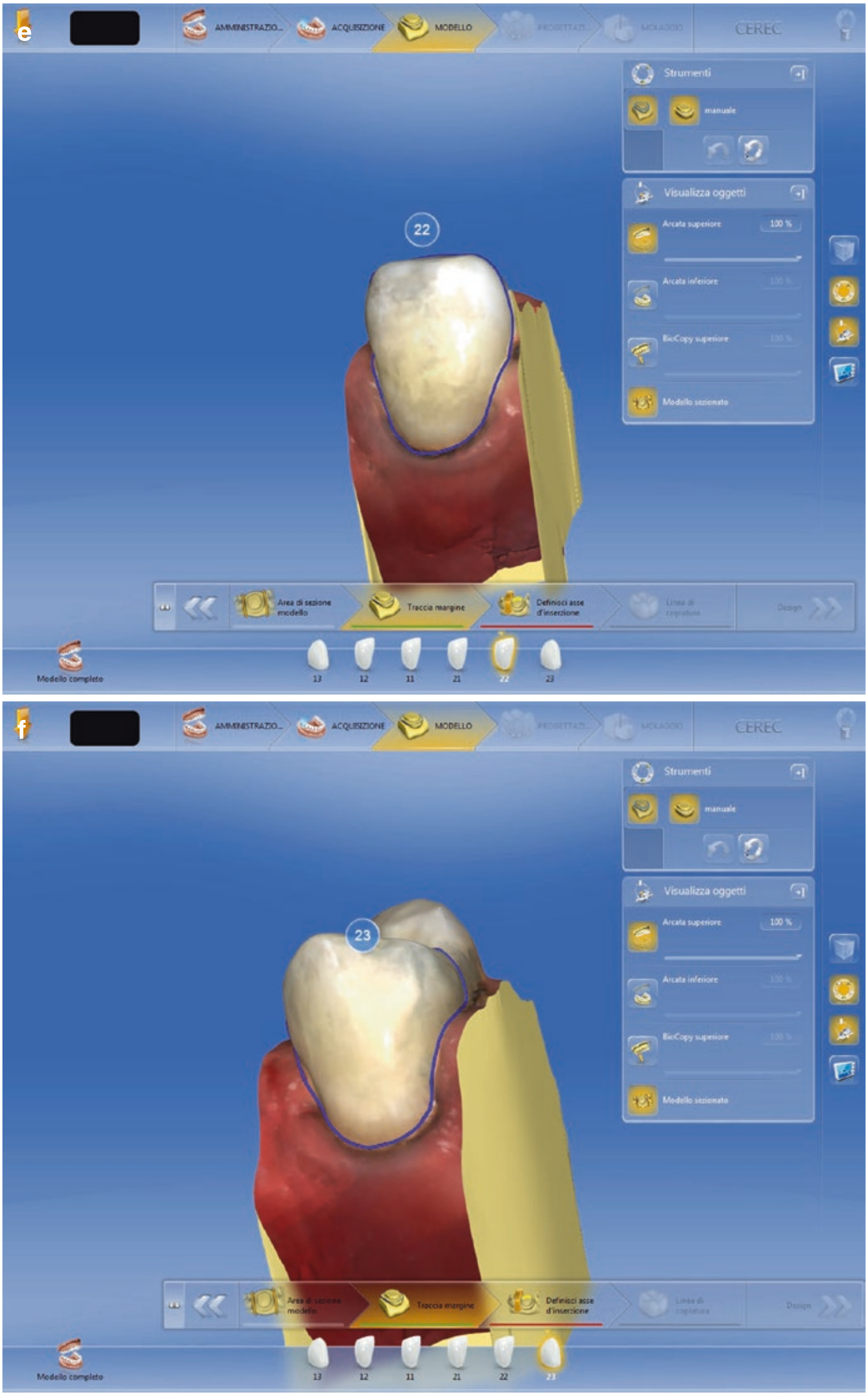


Fig. 11.69 (continued)

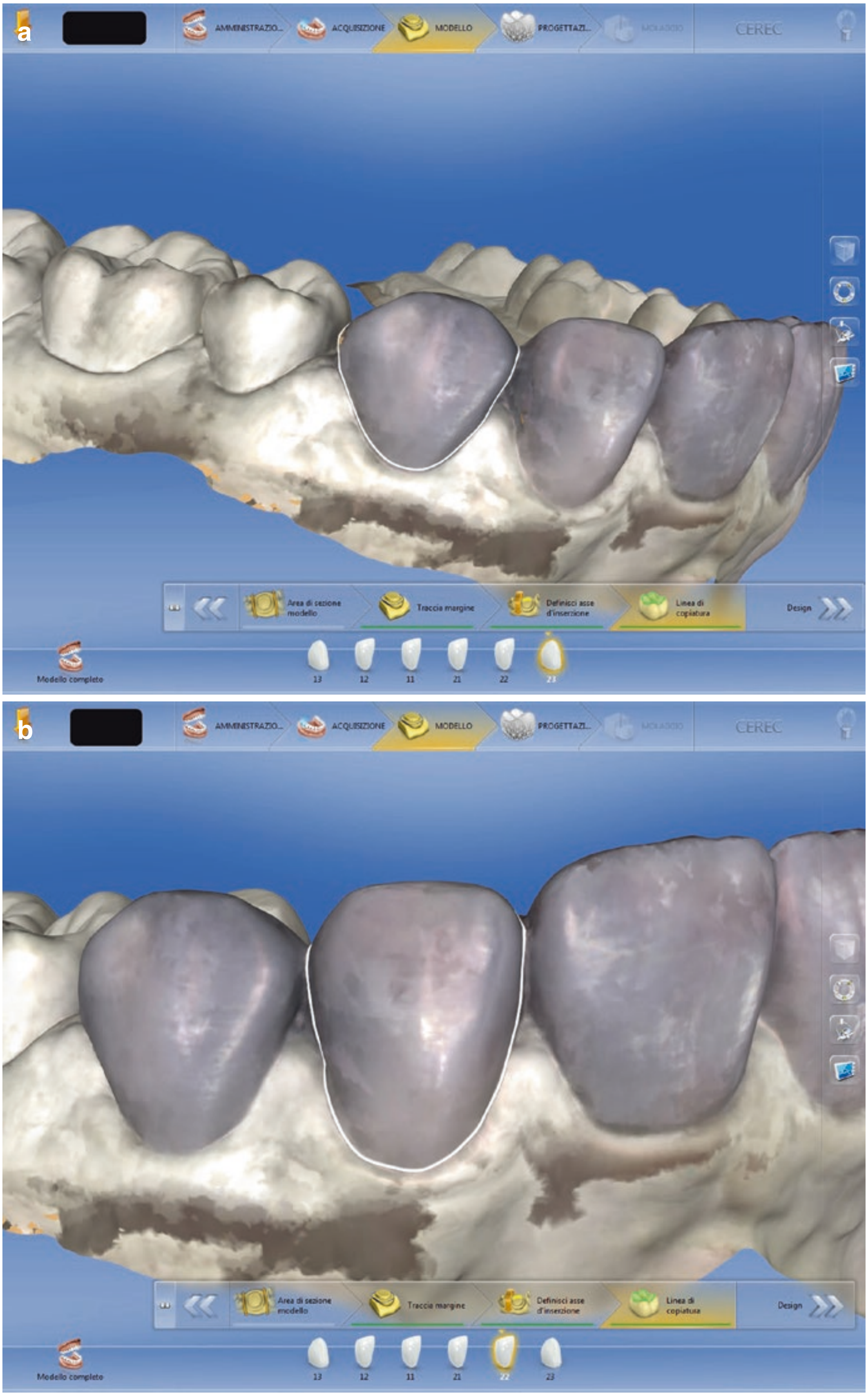


Fig. 11.70 (**a**–**c**) Screenshots from Cerec SW 4.4.4.: the copy lines on the diagnostic wax-up

Fig. 11.70 (continued)

Fig. 11.71 The frontal view at the end of the whole treatment; the six anteriors reshaped with CAD/CAM ultrathin no-prep veneers

One negative consequence of the interproximal composite buildup is related to the negative influence due to the thermal stress induced by his contact with the porcelain laminate [69].

If none of the previous procedures, preparation and undercut elimination or undercut filling, were carried out, the interproximal area will present an unnatural shape with a palatal niche inducing impossible plaque removal and therefore interproximal plaque accumulation with periodontal inflammation and increased caries risk.

Fig. 11.72 (**a**, **b**) The smile surrounded by the lip frame: before (left) and after (right)

Fig. 11.73 The 1-year follow-up

In some cases, the restorations are entirely additive, and, obviously, all the previous steps and the considerations about the tooth preparation become unnecessary and vain in order to only add a new "skin" to the present untouched enamel! (Figs. 11.21, 11.22, 11.23, 11.24, 11.25, 11.26, 11.27, 11.28, 11.29, 11.30, 11.31, 11.32, 11.33, 11.34, 11.35, 11.36, 11.37, 11.38, 11.39, 11.40, 11.41, 11.42, 11.43, 11.44, 11.45, 11.46, 11.47, 11.48, 11.49, 11.50, 11.51, 11.52, 11.53, 11.64, 11.65, 11.66, 11.67, 11.68, 11.69, 11.70, 11.71, 11.72, and 11.73)

We should take into account, before the impression and the luting steps, the possibility to perform a vital bleaching in case of a too intense chroma and low value (Figs. 11.64 and 11.67).

This eventual treatment has to be ended almost 1 month before the adhesive ultimate step to avoid any possible interference with the adhesion [70].

11.7 The Optical Impression

Once the teeth are prepared or already suitable for the impression, in case of completely additive no-prep veneers, we retract the marginal healthy soft tissues inserting a retraction cord into the sulcus (Fig. 11.36).

This is to highlight the margins or the dentin–enamel junction apically to the future restoration finish line in case of no-prep veneers.

In case of a deeper sulcus (between 1 and 3 mm), it is advisable also to deflect for few minutes the soft tissues by means of a second continuous cord impregnated with aluminum chloride not completely inserted but quite floating in the marginal area in order to displace the marginal tissues away from the area to be reproduced by the optical scanner.

The field insulation is of great importance! The teeth are to be dry, the tongue and the cheeks are to be away, the dental unit light is to be apart, and the scanner is to be cleaned and pre-warmed (to avoid the "fog" formation on the glass).

Frequently the metal surfaces of previous old restorations, if present particularly in the palatal/lingual and interproximal areas, can interfere with the reading process reflecting too much light; if necessary, it is advisable to make these opaque using a special powder to hamper the light reflection.

We start the procedure from the most distolingual corner coming in mesial direction and afterward following the same path on the buccal surface creating a kind of "scaffold" in which to lay the occlusal surface taken last.

The scanner should be kept as much as possible parallel to the reading surfaces and gently moved at constant speed without jumps.

To catch the "in-shadow" surfaces (as the interproximal areas), it is better to "wave" the camera in order to follow the tooth surface inclination catching the smallest details and avoiding black holes.

When the interproximal areas are devoided of papillae, it could be better to fill these empty spaces with any material (OpalDam Green Light Cured Gingival Barrier Ultradent, teflon, cotton pellets, etc.) avoiding the black holes in the virtual model.

The teeth are to be well cleaned from any stain; this problem is particularly present in case of smoking patients. In fact, tar dark stains are misinterpreted by the scanner as holes and not correctly reproduced on the digital model.

The most difficult areas to be read from the scanner are, of course, the zones where the light beams cannot reach the undercuts as the distal and the interproximal areas.

This last problem is due to the camera size that impinges to the adjacent teeth and oral tissues (tongue, cheeks, etc.) and becomes unable of the adequate inclination to lighten the hidden areas.

In order to overcome this difficulty, it is very important to spend enough time in moving and tilting the scanner in many directions trying to catch the last hidden detail with different mouth width openings to relax the perioral muscles allowing the optical camera to attain the magical corner.

In correspondence of the abutments, great care has to be taken to read every surface in detail “rolling” slowly and firmly the camera from the palatal to the buccal.

Finally it is mandatory to take the impression of the two arches in occlusion (maximal intercuspation) to give to the software all the functional informations about the occlusion.

We always also take a digital impression of the tested and eventually modified (with the patient approval) mock-up to match it with the working digital model in order to design the final veneers copying the tried mock-up without losing any previous precious information (Figs. 11.17, 11.40, 11.45, 11.70a, 11.70b, 11.70c).

11.8 The CAD (Computer-Aided Design) Phase

The usual first step to manage the “digital model,” greatly varying depending on the different softwares, is its space orientation in relation to some preformed templates.

Whereupon similar to the conventional laboratory steps, it is necessary to section the digital model in blocks to create the individual dies and to identify the restoration margins.

On the window reproducing the wax-up or the mock-up, it is to be identified the copy lines to be matched with the abutments and their margins (Figs. 11.17, 11.40, 11.70a, 11.70b, 11.70c).

The restoration insertion axis has to be determined too (Fig. 11.41). Moreover, all the setting parameters such as the minimal restoration thickness, the virtual spacing, the marginal precision, the emergence profile angle and the margin's thickness must be verified in advance (Figs. 11.19 and 11.42).

Once all these features have been carried out, the computer begins to work ending with its proposal; on the screen it will be evident the wax-up and, in transparency, the superimposed suggested project (Fig. 11.45).

At this point the “digital designer” can, if it is the case, carry out some customizations, changing the project by using the different available tools (Figs. 11.18, 11.46, and 11.47).

In the project phase, when setting the parameters, it is important to consider that the porcelain veneer thickness must be at least three times that of the luting composite cement; this to avoid the formation of possible cracks inside the laminate veneers [71].

It is also of meaningful importance the precision at the marginal area: the restoration fitting has to be at least less than 100 µm [72].

Once the project is considered to be satisfactory, we go to the last step: the milling phase otherwise named the CAM (computer-aided manufacturing) phase.

At this point, the restoration is spatially oriented into the ceramic/resin matrix ceramic ingot by the software, optimizing the time necessary for the milling procedure.

11.9 The CAM Phase: Milling

The first obvious step is represented by the chosen material ingot insertion in the milling unit fixing it firmly.

The process can be performed by different milling units, and every one of these has its own specific features; some works following on four and other following on five spatial axis.

In the most performing units, the burs are changed automatically depending on which phase is the process ongoing: these burs are different in shape, dimension, and coarseness.

During the initial steps, the most aggressive and coarse burs are used, whereas in the final steps, the finest one takes the place producing a smoother and more defined surface of the restoration.

During the CAD step, it is possible to set in different ways the operating restoration parameters: it is possible to set a fine or extra-fine grinding obtaining a different surface quality, for example, and depending on those factors, the milling step will take more or less time obviously.

Most materials require a wet milling with the exception of the monolithic zirconia that conversely needs a dry milling process.

The minimal restoration advisable thickness usually is 0.5 mm, otherwise it is very frequent the formation of cracks into the material.

11.10 The Printed Model and the Final Restoration

Usually the technician prefers to have a master model to work with and where to try the restorations during their finalization.

Following a complete digital path, it does not exist at all, but it is possible today to print it with a 3D printer.

Once the project is completed with the dedicated software, it is converted in STL open file and inserted in the 3D printer connected software where it is further processed by starting with the model printing on a metal plate where the sintering resin powder will be applied progressively shaping the master model, the pertinent holder, and the removable dies.

The model base can be realized either empty or solid according to the project; during its buildup, the resin powder is pre-polymerized by a LED into the 3D printer.

Once the process is finished, the model is cleaned twice in an ultrasound bath for 5 min, air-dried, and then inserted in a LED lamp for two more minutes to achieve the final surface polymerization.

The technician, at this point, can finalize the restoration having to do with more conventional procedures and a master cast where to place and check the restoration (Figs. 11.12, 11.13a-11.13b).

In this phase, depending on the different materials used, the restorations are superficially colored, sintered if necessary, and then polished. If we use lithium disilicate or zirconia-reinforced lithium silicate, the veneers are firstly manually refined, colored with the suitable colors, and then placed in the oven for the final sintering.

The CAD/CAM hybrid composites or resin matrix ceramics (polymers) are, on the other hand, to be sandblasted with 50 μm silica dioxide powder, superficially stained, and ultimately finished by using glossy diamond pastes (Fig. 11.48).

One more possible option to improve the esthetic result is to create a bilaminar restoration as suggested by Pascal Magne [30]. This technique contemplates an inciso-proximal cutback of the buccal surface on the CAD/CAM veneer in the incisal third; this is for an extension of about 0,7 mm. In this “cavity” it is applied, after airborne particle abrasion, ultrasonic cleaning, silane application and heat drying, a direct composite skin with inner incisal stains.

11.11 The Try-In Phase

As usual, the first step is represented by the one-by-one laminate try-in to attain an optimal fitting and marginal adaptation; for this we generally use a vinyl polyether silicon material (Fit Checker Advanced Blue GC) that highlights the interferences to be gently removed by the bur. In the second step the interproximal contacts are checked: if too tight, they are one more time gently touched. During the third step, all the laminates are placed together on the abutments verifying their shape, color, and the final result according to the previous diagnostic steps (DSD-mock-up); for that, it is advisable the use of a glycerin gel (Airblock Gel Dentsply Sirona) that helps in keeping in place the veneers.

The final check is carried out by means of dedicated try-in pastes with similar color as the corresponding composite cement (Variolink Esthetic try-in paste Ivoclar Vivadent); this kind of procedure can optimize the final esthetic result.

11.12 The Luting Step

The field is so far isolated by means of rubber dam avoiding any possible contamination from the oral fluids in view of the delicate adhesive cementation procedures (Fig. 11.6).

To obtain a wide and comfortable operating field, the rubber dam extends from premolar to premolar; since the laminate veneers are one by one luted, a supplementary clamp is placed on every single tooth to keep the rubber dam away from the restoration margin and retract the marginal soft tissues.

Once the individual clamp is in place, we one more time try-in the corresponding veneer to check any possible hindrance to its complete fitting eventually offered by the clamp.

The veneers are luted always starting from the central incisors and ending with the canines.

The intaglio laminate surfaces are treated following the manufacturer's instructions and depending on the chosen material (Table 11.1) and then ultrasonically cleaned for 5 min in an alcohol bath.

The following step is the silane application and heating for 1–3 min at 100°C in the oven; the silane allows an optimal joining between the composite cement and the silica ceramic's particles.

The dental surface is conventionally treated as follows:

- Enamel cleaning by using rubber cups or soft brushes and pumice powder mixed with water or 2% chlorhexidine solution.
- Airflow with glycine powder protecting the neighboring teeth with a matrix.
- Enamel acid etching for 30 s. With 35% orthophosphoric acid and its rinsing for 20 s and drying.

In case of dentin exposure, before the bonding application and after the etch rinsing, a chlorhexidine digluconate 20% solution is applied and gently scrubbed for 20 s. and eventually, once removed the excess with suction, the primer is applied and once again dried with suction and air blown.

In case of no-prep additive veneers, it is present a layer of untouched a-prismatic enamel; in this case it is mandatory to sandblast this enamel for 5 s. with aluminum oxide 50 µm powder before its etching [73, 74] (Fig. 11.52).

Table 11.1 Inner laminate veneer treatment

Feldspathic ceramic	90 s etching with 9% hydrofluoric acid (HF)	Careful 1 min rinse	5 min in alcohol bath Ultrasonic cleaning	Silane application	1–3 min 100 °C oven heating	Bonding application	
Lithium Di-silicate or lithium silicate zirconia reinforced	20 s etching with 5.5% hydrofluoric acid (HF)	Careful 1 min rinse	5 min in alcohol bath Ultrasonic cleaning	Silane application	1–3 min 100 °C oven heating	Bonding application	
Hybrid composites or Resin Matrix Ceramics (Cerasmart GC, Enamic Vita, Lava 3M etc.)	Sandblasting	60 s etching with 5.5% hydrofluoric acid (HF)	Careful 1 min rinse	5 min in alcohol bath Ultrasonic cleaning	Silane application	1–3 min 100 °C oven heating	Bonding application

In this latter case, it is very important to protect the adjacent teeth from the sandblasting with a steel matrix or isolating one by one the involved abutment with the rubber dam (Figs. 11.50 and 11.51).

The last step is the application of a thin unpolymerized bonding layer spread with the air blow both on the dental and on the intaglio laminate veneer surface carefully preventing them from light exposure.

As luting material it is possible to employ both a previously heated microhybrid light curing composite restorative material and a light curing resin cement.

This latter could be recommended if the laminates are very thin avoiding any possible fracture or tension during their seating in the luting phase.

Each restoration is placed on the tooth with a carrier (Stick-n-Place Directa) (Fig. 11.48), and once completely seated, the composite excess is removed with a probe and with a tape in the interproximal areas.

The cement is then exposed to the curing light for 60 s. palatally and buccally; a further polymerization is carried out after covering the margins with an air-block gel (Airblock Gel Dentsply Sirona) in the absence of oxygen to avoid its inhibition effect on the superficial cement layer.

In case light curing resin cement is used, the flowable excess is mostly removed by means of a brush and then pre-polymerized for 2–3 s. to allow a better cleaning once their consistency increased before the final complete polymerization step.

It is strongly advisable to protect, during the luting phase, the neighboring teeth with a thin matrix or with a wraparound teflon cover.

The final slight cement excess removal can be performed utilizing a scalpel blade and a thin curette; in the interproximal area, it could be useful to use a thin separating strip able to remove the bonding excess and preserve the contact point unlike the interproximal strips (separating strip Komet Germany).

The final margin polishing can be carried out with fine diamond burs on the handpiece and with sonic instrumentation (SFD2F-SFM2F Komet) followed by silicon points and brushes with diamond paste.

Once the rubber dam is removed, the occlusion has to be checked with fine articulating papers both in maximal intercuspation and in the protrusive/lateral lower jaw positions to avoid any possible interference.

11.13 Final Considerations

Nowadays the CAD/CAM laminate veneers certainly represent a good alternative to the conventionally baked or heat-pressed ones.

One main advantage, in comparison to the other techniques, is the possibility to be realized faster and also finalized in one clinical session with the chair-side or assisted chair-side approach.

This actually represents a great improvement considering the time lost and wasted in average by the patients to be treated and to attain the dental office especially in case of considerable distance between the dental office and home or in large metropolitan areas.

On the other side, one problem can be the thickness they can be milled; in fact the feldspathic and the heat-pressed laminates can be immediately realized of a very minimal thickness, till or up to 0.3 mm, whereas the CAD/CAM can be milled “only” to 0.5 mm; otherwise it is frequent their fracture.

This is a consequence of the different way they are realized indeed; the milling procedure can easily induce tensions into the materials particularly at minimal thickness.

This problem could be probably solved in the future if the CAM procedure in place of milling will shift in a layering and sintering manufacturing as in case of 3D printing.

Actually the 0.3 mm thickness can be achieved only manually once the milling ended.

The other main limit concerning this kind of restorations is linked to the fact that the shades and colors are to be placed on the surface as in the heat-pressed lithium disilicates differently from the feldspathic baked veneers that can be esthetically customized starting from the inner layers.

One of the most suitable indications is the anterior laminate veneers in case of young patients before or at the end of an orthodontic treatment in case of microdontia also if combined with a congenital agenesis.

In these particular situations, it is possible to obtain a good functional and esthetic result especially utilizing the new CAD/CAM resin matrix ceramics that can be more easily handled in obtaining minimal thickness restorations in comparison to the whole ceramic materials due to their greater flexibility.

On the surface of these materials, it is easy to bond the orthodontic brackets if veneers were cemented before or during the orthodontic treatment making it faster and more predictable in case of localized or generalized microdontia.

It is important to keep in mind that this kind of restoration is realized in a life period in complete evolution with great changes concerning the teeth eruption not completely achieved.

Therefore, the economical aspect plays a meaningful role in the choice of the procedure to be followed, and the CAD/CAM restorations can help us in this task; we prefer to consider, in this particular case, this kind of restoration as **“long-term temporary”** restorations frequently completely no-prep additive way realized keeping intact all the sound enamel.

In this case the minimal thickness can emphasize the possibility of chipping during the delicate luting procedures; for this reason, as aforementioned, it is more indicated the use of flowable composite cements.

Despite the possible indications of the CAD/CAM veneers, we consider, in the adulthood, as gold standard for the best esthetic result still today the feldspathic baked laminate veneers.

Once conversely are indicated veneers that assure a greater strength besides the heat-pressed, the CAD/CAM laminates can represent an optimal further option. Nevertheless, it must be taken into account that a longer follow-up is needed to validate their mechanical strength and performance over time, especially for ultra-thin restorations.

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Aesthetic and Functional Rehabilitation of Worn Teeth with Veneer Materials

12

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Contents

12.1 Introduction

Physiological dental wear is a natural process that occurs with human ageing. It can be conceptualized as the loss of mineralized dental tissues during oral function [1]. However, when a more evident degree of dental destruction is present, mainly associated with functional and aesthetic problems, dental wear is considered a pathological phenomenon [2]. Progressive and irreversible dental tissue losses result from the action and/or combination of several aetiological factors, responsible for the

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significant advance of dental wear in the adult population [3]. Furthermore, a considerable increase in the incidence of early dental wear in young and young adults has been observed in recent decades, representing a very worrying problem for future generations [4, 5].

Regardless of the aetiology, pathological dental wear can be conceptualized as a multifactorial and cumulative dental tissue loss process that involves the destruction of hard tissues and which can then affect the survival of the teeth and quality of life [6]. Wear modifies the anatomy and size of the teeth increasing the risk of sensitivity, as well as leading to endodontic and/or aesthetic problems [7, 8]. Radiographic images may show signs of sclerosis of the root canals and pulp chambers, secondary dentin deposition or formation of hypercementosis [9]. The diagnosis of tooth wear is very important for clinicians since it defines the treatment protocol. As dental wear increases, signs and symptoms such as occlusal instability, muscle pain and pulpal conditions can be observed [10, 11]. Depending on the amount and location of the dental wear, a considerable loss of the vertical dimension may be present [12].

The main causes of pathological dental wear are related to parafunctional habits, inadequate diet, stress, excessive force used during oral hygiene practices, use of abrasive dentifrices, systemic problems, eating disorders or unstable occlusal pattern [1, 7, 13]. The multifactorial aetiology is responsible for the different types or mechanisms of tooth wear currently known as abrasion, erosion, attrition and abfraction [7, 13, 14]. When the causes of pathological wear are identified and controlled, direct and/or indirect reconstructive procedures should be carefully performed with the objective of restoring occlusal balance, as well as function and aesthetics while preserving tooth vitality with the minimally invasive options.

12.2 Attrition, Abrasion, Erosion and Abfraction

Dental attrition is characterized by the loss of hard tissues caused by intense contact (friction) between the teeth during occlusal function and mastication [15] (Fig. 12.1). A loss of enamel of about 30–50 µm per year has been described in the literature as the amount of physiological dental loss [16, 17]. On the other hand, dental attrition

Fig. 12.1 Dental attrition in maxillary central incisors. Note the evident wear at the incisal edge

resulting from abnormal and intense loading accelerates the destruction of sound dental tissues, and in such cases, tooth wear often occurs much faster than physiological compensation mechanisms [2]. The resulting lesions are flat and shiny and have distinct margins. Dentinal exposure and colour change are also commonly observed. The occlusal, palatal and incisal edges are the most affected dental areas in this type of lesion.

While attrition type of wear becomes more severe during bruxism, with the evidence of rapid and advanced dental loss [15], abrasion is known as the loss of dental tissues resulting from the repeated mechanical action of an external agent (Figs. 12.2 and 12.3). Toothbrushing, performed vigorously in the horizontal direction or with abrasive dentifrices, parafunctional habits such as onychophagy (habit of nail biting), use of tobacco pipes and placement of objects in the mouth are the main predisposing factors of the abrasion [14, 15]. Depending on the aetiologic factor, abrasion may occur at the incisal edges or in the cervical area of the most prominent teeth of the arch (upper canines and premolars). The lesions have an indefinite contour where the enamel is smooth and shiny and the dentin appears highly polished. Dentinal sensitivity may also be present due to exposed dentin especially in the

Figs. 12.2 and 12.3 Dental abrasion resulting from intense horizontal dental brushing

Figs. 12.4 and 12.5 Dental erosion on the palatal and occlusal surfaces

cervical areas. Patients with removable partial dentures retained by clasps may also have cervical lesions, especially when metal clasps exhibit misfit.

Erosion is the loss of tooth structure due to a chemical process leading to the dissolution of mineralized dental tissues [1, 18] (Figs. 12.4 and 12.5). In this category, the teeth are usually exposed to acid and/or chelating agents, resulting in erosive lesions. Also, known as corrosion, erosion is considered the most complex category among all types of dental wear due to multiple aetiologies [15]. Extrinsic aetiological factors, such as excessive consumption of citrus fruits, acidic juices, soft drinks, alcohol and medications based on acetylsalicylic acid and ascorbic acid, are directly related to dental erosion [18]. In addition, environmental factors related to the profession (chemical, pharmaceutical and wine industries), involuntary regurgitation (vomiting, esophagitis, hiatal hernia) and voluntary regurgitation (bulimia) have also been correlated with erosion [19]. Erosive facets could be localized both in the buccal, occlusal and palatal/lingual surfaces. Dental wear occurs slowly and progressively, resulting in erosion lesions with rounded and irregular shapes. On the occlusal surfaces, small depressions can be easily observed.

In abfraction, pathological dental loss occurs due to biomechanical forces that cause dental flexion and, consequently, fatigue of dental tissues (enamel, dentin and cement) at a location distant from the point of occlusal loading [20, 21] (Fig. 12.6). The premolars are the most affected teeth, with cervical lesions usually seen on the

Fig. 12.6 Dental abfraction

buccal surface. The lesions are wedge-shaped, located at the cementoenamel junction, with very evident internal and external angles. Dentin sensitivity is quite frequent, indicating that restoration of the area should be performed after adequate occlusal analysis.

Dental wear mechanisms can act independently or in combination. Combinations of attrition/abfraction, abrasion/abfraction, erosion/abfraction, attrition/erosion or abrasion/erosion also frequently require efficient follow-up protocol.

12.3 Signs and Symptoms of Pathological Dental Wear

The clinical evidence and treatment of dental wear depend directly on the location and size of the lesions. Cervical lesions, most frequently observed in cases of abrasion and abfraction, are usually small or medium and are located on the buccal surfaces, being very sensitive when dentin is exposed. Typically, wedge-shaped defects are observed, with smooth and shiny enamel and dentin, especially if the lesions result from abrasion. Dental abrasions associated with attrition and erosion are responsible for the greatest wear of dental tissues. The wear usually begins on the palatal/lingual surfaces, going to the incisal/occlusal and buccal surfaces. In addition to dental wear, loss of vertical dimension of occlusion may also be present in such cases.

The loss of vertical dimension is the most commonly observed clinical sign after tooth wear which is at the same time the most complex problem to be solved [22, 23]. The progressive loss of dental tissues may result in functional, phonetic, postural and aesthetic problems that pose negative impact to the patient's quality of life. In patients who lost vertical dimension, phonetic space is usually increased with overload to the periodontal tissues and the temporomandibular joint [12]. In more severe cases, the face appears short due to the decrease in height in the lower third, excessive lip contact and angular cheilitis [24]. Loss of vertical dimension may occur either quickly or slowly. Bruxism is a classic example of rapid dental wear [15, 22]. In cases of slow wear, physiological dental compensation is usually present [1, 22].

The amount of tooth wear is studied in the literature through various quantitative and qualitative indices [11, 25–28] that are proposed to classify the severity of wear. Quantitative indices are typically based on objective measures, such as the size of the wear area, height of the dental crown and degree of dental mobility, whereas qualitative methods employ subjective descriptions and depend on operator training and calibration. Both methods employ classification or scoring systems that identify the amount of dental wear and the progression of the problem. The best-known and commonly practiced index is the "Tooth Wear Index" (TWI) that evaluates the loss of dental tissues with scores ranging from 0 to 4, regardless of considering the reasons (Table 12.1) [4, 25]. In addition to this index, more recently, simplified and

Table 12.1 Classical Tooth Wear Index (TWI) proposed by Smith and Knight, 1984 [25]

Score	Surface	Criteria
0	B/L/O/I/C	No loss of enamel surface characteristics
	C	No loss of contour
1	B/L/O/I/C	Loss of enamel surface characteristics
	C	Minimal loss of contour
2	B/L/O/I/C	Loss of enamel exposing dentine for less than one third of surface
	C	Loss of enamel just exposing dentine
		Defect less than 1 mm deep
3	B/L/O/I/C	Loss of enamel exposing dentine for more than one third of surface
	C	Loss of enamel and substantial loss of dentine
		Defect less than 1–2 mm deep
4	B/L/O/I/C	Complete enamel loss, pulp exposure, secondary dentin exposure
	C	Pulp exposure or exposure of secondary dentine
		Defect more than 2 mm deep, pulp exposure, secondary dentine exposure

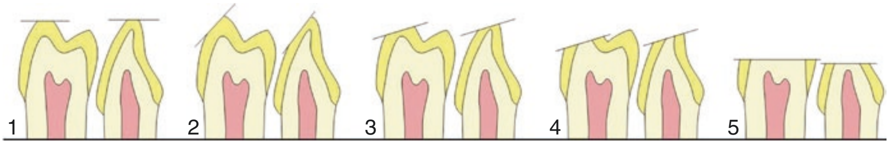


Fig. 12.7 Tooth wear severity: (1) Minimal wear, enamel only; (2) facets parallel to normal planes of contour, enamel only; (3) noticeable flattening of cusp or incisal edges, enamel only; (4) total loss of contour and dentin exposure; (5) total loss of contour, dentin exposure over half of former crown of tooth. Adapted from Pullinger and Seligman [12] and John et al. [27]

visual analysis methods have also been suggested in the literature and employed especially for consideration in epidemiological studies [25–27] (Fig. 12.7).

12.4 Treatment Modalities for Worn Teeth

The treatment of dental wear is closely related to the aetiology of the lesions [1, 23]. Whenever necessary, the restorative approach should be performed only after identification and control of aetiological factors. As the aetiology of the lesions is multifactorial, the evaluation of the wear status should include complete oral examination, medical history, intraoral radiographs, and, if necessary, photographs [22, 29]. The restorative intervention of the lesions should be performed when they are active due to the fact that the structural integrity of the tooth is in question, masticatory efficiency is reduced, dentin sensitivity and risk of pulpal exposure or carious lesions are associated, and/or the defect created by the lesion could generate an aesthetic problem [13].

The location and amount of lost dental tissues dictate which restorative intervention should be performed. Lesions resulting from abrasion and abfraction are usually located in the cervical area and can be easily restored directly using resin composite, after controlling the parafunctional habits, presence of incorrect brushing, use of abrasives or an object or occlusal adjustment [1]. In cases of abrasion, it is essential that the patient is provided with professional advice on the aetiology of the lesions, adequate brushing techniques and increasing awareness on the importance of controlling the parafunctional habits [15]. Moreover, erosion and attrition cases present much more pronounced dental wear, which could not be always adequately solved by direct restorations. Such patients usually have functional problems related to loss of vertical dimension. Aesthetic compromises are also observed, especially when the wear pattern involves the anterior teeth [13, 18, 29–31].

Most of the time, the patient seeks dental care for an aesthetic resolution, being completely unaware of the general condition and the severity of the problem. In such cases, restorative treatment should always be considered, aiming at restoring the quality of life of the patient. However, since the aetiology of these lesions is multifactorial and complex, there is greater difficulty in controlling aetiological factors. In some cases, the patient may experience recurrences after treatment, compromising the oral rehabilitation performed. Multidisciplinary approaches are essential for the success of such cases [1]. The professional should elucidate the causes of the dental wear in question; perform the control and intense monitoring of the use of soft drinks, juices and acidic fruits; and, when other causes have been involved, refer the patient to specialized professionals (i.e., bulimia, continuous medicines, alcohol, esophagitis or gastric reflux). In cases of severe attrition, occlusal splints could also be indicated for the protection of the reconstructions [24].

Oral rehabilitation of patients with worn teeth could be performed by direct or indirect restorations or a combination of both. Direct restorations are employed mainly in cases of small wear as short- to medium-term resolutions or for young patients [32]. They are made directly in the mouth, with or without the use of guides, dispensing with the laboratory steps necessary to make indirect restorations. When restorations are performed manually employing freehand technique, without the use of guides, it is essential that the professional is familiar with dental anatomy and proportions [33]. When many restorations need to be performed, the use of transparent guides (index technique) obtained from waxing diagnosis could reduce acquired skills and chairside time [34]. This technique is indicated for clinical cases where there is minimal or moderate dental loss and to modify dental volume [33]. Direct restorations are more economical, conservative and reversible through which structural integrity could be quickly recovered with low financial and biological costs. However, their success depends highly on the knowledge on adhesive dentistry and the manual skills of the professional. Direct resin composites require excellent polishing of the restorations in order to ensure a greater longevity of the restorations, as they are more prone to staining and wear compared to those of indirect ones. Nevertheless, the maintenance protocols for resin composites are simple through repolishing or direct repair protocols [30].

The long-term longevity of direct resin composite restorations in patients with extensive dental abrasions due to attrition lesions or bruxism is still uncertain as there are a limited number of studies [5, 32]. Severe dental wear cases are best solved by indirect restorations made of ceramics, laboratory resin composites or hybrid materials. This approach includes longer treatment sessions associated with higher costs. After informing the patient with both direct and indirect options, the best combination of cost–benefit analysis, longevity of restorations and health of the remaining dentition should yield to the final decision for the restoration type [1]. It has to be however emphasized that whenever possible, a minimally invasive restorative approach should be considered which today possible with employing adhesive technologies.

In the majority of the cases, the worn dentition does not present carious lesions. In that respect, classical preparations could be considered more aggressive since sound dental tissues need to be removed in order to construct prosthetic restorations with greater thickness for better resistance to masticatory forces [22, 35, 36]. Traditional full-coverage prostheses require sacrifice of three to four times more healthy tissues with the possibility of loss of dental vitality when compared to additive techniques using resin composite or other minimally invasive restorations [22, 36]. Minimally invasive preparations maintain more viable dental tissues for durable adhesion [35]. In this technique, the professional must achieve a balance between the space obtained after dental preparation and the minimum thickness required for the selected restorative material [35, 36]. The interdental space existing after the increase of the vertical dimension becomes determinant for the selection of restorative material since the thickness of the material influences the functional performance of the adhesive restoration [37].

12.5 Minimally Invasive Indirect Restorations

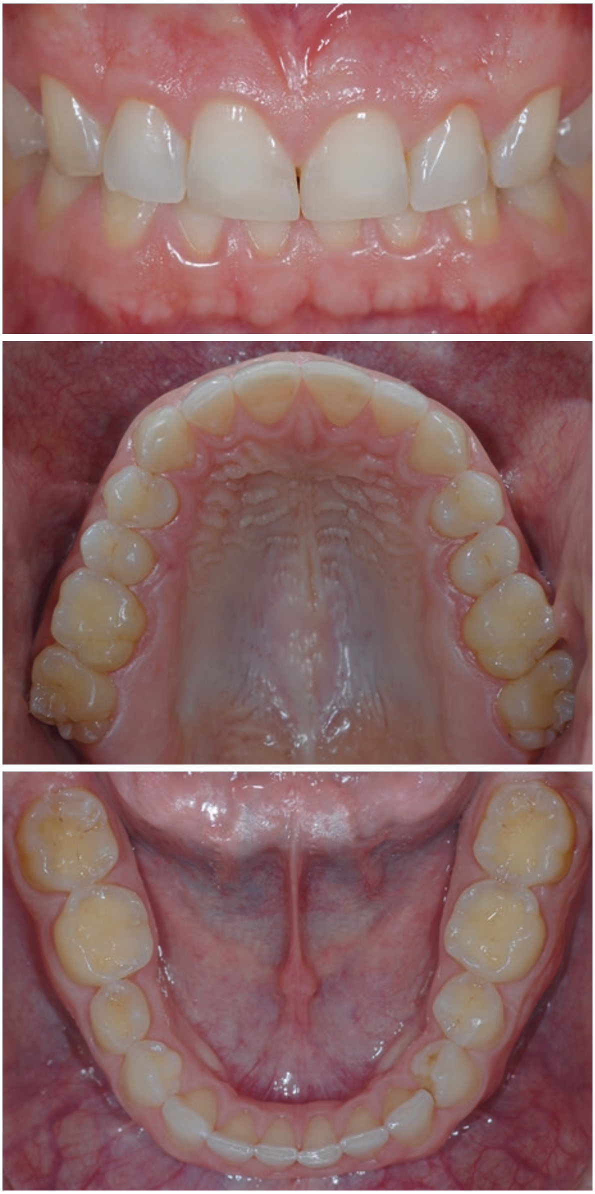
Minimally invasive restorations are currently possible due to advances in adhesive luting cements, restorative materials and computer-aided design and computer-aided manufacturing (CAD/CAM) technologies. More resistant materials, such as lithium disilicate-based ceramics and high-performance hybrid resin/ceramic composites, allow for fabrication of ultrafine restorations using CAD/CAM systems and are successfully employed in the treatment of worn teeth.

The first step in minimally invasive rehabilitation is to check the available space between the teeth by increasing the vertical dimension of occlusion. This strategy makes it possible to take advantage of the existing space available as a consequence of wear yielding to removal of less amounts of healthy dental tissues during dental preparation and enables small corrections of anatomy, shape and position. After an adequate clinical examination, gypsum models should be mounted in an articulator in order to perform diagnostic waxing in the proposed new vertical dimension. Waxing will define the tooth shape, identify how much space is present between the teeth and how much tooth preparation should be performed. Thereafter, silicone guides are made on diagnostic waxing in order to obtain mock-ups, provisional restorations or guides for tooth preparations. The mock-up should be fabricated prior to preparation as it allows the patient to check the result in the mouth before the restorations are made. In addition, the mock-up helps the professional effectively visualize the amount of dental wear present. Sufficient time and effort should be given at this stage of treatment. If the mock-up does not present well-accepted results for the patient and the professional, the diagnostic waxing should be corrected for a new mock-up.

Only after diagnostic waxing and mock-up result in satisfactory outcome, it is possible to define which restorative material will be used in the fabrication of indirect restorations and, consequently, the design of the tooth preparations. Depending on the amount of dental tissues present, direct and indirect restorations can be employed in the same clinical case. If the interocclusal space is sufficient, the tooth preparations for indirect adhesive restorations should involve only rounding the sharp angles, especially if the teeth do not present old restorations. In the presence of restorations, it is important to confirm the quality of the existing restorations prior to preparation. On the contrary, when the interocclusal space is limited, it is important to consider the possibility of restoring the teeth with direct restorations, before opting for more aggressive preparations just for the sake of obtaining space. Subsequent steps involve the fabrication of provisional prostheses, impression, working casts and indirect restorations. Such restorations are delicate pieces due to their low thickness and therefore should be handled carefully during clinical trials and adhesive procedures.

During luting of these restorations, the colour of the cement is selected with the aid of try-in cements, and after clinical trial, the restorations must be cleaned ultrasonically [38]. Adhesive resin cementation is the most critical step since it has many steps and is sensitive to moisture. Whenever possible, adequate absolute isolation should be achieved. Then, the intaglio surface of the indirect restorations should be conditioned with respect to the protocol for each material type. Accordingly, vitreous ceramic restorations should be conditioned with hydrofluoric acid (HF) gel (feldspathic ceramics, 9.6% HF for 2–3 min; leucite-reinforced ceramics, 5% HF for 1 min; lithium–disilicate-reinforced ceramics, 5% HF for 20 s) and then washed and dried [39]. A layer of silane coupling agent is then applied to the etched intaglio surface of the ceramic restorations, and the solvent is dried with oil-free air. A layer of adhesive resin is then applied on the intaglio surfaces and air-thinned with oil-free air but should not be photo-polymerized in order not to increase the cement film thickness. The adhesive resin applied on the tooth preparation however should ideally be photo-polymerized for stability of the hybrid layer. Thereafter, resin-based luting cement is placed inside the restoration, and this is positioned on the prepared tooth. Excess cement should be removed before photopolymerization, so that they do not remain in places difficult to reach or break during their removal after complete polymerization. Since, most of the time, such restorations are thin and translucent, photopolymerization could be performed through the ceramic restoration, orienting the tip of the polymerization device from occlusal, mesial, lingual and buccal directions with 2 mm distance to the surface [38] (Figs. 12.8–12.10, 12.11–12.13, 12.14–12.16, 12.17, 12.18, 12.19, 12.20, 12.21–12.23, 12.24, 12.25–12.27, 12.28, 12.29, 12.30 and 12.31, 12.32–12.34, 12.35, 12.36, 12.37, 12.38, 12.39 and 12.40, 12.41–12.45, 12.46 and 12.47, 12.48, 12.49, 12.50).

Restorations made of indirect resin composite or nanocomposite resins should be conditioned according to the manufacturers' instructions. The surface of these materials typically needs to be initially air-abraded prior to the application of the adhesive resin in order to increase roughness and provide both micromechanical interlocking and chemical adhesion of the resin cement [40]. Nanocomposite materials could show slight resistance to HF acid etching, without proper dissolution of the inorganic fillers [41]. The universal bonding agent should be then applied to the



Figs. 12.8–12.10 Young patient with minimal dental wear on posterior teeth and moderate wear on anterior teeth

Figs. 12.11–12.13 Digital and physical diagnostic waxing, recovering the worn dental area and vertical dimension

Figs. 12.14–12.16 Maxillary and mandibular mock-ups made of bis-acryl composite resin (Protemp, 3 M ESPE, USA). The resin is positioned within the silicone guide obtained from diagnostic waxing which is then removed from unprepared teeth

Fig. 12.17 Resin composite restorations made in the laboratory on the plaster model

Figs. 12.18 Absolute isolation achieved using rubber dam to keep the area dry and allow for reliable adhesive procedures

Fig. 12.19 Sharp angles present after dental wear are rounded with a diamond bur to allow better adaptation of the restorations

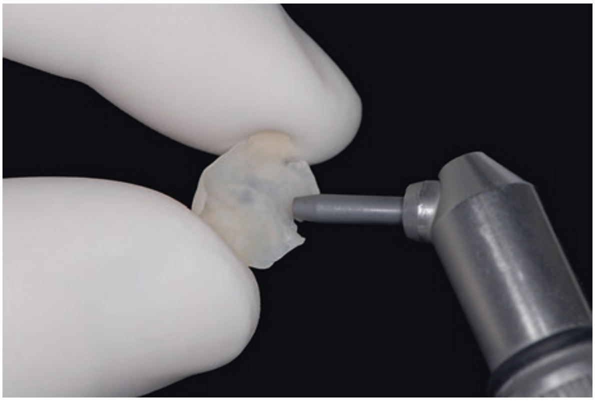
Fig. 12.20 Cleaning tooth surfaces with air abrasion

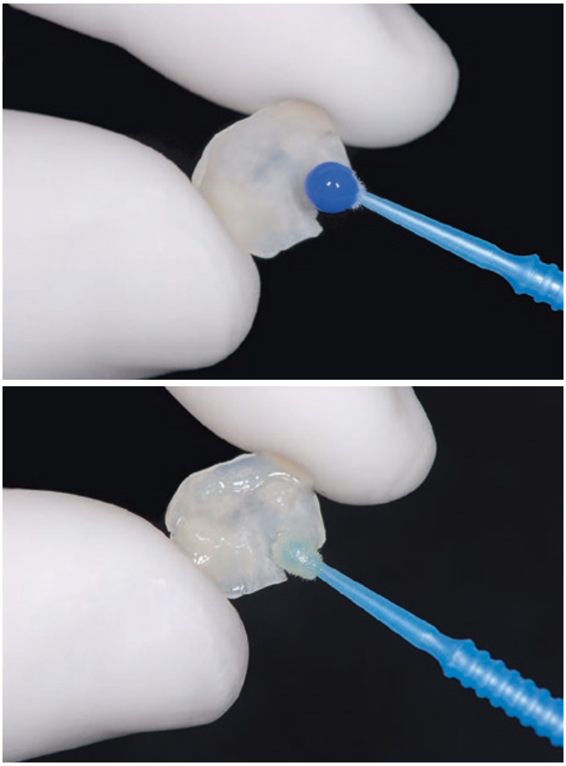
Figs. 12.21–12.23 Conditioning of the teeth and situation after washing and drying

Figs. 12.21–12.23 (continued)

Fig. 12.24 Application of adhesive resin on dentin with a disposable microbrush

Figs. 12.25–12.27 Air abrasion, cleaning and adhesive resin application to the intaglio surfaces of indirect restorations





Figs. 12.25–12.27 (continued)

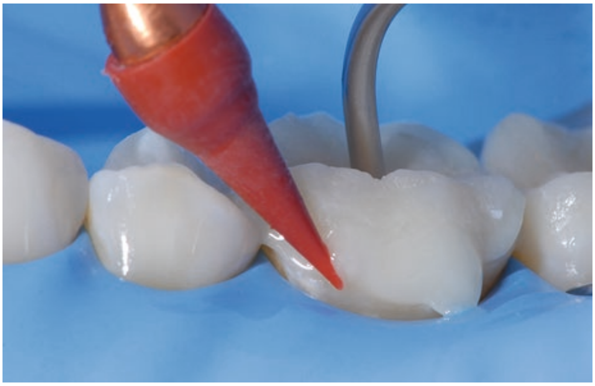
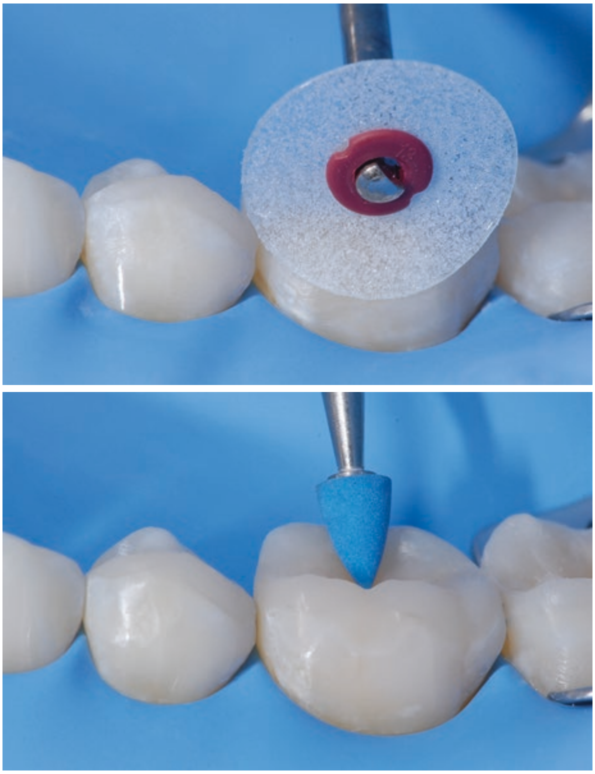


Fig. 12.28 Excess cement removal with rubber tips and brushes

Fig. 12.29 Photopolymerization from the occlusal, buccal and lingual surfaces



Figs. 12.30 and 12.31 Finishing and polishing of restorations with finishing disks and rubber tips

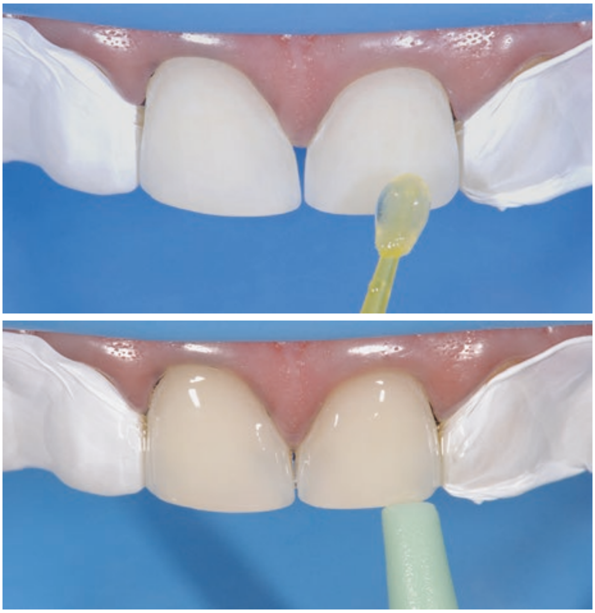
Figs. 12.32–12.34
Indirect posterior restorations in situ after adhesive cementation

Fig. 12.35 After bonding posterior restorations, anterior teeth were prepared to receive ceramic veneers

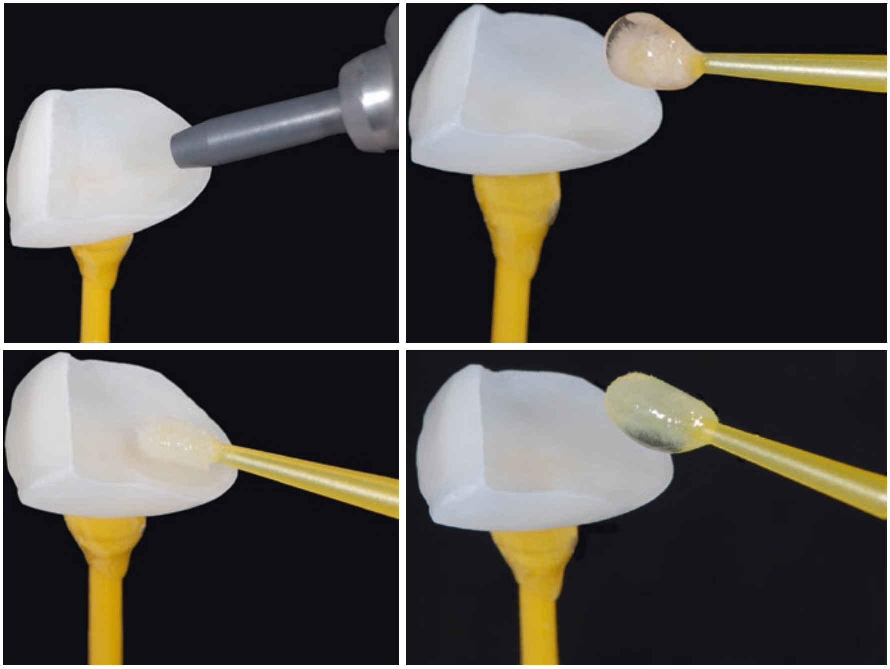
Fig. 12.36 Feldspar porcelain veneers on the plaster model

Fig. 12.37 Clinical trial of the veneers, selection of the shade of the resin-based luting cement

Fig. 12.38 Acid etching of the tooth surface

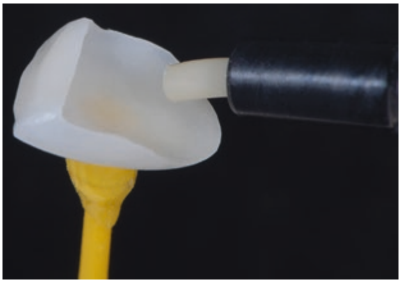


Figs. 12.39 and 12.40 Adhesive resin application with a disposable brush and suction of the excess resin



Figs. 12.41–12.45 Air abrasion of the intaglio of the veneers, conditioning with hydrofluoric acid, and application of silane coupling agent and adhesive resin

Figs. 12.41–12.45 (continued)



Figs. 12.46 and 12.47 Excess cement removal with rubber tips and fine brushes

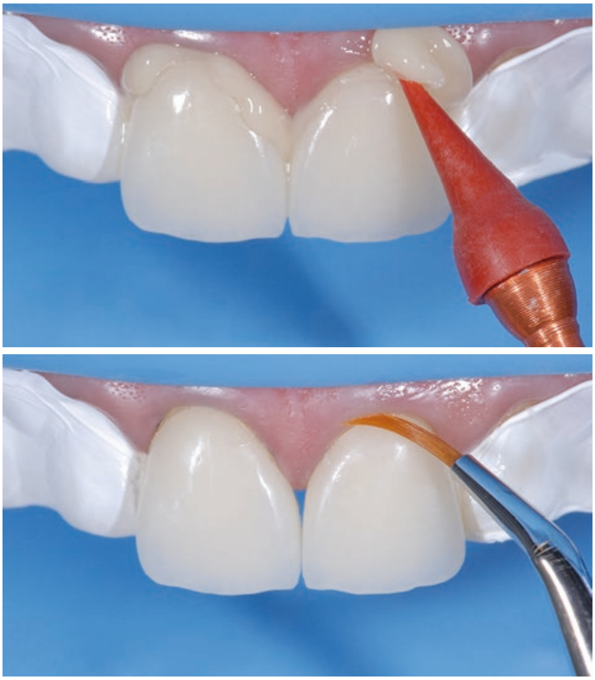


Fig. 12.48 Photopolymerization from palatal, incisal and labial surfaces

Fig. 12.49 After the photopolymerization, removal of the retraction allowing the removal of excess cement partially

Fig. 12.50 Clinical case of young patient with discrete to moderate dental wear resulting from erosion and attrition, rehabilitated with indirect resin composite on posterior teeth and ceramic veneers on anterior teeth

cementation surfaces with a microbrush for 20 s, and the adhesive cementation should be performed in the same manner as described for ceramic restorations.

12.6 Conclusions

Pathological tooth wear is a multifactorial and cumulative process that involves the destruction of dental hard tissues and compromises the patient's oral health. Regardless of the type of tooth wear present, the professional must diagnose the problem, inform the patient about the aetiological factors and then perform the appropriate treatment accordingly. Both direct and indirect minimally invasive restoration types could be considered depending on the amount of worn dental tissues, loss of vertical dimension, aesthetic and phonetic compromise and cost–benefit analysis. The presence of aetiological factors and clinical performance of the restorations must be monitored regularly, and maintenance protocols (i.e., repolishing or repair) should be practiced where needed.

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Transforming Discolored Anterior Teeth

13

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13.1 Introduction

A smile is extremely important in business and social interaction. During the past decade, the interest in conservative esthetic dentistry has grown extensively. Tooth discoloration is often found clinically and is identified with clinical and esthetic problems. Even the slightest form of tooth discoloration is cosmetically not acceptable, and it is a cause of concern for an affected person psychologically. A variety of etiology, appearance, composition, location, severity, may be exhibited. There are two types of tooth discolorations: those caused by extrinsic factors and those caused by intrinsic congenital or systemic influence. Extrinsic discoloration is present on the outer surface of teeth and is caused by tea, coffee, and tobacco smoking. This type of staining can be removed by scaling and polishing of teeth. In intrinsic discoloration, stains are placed within the enamel or dentin during the development of tooth (e.g., tetracycline stains). Discoloration can also be classified as metallic or nonmetallic stains and based on the chemistry of staining [1]. The intensity of stains may be aggravated if there are enamel defects. Tooth discoloration demonstrates two major challenges to the dental clinician. The first challenge is to ascertain the cause of the stain; the second is its management. A detailed clinical examination is required to elucidate the cause and derive appropriate treatment. The patient's oral hygiene, diet, history of trauma, medications and where they live are important considerations as possible causes. Drugs, mouth rinses, physical agents, or common environmental chemicals can unfavorably affect human teeth during their embryonic development and after their eruption into the oral cavity. The permanent dentition starts to form in utero and mineralization is usually complete by the age of 4 or 5 years and root development by 2–3 years after eruption. Teeth are more susceptible to growth disturbances during mineralization stage of tooth development, and permanent dentition is more susceptible to disturbances in mineralization by drugs and environmental toxicants than the primary dentition [2].

13.2 Fluorosis

Dental fluorosis is a hypoplasia of the dental enamel resulting from exposure to ingested fluoride during tooth development causing outer hypermineralization and subsurface hypomineralization [3]. Fluoride has been shown to affect principally the development stage of enamel formation, and the hypomineralization increases with the fluoride exposure, reflecting in dissimilar degrees of severity, with growing clinical effects in the esthetic appearance of the teeth. This hypomineralized enamel appears to be directly connected to interruption in the removal of amelogenin at the early maturation stage of enamel formation. Dental fluorosis is a dose-dependent disorder, and the higher the level of exposure during tooth development, the more severe the fluorosis [4]. Milder forms of fluorosis-induced enamel changes appear as thin white lines following the perikymata, cuspal snowcapping, and a snowflaking presence without defined borders [5, 6]. The treatment choices for fluorosis are limited. For the mildest forms of fluorosis, bleaching has been suggested [7, 8].

Clinical modalities for modest dental fluorosis include enamel microabrasion, in which the outer affected layer of enamel is abraded from the tooth surface in an acidic environment. Severe spots require composite restorations alone or combined with enamel microabrasion [9, 10]. Porcelain veneers may also be needed, and in more severe cases, crowns might be required.

13.3 Drug-Induced Intrinsic Tooth Discoloration Tetracycline

The exact means of tetracycline discoloration is not fully understood. However, several clinical studies have indicated that tetracycline becomes permanently bound to calcified tooth structures if taken during calcification stage of tooth development [11]. It is acknowledged that staining is thought to be a photoinitiated reaction [12]. Tetracyclines are thought to cause tooth discoloration taken during second or third trimester of pregnancy. Jordan and Boskman classified tetracycline discoloration into three groups according to severity: first degree, light yellow gray or brown without banding; second degree, darker and more extensive yellow or gray staining without banding; and third degree (severe staining), dark gray or blue discoloration with horizontal banding [13]. The degree of staining may vary contingent on the type of tetracycline, doses, duration of intake, and patient's age at the time of administration [14]. Minocycline, a semisynthetic derivative of tetracycline, is used as an adjunct in the treatment of periodontal diseases. Minocycline has also been shown to cause tooth discoloration. Minocycline can cause generalized intrinsic tooth staining post-eruption which differs from tetracycline. The precise mechanism by which minocycline causes tooth discoloration has not been established [15].

Three case reports will illustrate treatment depending on the age and severity of the discoloration. Diagnosis and selection of the least invasive treatment that will accomplish the results the patient desires should be selected. Sometimes additional factors other than discoloration may be present requiring more aggressive treatment such as veneers or crowns that are required to meet patient esthetic expectations.

13.4 Case Report 1: Treating Fluorosis Lesions with Bleaching and Icon

Ylva Khatau

A young female patient C. C., born in 1992, presented to the Esthetic Department at NYU College of Dentistry, having been told she needed veneers for her dental condition.

Her chief concerns were white and brown lesions on her maxillary teeth, especially visible from canine to canine.

Medical history revealed no significant findings.

Dental history: C. C. suffered from periodontitis a few years ago. She had scaling, and root planning performed, and since then she has had pocket depth within normal limits. She is currently on a 3-month recall schedule with her family dentist.

Fig. 13.1 Initial picture of patient with fluorosis against a black background

Dental history specific to the enamel lesions. During her childhood, the lesions appeared only as white chalky spots, and they only started turning progressively brown during her teens (Fig. 13.1).

Family history revealed that her older brother and younger sister also suffer from the same type of lesions. C. C. spent the first 7 years of her life living in Far Rockaway, NY, with her siblings. Their parents do not have these sorts of lesions.

The patient currently lives in Manhattan, NY.

Extraoral (EO) and intraoral (IO) examinations were performed. EO and IO photos and videos were taken for diagnostic purposes. Periodontal health was assessed. Full mouth X-ray series was taken. No pathology was found besides the white and brown lesions.

Upon examination and with the dental history in mind, the lesions seemed to be severe fluorosis lesions, presenting white and brown stains as well as some enamel pitting.

Fluorosis is a qualitative and/or quantitative defect of enamel depending on its severity. Fluorosis is due to an excessive amount of fluoride intake during enamel formation of permanent teeth during early childhood. Fluorosis may appear under different forms ranging from white spots and white streaks to broader white patches and brown stains. Patients can present with various severities of lesions from mild (white spot) to severe (brown and/or pitted enamel).

Based on dental history of progressive appearance of the brown color, we decided to first do an in-office bleaching with “Opalescence Boost” 40% hydrogen peroxide (HP) (Ultradent, South Jordan, UT, USA).

The patient was informed of the treatment’s unpredictability and that the results could range from only partial improvement to almost total disappearance of the stains.

The patient was then given Opalescence 15% HP for home use with bleaching trays with reservoirs on the four upper incisors. She wore them for 45 min twice a day (mornings and evenings) for 2 weeks. After 2 weeks, it was decided to continue a whitening for 1 more week as the patient was not experiencing any sensitivity and wanted to get the best possible result.

Photos were taken after 3 weeks of bleaching (Fig. 13.2). Improvement was noted but still did not meet the patient’s requirements. Resin infiltration of the lesions was suggested and approved by the patient. As the resin infiltration relies on bonding to enamel, one must wait at least 2 weeks after the last bleaching day

Fig. 13.2 Patient after 2 weeks of bleaching

Fig. 13.3 Patient before and after Icon

before applying Icon (DMG, Hamburg, Germany). This is because bleaching interferes with bonding [16].

In this case, we decided to wait 3 weeks due to patient's availability.

Icon was applied according to manufacturer's instructions:

3× 2 min Icon-Etch (a third etch application was necessary in this case, as the white spot on tooth #9 was still visible after the two first etching applications) followed by 1 × 3 min Icon-Infiltrate and light curing, followed by another application of 1 × 1 min Icon-Infiltrate and light curing, final polishing (Fig. 13.3).

Patient came for a follow-up 3 weeks later. She had experienced no sensitivity whatsoever and demonstrated a vast improvement of the esthetic appearance of her teeth. This satisfied her esthetic expectations, and she required no further treatment at this time (Fig. 13.4).

Fig. 13.4 Patient final picture of smile after bleaching and Icon treatment demonstrates the possibility of minimally invasive treatment

Fig. 13.5 Retracted intraoral front view: a wide front overview of upper and lower dentition to evaluate existing esthetic concerns and permit dental and soft tissue microesthetic analysis

13.5 Case Report 2: Treating Fluorosis with Porcelain Veneers

Abdullah A. Alnahdi

A 23-year-old female patient presented to the Esthetic Department at New York University College of Dentistry. She was not happy with the look of her smile as her teeth were discolored and small. She wanted to improve the way her teeth looked so she could smile more confidently.

Patient was not aware of any medical problems. Data collection was initiated to establish an esthetic analysis (facial, dentofacial, and dental aspects) which included full-mouth radiographs, periodontal charting, dental charting, extra- and intraoral photographs, functional occlusion analysis, patient interview, and high-definition impressions of the mandible and maxilla.

Upon clinic examination, the patient demonstrated severe fluorosis of her upper and lower teeth due to high-fluoride exposure during her early development (Figs. 13.5, 13.6, 13.7, and 13.8). Patient was born and raised in Quetta, Pakistan, which found to be an area of high level of water fluoride concentration at a level of 0.91 ppm with 65% fluorosis among 12-year-old schoolchildren [17]. Khan et al. in 2004 compared the recommended level which is 0.35 ppm for maximum reduction of dental caries and mild degree of fluorosis at 10% [18].

Fig. 13.6 Extraoral initial front smile: facial and dental facial overview. Lips in relation to teeth and amount of soft tissue displayed when patient smiles

Fig. 13.7 Right lateral smiling view: To evaluate incisal edge position of upper anterior teeth in relation to lower lip and how many teeth are displayed

Fig. 13.8 Left lateral smiling view: To evaluate incisal edge position of upper anterior teeth in relation to lower lip and how many teeth are displayed

Patient claims that most of her family have a similar teeth condition. There was no display of her maxillary incisors in the rest position (Fig. 13.9).

Initial impressions were taken by regular body polyvinyl siloxane impression material (Reprosil®, Dentsply Sirona), and stone models were obtained. These were then mounted on a semi-adjustable arcon dental articulator (Artex® Type CP Articulator) in centric relation (CR) and centric occlusion (CO) for functional occlusion analysis. Based on the data collected, a diagnostic wax-up was initiated to restore function and patient esthetics. All possible changes were transferred to patient mouth by means of intraoral mock-up which was fabricated using a putty index loaded with bis-acryl Luxatemp Automix Plus (DMG) to reproduce proposed

Fig. 13.9 Rest position: The amount of exposure of the maxillary incisors with the patient in the rest position will help determine the incisal edge position and initiate the determination of the correct anterior teeth proportions

Fig. 13.10 Esthetic pre-evaluative temporary (APT) technique. Mock-up in rest position to evaluate prospective esthetic incisal edge position

Fig. 13.11 Esthetic pre-evaluative temporary (APT) technique. Mock-up while smiling to evaluate new teeth positions and proportions relative to lower lip and assess the amount of soft tissue exposure

modifications of the patient dentition including increased incisal edge position, minimizing gingival display, correcting gingival contours, and creating ideal tooth and tooth-tooth proportions (Figs. 13.10, 13.11, and 13.12). This technique was helpful to better communicate and educate the patient while presenting possible treatment modalities.

In this case, phonetics and functional occlusion were important aspects to test preoperatively especially with the new incisal edge position.

Fig. 13.12 Retracted intraoral view of APT to appraise the proposed esthetic changes in relation to gingival symmetry, tooth, and tooth-tooth proportions

Fig. 13.13 Crown lengthening procedure. Based on the APT, osseous crown lengthening was performed using the APT as a surgical guide for a more predictable outcome

Patient accepted and approved proposed treatment plan as follows:

- Osseous crown lengthening for upper premolars and anterior teeth #4–13.
- Bonded ceramic *IPS e.max lithium disilicate* (Ivoclar Vivadent, Amherst, NY) veneers to restore upper premolars and anterior teeth #4–13.
- Combined in-office and home bleaching for her lower teeth.

Diagnostic wax-up was finalized and used to fabricate an intraoral surgical guide to follow during surgical osseous crown lengthening procedure for predictable ideal gingival contour and symmetry. Under local anesthesia, guided osseous crown lengthening was performed to reposition gingival margin and expose 1.5 mm of tooth structure as planned (Figs. 13.13 and 13.14). Postsurgical instructions were given to patient, and oral hygiene instructions were reinforced during follow-up visits over 12 weeks of healing time.

While waiting for periodontal tissues to heal, the bleaching process for lower teeth was started with two in-office bleaching cycles, 15 min each (Fig. 13.15). Chemically activated 40% hydrogen peroxide gel (Opalescence Boost, Ultradent) was used to achieve teeth whitening from shade A2 to shade B1 (VITA North

Fig. 13.14 Pre and post crown lengthening procedure demonstrates improved gingival contour and exposed clinical crowns before restorative phase

Fig. 13.15 Bleaching lowers dentition with chemically activated 40% hydrogen peroxide after proper gingival isolation

America, Yorba Linda, CA). This was followed by at-home whitening to maintain and stabilize results over 2 weeks of time by using 10% carbamide peroxide (Opalesence boost).

To control a conservative teeth preparation, the esthetic pre-evaluative temporary (APT) technique was used and verified with incisal and buccal preparation guides (Figs. 13.16 and 13.17). Single Ultrapak (Ultradent) retraction cord size #00 was used to achieve proper gingival retraction. Final impressions were taken with light and heavy bodies' polyvinyl siloxane impression material (Reprosil). Bite registration, facebow relation, and stump shade were recorded.

The prepared teeth were spot etched, and bonding agent (Scotchbond™ Universal Adhesive, 3M, St Paul MN) was applied covering all preparation surfaces. Silicone index made from the final wax-up was used to fabricate provisionals with self-cured bis-acryl (Luxatemp) shade B1. Light curing was done over each tooth for 20 s to aid bonding of provisional to tooth structure (Fig. 13.18).

E.max veneers made by master ceramist Mr. Peter Pizzi CDT, MDT, were returned for the try-in phase. Transparent try-in paste (Variolink II, Ivoclar Vivadent) was used intra-orally. The fit and esthetics were approved by the patient prior proceeding to final cementation. Under optimum isolation, teeth were etched with 35% phosphoric acid gel (Ultra-Etch, Ultradent) for 15 s and then rinsed thoroughly with water for 30 s and dried with high volume suction. Final cementation was performed with dual-cure resin cement (Variolink II) transparent shade. Excess cement was removed with microbrushes and dental floss before light curing. Manufacturer recommendations were considered and followed during cementation step.

Fig. 13.16 APT. Minimally invasive technique to control a conservative tooth preparation

Fig. 13.17 Final teeth preparations. Incisal reduction guide to verify amount of preparation for prospective restorations

Fig. 13.18 Intraoral view of provisional restorations demonstrates ideal tooth proportions and masking of discolorations

Fig. 13.19 Intraoral view of final ceramic veneers

Fig. 13.20 Rest position. Incisal edge position re-established to show more tooth structure at the rest position and reflect a more youthful appearance

Fig. 13.21 Left lateral view showing veneers in relation to the upper and lower lip

Post cementation X-rays were taken to verify accurate seating and removal of all excess resin cement. The patient's occlusion was checked, and required adjustment was made followed by finishing and polishing of touched porcelain surfaces. The results demonstrated the effect the patient was trying to achieve as the size and esthetics of the teeth were vastly improved (Figs. 13.19, 13.20, 13.21, and 13.22).

Fig. 13.22 Extraoral front view of smile postoperatively demonstrates achievement of treatment objectives: improved esthetics and meeting patient's expectations

13.6 Case Report 3: Treatment of Moderately Stained Tetracycline Teeth Using Feldspathic Veneers

Prachi Shah

The patient, a Caucasian working female in her mid-40s, presented to the clinic to replace her old discolored composite veneers in her upper front teeth (Figs. 13.23, 13.24, 13.25, and 13.26). She wanted to get rid of her tetracycline stained teeth and desired natural looking white teeth. A medical history was taken, and a comprehensive extraoral and intraoral examination was conducted. Patient's previous dental history consisted of composite veneers placed on the upper front teeth almost 15 years ago. Patient also had a few alloy restorations and endodontically treated posterior teeth which were treated more than 10 years previously and currently appeared to be in good condition. Patient recently underwent 2 years of invisalign treatment to correct minor rotations in the upper and lower arch.

A series of clinical extraoral and intraoral photographs and radiographs were made.

Dental history:

1. Veneers in the upper anterior teeth #6–11.
2. Orthodontic alignment for upper arch.
3. Amalgam restorations in posterior teeth.
4. Root canal treatment on #5, 18, 19, and 32.
5. PFM crowns on #5, 18, and 31.

Oral hygiene habits: Good oral hygiene, brushes once daily, uses mouth rinse, and flosses regularly.

Smile analysis was performed using the NYUCD Esthetic Evaluation Form. Face height is usually measured by dividing the face into thirds. The upper third may fluctuate due to the variability of the hairline. The middle and lower thirds are

Fig. 13.23 Full-face view displays discolored composite veneers

Fig. 13.24 Retracted view of discolored composite veneers in occlusion

Fig. 13.25 Right retracted view of discolored composite veneers

Fig. 13.26 Left retracted view of discolored composite veneers

more involved in esthetic perception. The midface is measured from the glabella to the subnasale (the most protruding area on the forehead between the eyebrows and the point directly under the nose). The lower face is measured from the subnasale to the soft tissue menton. Nasolabial angle was maintained between 90° and 110° to maintain an esthetic profile. At rest, young women usually display 3–4 mm of the maxillary central incisors, and young men display an average of 2 mm or less [19–21]. Curve of Spee was analyzed prior to wax-up and treatment planning. Phonetics was checked. Periodontal probing and bone sounding were done to verify the soft and hard tissue. Upper and lower polyvinyl siloxane impressions were made, and stone models were poured and mounted in centric relation using a face-bow transfer.

The following problem list was created for this patient:

- Moderately stained teeth and discolored old composite veneers.
- Uneven gingival zenith in the upper front teeth.
- Missing crown on root canal treated #19.

- The objective of this treatment was to follow a minimally invasive protocol for restoration of moderately stained tetracycline teeth, understanding the requisites for material selection to completely mask the stains and knowing the preparation techniques to obtain the ideal result.

Full arch diagnostic wax-up was done on both the arches increasing the incisal edge by 1.5 mm. Anatomical detail was added, and teeth #3–14 and #19–29 were given ideal proportioning. A diagnostic wax-up, in conjunction with an intraoral mock-up, would also allow the patient to visualize the outcome of the proposed treatment. Intraoral mock-up was done using silicone putty matrix (Lab Putty, Coltène Whaledent) and bis-acryl (Luxatemp Ultra, DMG). The incisal edge position and parallelism to the horizontal reference line were verified. The proposed restorations were checked for phonetics and esthetics.

A few minor intraoral modifications were carried out, and an impression of the mock-up was made. The final wax-up was created on the newly poured models. Indices fabricated from this new wax-up were used as the surgical and preparation guides (Fig. 13.27).

The patient's approval to proceed with the treatment was based on her viewing the potential outcome via the photos of her chair-side mock-up.

Gingival zenith correction: Crown lengthening was carried out on #11, and simple gingival recontouring was performed from #6 to 11 using a 15C scalpel. Minimal surgical correction was needed; hence, there was no need to provisionalize the teeth. Healing time of about 2–4 weeks was expected.

Prior to beginning the surgical procedure, communication with the lab was of significant importance. Feldspathic porcelain was the material of choice for the veneers, and monolithic zirconia was selected for the full-coverage crowns in this case. Feldspathic veneers are more esthetic, provide better color control, and require lesser tooth reduction.

Using the esthetic pre-evaluative temporary (APT) technique with the aid of silicon reduction guides (Figs. 13.28 and 13.29), tooth reduction of 0.9 mm was done for veneer preparation on #3, 4, 6–14, and 20–29 and full-coverage preparation on #5 and #19. Margins were mostly kept equigingival for all teeth. Maxillary teeth

Fig. 13.27 Indices fabricated from this new wax-up were used as the surgical and preparation guides

Fig. 13.28 Facial prep-guide. Maxillary teeth preparations needed slightly aggressive reduction and subgingival margins

Fig. 13.29 Incisal prep-guide. Maxillary teeth preparations needed slightly aggressive reduction and subgingival margins

preparations needed slightly aggressive reduction and subgingival margins. This was done to allow complete removal of the pre-existing composite veneer restorations and to allow restorative margins to finish on natural tooth structure for better retention (Figs. 13.28 and 13.29).

Retraction cords of 00 and 000 (Ultrapak, Ultradent) were packed, and a polyvinyl siloxane impression material (Aquasil, Dentsply Caulk) was used to make the master impression. Maximum intercuspation (centric occlusion) bites were recorded (Blu-Bite HP, Henry Schein).

Stump shade was selected (Fig. 13.30). The patient, lab technicians, and the treating surgeons had a mutual agreement of changing the existing stump shade of A3 to a final shade of B1. Temporary crowns and veneers were made with the desired final shade B1. Spot etch and bond technique was used with silicone putty matrix (Lab Putty, Coltène Whaledent) and bis-acryl (Luxatemp Ultra, DMG). The approved provisionals are a blueprint for the ceramist to fabricate the final restorations.

Lab communication: The working lab was given specific instructions and provided with the final impression of both arches, bite registration, stump shade,

Fig. 13.30 Stump shade was selected

Fig. 13.31 Willi Geller dies

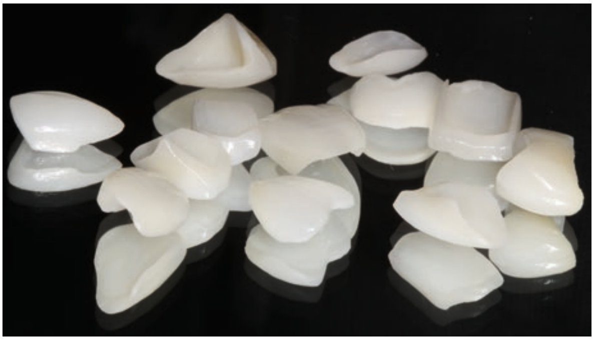

Fig. 13.32 E.max restorations

desired final shade, close-up smile, and dentofacial pictures. The final wax-up models were mounted in centric relation on a semi-adjustable articulator with a facebow transfer (Artex® Articulator System, Amann Girrbach).

Final feldspathic veneers and monolithic zirconia crowns were fabricated on Willi Geller dies (Fig. 13.31). These were then analyzed and inspected for conformity to the final wax-up (Figs. 13.32, 13.33, 13.34, 13.35, and 13.36). They were tried into the patient's mouth using transparent shade try-in gel (Variolink II, Ivoclar Vivadent). Try-in photos were taken, and phonetics and function were checked (Fig. 13.37). Patient was able to visualize the restorations in her mouth using a face

Fig. 13.33 Restorations on model facial view

Fig. 13.34 Restorations on model. Right side

Fig. 13.35 Restorations on model. Left side

mirror and the clinical try-in photos. Patient approval and consent were obtained prior to preparation for cementation.

The restorations were taken out of the patient's mouth. The internal surfaces of the restorations were scrubbed for 15 s with a 35% phosphoric acid solution (Ultra-Etch, Ultradent) and ultrasonically cleaned in alcohol for 1 min. Silane primer (Ultradent) was placed on the internal surface of the veneers and allowed to air-dry. Bonding agent (Prime & Bond NT, Dentsply) was applied, allowing 30 s for the

Fig. 13.36 Translucency of incisal edges

Fig. 13.37 Try-in of veneers

Fig. 13.38 Veneers against black background

solvent to evaporate. The veneered teeth were etched with Ultra-Etch for 15 s and then rinsed with water for 30 s. Prime & Bond NT bonding agent was applied to the internal surface of the veneers. The restorations were then loaded with the base shade (Variolink II cement transparent) and seated on the teeth. A small brush as well as floss was used to remove the excess cement before light curing for 40 s. All of the above procedures were carried out with single tooth rubber dam isolation and a custom modified #2 stainless steel clamp.

A final check of the occlusion was made with articulating paper (AccuFilm, Parkell), and minor adjustments were performed. Esthetic evaluation was done posttreatment. Post-op photos were taken, and 1-week recall was performed (Figs. 13.38, 13.39, 13.40, and 13.41).

Fig. 13.39 Improved esthetics of smile

Fig. 13.40 Retracted view of restorations

Fig. 13.41 Full-face view with highly esthetic restoration replacing the previous composite veneers

13.7 Discussion

As the cognizance of dental esthetics intensifies, an increasing number of people are seeking treatment for discolored teeth. However, prior to treatment, the cause and the amount of discoloration need to be determined. Although the increased esthetic awareness among patients has made porcelain veneers popular, minimally invasive treatment that will satisfy the patients' esthetic goals should be attempted first especially for the younger patient [22]. If porcelain veneers are selected, the challenge is to mask the discoloration yet remove minimal tooth structure during preparation [23]. Dental fluorosis (DF) is a developmental disturbance of enamel caused by excessive fluoride on ameloblasts during enamel formation [24]. The treatment plan for DF depends on the severity of disease [10]. Moderate dental fluorosis may be treated with enamel microabrasion, in which the surface affected layer of enamel is scraped from the tooth surface in an acidic setting [25]. Minor forms of fluorosis may also be managed with bleaching [9]. Moderate fluorosis spots may also be treated by the infiltration of low-viscosity resin-based material (Icon, DMG). This technique, which might constitute an alternative to white-masking of fluorosis spots, demonstrated optimal esthetic results as shown in the first case report [26, 27]. The use of resin infiltration was a different approach compared with previous DF treatments. The rationale for this selection was based on the structure of fluorosed enamel and the properties of resin infiltration. Fluorosed enamel includes areas of diffuse hypomineralization and porosities in the subsurface enamel. The resin infiltrate demonstrates a very low viscosity, low contact angles to enamel, and high surface tensions, so that it penetrates the porosities. Due to the similar refractive indices of resin and enamel, resin infiltration would improve the white opaque appearance of pores and reduce the original contrast between pores and enamel caused by light scattering [28].

Dealing with teeth that have been discolored by tetracycline-based medications presents a problem. The degree of staining is contingent on many factors, including the stage of calcification of the teeth at the time of tetracycline administration. When the enamel layer of these teeth is prepared for PLV restorations, the ensuing tooth color is often yellowish, gray-brown, or brown. Producing a porcelain veneer for a discolored anterior tooth can be extremely challenging for both the dentist and the technician. The staining of the prepared teeth for PLV restoration has been classified into four colors; orange, brown, blue-purple, and reddish gray. Yamada has suggested using complementary colors to rectify this problem [29]. This theory prescribes the use of a porcelain color that neutralizes (complements) the shade of the prepared teeth. The shades are not actually complementing but act for that use in ceramics [29]. The complimentary porcelain color is used as the base layer for the restoration and acts as a subtractive color mixture. This creates a gray mixture to which a white modifier is added to increase the value. The use of a thick masking porcelain to block the discolored tooth tends to produce a reflective, white color that does not look natural, but some patients prefer this compared to a more natural appearance.

The dental technician must be aware of the shade of the tooth prior to and after preparation. Adequate preparation needs to be discussed with the technician before preparing the tooth so that it will be prepared as ideally as possible depending on the material and technique the technician will utilize. Some ceramic restorations can be very translucent. The shade of the prepared tooth, the type of ceramic material, the thickness of the restoration, and the color of the luting agent will affect the esthetic result with such restorations [30]. The opacity of porcelain can be estimated by calculating the contrast ratio (CR), which is defined as the ratio of illuminance of the test material when it is placed over a black background to the illuminance of the same material when it is placed over a white background. A high CR represents low transmittance of light through the material. The clinician has to evaluate how much tooth structure needs to be removed in order to create a restoration with adequate masking of the discolored tooth structure yet still maintain a vital appearance (not too opaque). More tooth structure may need to be removed to provide more space for a thicker veneer that may need to be fabricated and to avoid over contouring of the restoration. However, the removal may expose dentin and the bonding to dentin is not as reliable as the bond to enamel [31]. The concealing capacity of an all-ceramic restoration can be determined by measuring the color difference ($\Delta E*$) when it is placed over different backgrounds [32, 33]. Vichi et al. examined the camouflaging ability of ceramic restorations of various thicknesses (1.0, 1.5, and 2.0 mm) of a leucite-reinforced ceramic material (IPS Empress; Ivoclar Vivadent, Schaan, Liechtenstein) over a variety of opaque posts and stated that full masking or acceptable $\Delta E*$ was achieved only with the 2-mm-thick ceramic material [34]. While it is accepted that augmented opacity after additional ceramic thickness could be more effective in concealing the underlying background, the increased amount of tooth reduction required can jeopardize pulpal health. The opacity can also be increased by the addition of an opaque modifier but with unpredictable results [35]. The shade of the cement appears to effect the final shade of the restoration to a small degree [36].

For color match, the color of a restoration is acceptable visually if the $\Delta E*$ is less than or equal to 3.3 when compared with that of the adjacent control [37]. The typical layered porcelain veneer is limited by the ability of the ceramist to adjust the opacification required to successfully hide the discolored tooth but still retain an acceptable optical result. Some studies have suggested removing additional tooth structure allowing the placement of an opacifying resin material [38, 39]. Others have suggested bleaching [40].The parallel stratification masking technique mitigates the unnecessary elimination of tooth structure by the application of fluorescent porcelains [41]. These porcelains are originally placed and evaluated as a thin wash on the dentin porcelain stump shade guide and then later placed on the refractory die before the stratification in the laboratory. This concept may be used with the alveolar model which comprises a dentogingival alveolar base with removable and interchangeable dies that aid in the fabrication of porcelain veneers [42]. The steps in this process are as follows:

1. Photographs of the tooth after preparation and before the impression with shade guides adjacent to the preparation.
2. The laboratory fabricates an alveolar model and then a modified chromatic dentin tab out of porcelain similar to the most discolored tooth. This is used to check the masking effect of the fluorescent porcelain.
3. Masking layers are then applied as a thin wash and fired until the wanted shade is accomplished. The technician uses the information acquired to start the stratification process.
4. The initial masking layer hides the discolored area. The second layer is applied over a broader area to hide the transition zone between the masking layer and natural tooth. This is usually the technique used for typical tetracycline banding. Sometimes an opaque modifier powder is needed to block very dark teeth, but too high a concentration can cause cracks to occur. Many studies have confirmed acceptable esthetic results in cases of moderate to severe fluorosis where restoration with porcelain veneers was achieved [9].

13.8 Conclusion

In the past, layered porcelain veneers have been limited in their ability to mask severely discolored teeth. This is due to the difficulty the ceramist may have in regulating the degree of opacity needed to adequately hide the discolored tooth but still provide a good optical result. Too opaque renders the restoration monochromatic and too little opacity reduces the ability to mask the substrate. Most tetracycline-stained teeth are unable to absorb and reflect light like a normal tooth. There are three things that are possible when light hits an object. A transparent object will allow all the light to pass through. On the other hand, an opaque object will not allow any light to pass through, i.e., it will absorb all the light [43]. The heavier the tetracycline staining, the less light can pass through, making the tooth less transparent or more opaque [44]. Wax-up and the creation of an APT [45] allow only necessary reduction of tooth structure to meet the technician's requirements. The technician requires adequate photographic documentation to create a masking map to be able to block the discolored areas yet create a restoration that provides effective color matching and translucency. Maintenance of as much enamel as possible is also important to minimize staining or debonding [46].

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Occlusal Considerations for Esthetic Rehabilitation

14

Mary Kang and Farhad Vahidi

Contents

14.1 Introduction

Form follows function. This is an architectural principle coined in 1896 by American architect, Louis Henry Sullivan [1]. As the father of skyscrapers, Sullivan believed that the shapes of buildings should be related to its function. In essence, by building for functionality, the esthetics would follow naturally.

Similarly in esthetic dentistry, this very principle holds true: “Dental esthetics (form) follows proper occlusion (function)” [2]. It is evident that beautiful teeth and

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occlusion are interrelated [2–5]. However, patients interested in getting esthetic restorations are commonly unaware of their underlying functional issue that has contributed to the compromised appearance. A study conducted by Wazani et al. showed that the most prevalent symptom among a group of wear patients was their esthetic appearance [3]. Fifty-nine percent of the wear patients were dissatisfied with their appearance, which is what prompted their visit to the dentist for treatment [3]. Only 17% sought treatment for having functional problems related to their tooth wear [3].

Patients often seek dental treatment focusing on the appearance of their maxillary anterior teeth, also known as the "social six" [4]. However, prior to restoring the "social six" with laminates, the dentist must evaluate the overall existing tooth wear which have been contributing to the compromised appearance of the anteriors. It would be prudent to reconstruct the posterior occlusion in conjunction with the esthetic appearance of the maxillary incisors for long-term success. Figures 14.1a–c

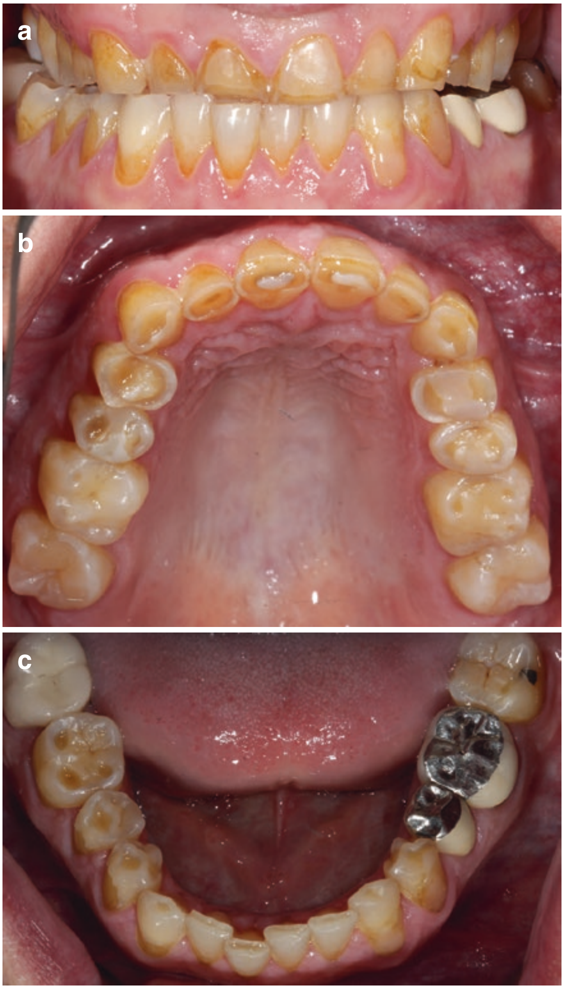

Fig. 14.1 (**a**–**c**) Patient presents to the dental office seeking treatment for the shortened and discolored appearance of the maxillary anterior teeth. Patient would like longer, more "esthetic" looking teeth. Existing conditions of the maxillary and mandibular arches. Worn down posterior occlusal surfaces along with anterior tooth wear. Patient is unaware of the current status of tooth wear that has contributed to the compromised esthetics of the maxillary anteriors. A comprehensive treatment must be provided for long-term success with esthetic restorations. (**a**) Patient in maximum intercuspation of existing condition. (**b**) Maxillary arch of existing condition. (**c**) Mandibular arch of existing condition

demonstrate a common example of a wear patient that presents to the dental office seeking for esthetic treatment of only the maxillary anterior teeth. The patient is unaware of the current wear condition at hand and is focused on restoring the short, discolored teeth of only the “social six” teeth. It is the dental provider’s responsibility to diagnose and determine the cause of wear to provide a comprehensive treatment for the patient [6].

Esthetics and function are achieved by having the jaw and teeth work harmoniously together to prevent further breakdown of the teeth. If proper occlusal principles are followed and maintained, the esthetics will follow, and the treatment delivered will have a favorable prognosis. Numerous studies have shown that teeth need to be restored with anterior guidance and mutually protected occlusion for long-term success [5–10].

Advances made in dental technology and the dental materials available today allow for new techniques, such as minimally invasive procedures [5, 11–14]. Adhesive dentistry also permits for the preservation of natural tooth structure. Yet, despite the introduction of new materials and methods, the fundamentals and principles of occlusion related to conventional fixed prosthodontics remain the same.

The longevity of the restorations also relies on several factors: proper diagnosis for the proposed treatment, understanding the etiology of a worn dentition, evaluating the patient’s risk factors, selecting the appropriate occlusal scheme, and having the patient placed on a maintenance protocol.

Preservation of tooth structure is vital as people are living longer today than before [3, 15, 16]. Delivering beautiful, esthetic restorations is more easily achievable with the advent of technology. However, in order to have long-term success of these esthetic restorations, a concerted effort must be made to achieve a harmonious and stable occlusion.

14.2 Diagnosis for the Worn Dentition

Tooth wear can be attributed to either a physiologic process or pathologic response [17]. It is common to expect generalized wear among the older population. As people live longer, their teeth will eventually wear [15]. It is part of the natural aging process. Spijker found that the prevalence of tooth wear in adults increased from 3% at the age of 20–17% by the age of 70 [16]. There was a clear association with increased age to increase in tooth wear.

Surprisingly, there is profound, new evidence demonstrating an incidence of a worn dentition being commonly found among the younger generations [17–20]. The prevalence of severe wear among 16–24 year olds was 4 and 12% for 25–34 year olds [3]. However, the wear observed in the younger generation is not due to a physiologic attribute but rather a pathologic effect [3, 18, 19]. It was found that 63% of the wear seen among 14–24 year olds was due to erosion [3] (Fig. 14.2). Tooth wear is no longer a disease observed in adults only. Children as young as teenagers are exhibiting signs of tooth wear, albeit due to pathologic adversities. Pathologic tooth wear occurs when rate of wear is greater than the natural progression of physiologic wear.

Fig. 14.2 Young patient with pathologic wear due to erosion. Patient has a history of bulimia which has caused loss of tooth structure by a chemical process along palatal and occlusal surfaces of the teeth. Premature wear in need of comprehensive treatment, preservation of tooth structure with minimally invasive preparations, adhesive dentistry, and harmonious anterior-guided occlusion for long-term success

In the past, oral rehabilitation for worn dentition patients involved preparation of teeth for parallelism, retention, and resistance forms in efforts to cement on full-coverage restorations to restore the worn dentition [21, 22]. As younger patients are being treated to restore their missing tooth structure, it is now even more prudent to preserve as much of the natural tooth structure for as long as possible. Hence, minimally invasive preparations and adhesive dentistry can benefit all patients by maintaining the integrity of the remaining tooth structure. However, anterior-guided and mutually protected occlusal principles must be respected for the longevity of the restorations to survive and succeed.

In 1984, Turner and Missirlian differentiated the types of occlusal wear that were prevalent into three categories [23]:

- Category no. 1—Excessive wear with loss of occlusal vertical dimension (OVD)
- Category no. 2—Excessive wear without loss of OVD, but space available
- Category no. 3—Excessive wear without loss of OVD, but with limited space

The misconception of this article, however, was that it related the patient's occlusal vertical dimension to the patient's postural rest position. According to the Glossary of Prosthodontic Terms (GPT-9), occlusal vertical dimension (OVD) is defined as "the distance between two selected anatomic or marked points (usually one on the tip of the nose and the other on the chin) when in maximal intercuspal position" [24]. Multiple studies have shown that patient's muscles of mastication are able to adapt to an occlusal vertical dimension beyond their freeway space [25–29]. Abduo has shown that the OVD could safely and predictably be increased definitively up to 5 mm without any detrimental effects [25, 26]. Certain parameters and guidelines, however, must be adhered to for a predictable outcome. For instance, prior to irreversibly increasing a patient's OVD, a thorough medical and dental history must be completed in efforts to determine the etiology of tooth wear and to prevent the further destruction of teeth [30].

14.3 Etiology of Tooth Wear

Patients with tooth wear can appear to exhibit similar clinical presentations. However, the root cause contributing to the breakdown of tooth structure can be variable. When rehabilitating patients with a worn dentition, it is essential to correctly diagnose the etiology of wear to prevent further destruction of the teeth post-reconstruction. This may be difficult to discern at times, as the etiology can be multifactorial (Fig. 14.3).

Wear can be caused by *mechanical* factors, *chemical* factors, or a *combination* of factors [17, 21]. When interviewing patients, gathering as much information related to their habits, dental history, and their signs and symptoms is critical in correctly determining the etiology and contributing factors to prevent the further break down of teeth.

Loss of tooth structure can be attributed to four types [17] (Fig. 14.4a–d):

1. Attrition: "the *mechanical* wear resulting from mastication or parafunction, limited to contacting surfaces of the teeth" [31].
2. Abrasion: "an abnormal (*mechanical* process) wearing away of the tooth substance by causes other than mastication" [31], i.e., toothbrush.
3. Erosion: "the progressive loss of tooth substance by *chemical* processes that do not involve bacterial action, producing defects that are wedge-shaped depressions often in occlusal, facial and cervical areas" [32].
4. Abfraction: "the pathologic loss of hard tooth substance caused by *biomechanical* loading forces; such loss is thought to be the result of *flexure* and *chemical* fatigue degradation of enamel and/or dentin at some location distant from the actual point of loading" [33].

Mechanical wear and chemical wear may appear to be similar but can be differentiated by a few distinct clinical presentations. Patients with mechanical deterioration may have a parafunctional habit, and the rate of wear will be consistent around

Fig. 14.3 Multifactorial etiology of tooth wear. A combination of abfraction and abrasion along the cervical aspects of the facial surfaces of teeth (Photo courtesy of Dr. Takanori Suzuki, DDS, PhD)

Fig. 14.4 (**a**) Attrition. Worn down dentition due to a natural physiologic process of mastication and parafunction. (**b**) Abrasion. Abnormal mechanical wear of teeth from pen cap chewing habit. (**c**) Erosion. Chemical degradation of occlusal tooth structures from the acids produced by GERD. (**d**) Abfraction. Biomechanical loading forces causing flexure and chemical degradation of enamel and/or dentin

the area of focus. The wear facets have sharp, defined borders that are congruent with the opposing arch when articulating the casts. Patients are usually asymptomatic and lack sensitivity to their teeth [17].

Chemical erosions, on the other hand, create rounded margins with cupping surfaces on the teeth due to the prolonged exposure to acidic solutions [17]. The wear patterns are irregular and are often difficult to articulate to the opposing arch, as the eroded surfaces do not correlate. Restorations tend to appear as "islands" elevating off the surfaces of the teeth. Patients with chemically erosive lesions are generally symptomatic with sensitivity to their teeth. Dental erosion can be attributed to dietary habits (i.e., citrus), gastroesophageal reflux disease (GERD), or bulimia. Dependent on the location of the erosion and a thorough patient interview, the causative factor for tooth erosion can be determined [17].

Diagnosing the etiology and root cause for tooth wear is essential prior to rehabilitating a worn dentition patient with restorations. It has been found that severe tooth wear is predominant in men compared to women [3, 17]. This may be attributed to the increased bite force that men have as they masticate [17, 34]. Age used to be a factor, but it has now become common to find younger patients exhibiting severe signs of wear. Whether the patient has parafunctional habits, aggressive toothbrush habits, or dietary habits, these tendencies must be resolved prior to delivering any restorations definitively. By identifying the contributing factors causing wear, one can focus on eliminating the sources needed to possibly rehabilitate the oral health of the patient back to function and esthetics (Table 14.1).

Table 14.1 Categories of wear and diagnostic factors

	Attrition	Abrasion	Erosion	Abfraction
Process	• Physiologic	• Pathologic	• Pathologic	• Pathologic
Wear type	• Mechanical	• Mechanical	• Chemical (non-bacterial)	• Biomechanical (loading forces)
Cause	• Contacting tooth surfaces • Mastication • Parafunction	• Abnormal habits with foreign objects i.e.: toothbrush, nail biting, pen chewing.	• Prolonged exposure to acidic solutions (i.e.: internal, dietary, environmental)	• Flexure and chemical fatigue degradation
Symptoms	• Asymptomatic	• Sensitivity	• Hyper-sensitivity	• Symptomatic • Asymptomatic
Clinical presentation				
Clinical descriptions	• Wear facets • Sharp, defined borders congruent with opposing arch	• Abnormal wear • Localized to source of cause	• Smooth depressions (occlusal, cervical) • Rounded margins • Cupping surfaces • "Irregular" islands elevating off surfaces of teeth	• Wedge-shaped defects in the cervical area (enamel and/or dentin)

14.4 Harmonious Occlusion-Based Esthetic Dentistry

During the 19th century, American architect Sullivan first coined the phrase, “form follows function” [1]. This philosophy holds true when restoring the worn dentition. There is compelling evidence to suggest that in order to achieve long-term esthetic success, a harmonious occlusion must be established with mutually protected articulation [5–10]. According to the GPT-9, a mutually protected articulation is “an occlusal scheme in which the posterior teeth prevent excessive contact of the anterior teeth in maximal inter-cuspal position, and the anterior teeth disengage the posterior teeth in all mandibular excursive movements” [35].

The patients must be restored in centric occlusion (CO) at the proper occlusal vertical dimension (OVD) with even posterior contacts in maximum intercuspation (MI). As the mandible functions in excursive movements, the anterior teeth must guide the posterior teeth away from contacting to prevent damage to the system. This occlusal scheme will help to minimize tooth wear and to maintain the longevity of the esthetic restorations [5–10].

The appropriate occlusal vertical dimension for the patient can be determined with either a removable or fixed prosthesis during the transitional adaptation period. Studies have shown that fixed prostheses had more favorable adaptive responses compared to removable prostheses [25]. Abduo also concluded that the OVD could safely be increased up to 5 mm predictably without any harmful effects [25, 26].

Once the patient is able to function at the new OVD and the esthetics is acceptable, the operator can move forward with the definitive esthetic restorations for the patient. Esthetic restorative options include resins or ceramics. Composite resins have shown favorable results as an interim restorative material [36]. However, for long-term stability, glass ceramics, such as lithium disilicate, is preferred.

Numerous studies have shown that the fatigue of composite materials contributes to its wear making it an inferior material of choice to use for posterior teeth [36, 37]. Furthermore, composites have shown to undergo hygroscopic expansion compromising the integrity of the material as a long-term restoration [38]. Glass ceramics and feldspathic porcelains, on the other hand, have superior esthetics and are more wear resistant [39]. It has been demonstrated that lithium disilicates have an estimated survival rate of 92–95% at 5 years and 91% at 10 years [39].

With the appropriate occlusal scheme and proper dental material selected, the worn dentition patient can be rehabilitated predictably and successfully. Esthetic form follows occlusal function, and if the harmonious occlusion is maintained, minimal pathologic wear can be expected in the patient’s future.

14.5 Clinical Procedures to Restoring the Worn Dentition

When rehabilitating the worn dentition patient, proper assessment and treatment planning are critical for long-term success. It is advantageous to follow the “5P Rule” when restoring complex treatments: “**P**roper **P**lanning **P**revent **P**oor **P**rosthetics.” By planning the esthetics in conjunction with occlusal function, future catastrophes can be avoided, such as porcelain fractures or, worse, temporomandibular disorder (TMD) issues.

Prosthetic rehabilitation can be successfully managed by dividing the treatment into four phases:

- Phase I—Prosthodontic/restorative assessment
- Phase II—Auxiliary preparation
- Phase III—Definitive prosthodontic treatment delivery
- Phase IV—Maintenance

14.5.1 Phase I: Prosthodontic/Restorative Assessment

14.5.1.1 Chief Complaint and History of Present Illness

Prior to embarking on any irreversible dentistry, it is important to initially assess the patient for the appropriate treatment. The patient's chief complaint must be addressed, and a thorough dental history must be investigated to evaluate any contributing factors to the patient's current dental status. With the information provided, the dentist can enlist a set of possible differential diagnosis and deduce the etiology, or etiologies, for the diagnosis in efforts to prevent further progression of the contributing risk factors [40].

14.5.1.2 Comprehensive Examination and Pretreatment Photographs

A comprehensive oral examination and a thorough medical, dental, and social history should be completed with pretreatment clinical photographs taken (Figs. 14.5a, 14.5b, 14.5c, 14.5d, 14.5e, 14.5f, and 14.5g). Tooth wear has been shown to be associated with multiple medical conditions, such as GERD, eating disorders, and xerostomia. By diagnosing tooth wear and its etiology, the treating dentist can not

Fig. 14.5a Pretreatment frontal view in repose

Fig. 14.5b Pretreatment frontal view in smile

Fig. 14.5c Pretreatment profile in repose

Fig. 14.5d Pretreatment profiles in smile

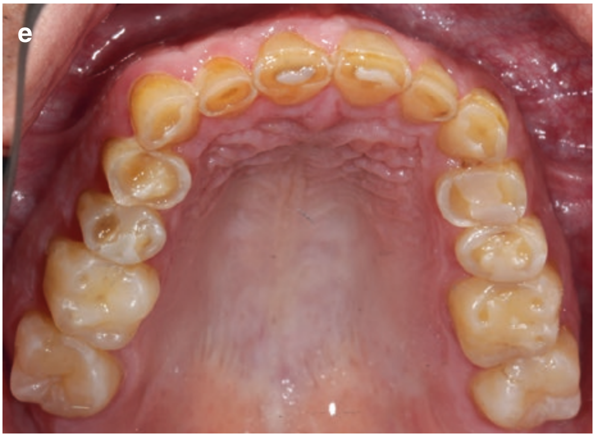

Fig. 14.5e Pretreatment maxillary occlusal

Fig. 14.5f Pretreatment mandibular occlusal

Fig. 14.5g Pretreatment profile in maximum intercuspation

only help with the patient's oral condition but also aid the patient in seeking professional medical attention for their overall health [40, 41].

14.5.1.3 Extraoral and Intraoral Examination

Extraoral and intraoral examinations must be completed. Identifying any muscle and/or temporomandibular joints issues must be addressed prior to starting any treatment. If the patient is symptomatic with muscle or joint pains, these are contraindications to starting any type of dental treatment. Oral rehabilitation can only begin once the patient is free from joint and muscle issues.

The patient's occlusal vertical dimension (OVD) must also be evaluated with their esthetic and phonetics tested to help determine the proper OVD [42]. While examining the patient's occlusion in maximum intercuspation and in centric relation, it would be prudent to study the patient's mandibular movements as they protrude and function into lateral excursive movements. If any working or nonworking interferences exist, it should be noted, and efforts must made to avoid the same interferences with the definitive restorations.

14.5.1.4 Periodontal and Radiographic Assessments

A comprehensive periodontal charting along with a full-mouth radiographic assessment should be completed to determine the integrity of each tooth. Any teeth that have unfavorable crown/root ratios or have large pathologies with guarded prognoses should not be subjected to partake in the oral rehabilitation. Rather, these unfavorable teeth need to be referred for extractions during the auxiliary preparation phase of the treatment. Phase II. The foundation and bone support of each tooth being restored must be favorable in order to receive a definitive restoration.

14.5.1.5 Articulated Diagnostic Casts for Diagnostic Wax-Up

After gathering all of the patient's history and data, two sets of diagnostic casts need to be articulated on a semi-adjustable or fully adjustable articulator with a facebow record. The casts will be cross-articulated to one another in centric relation. The first set of diagnostic casts will remain untouched throughout the treatment as the initial record for the patient (Fig. 14.6). The second set of diagnostic casts will be utilized for the diagnostic wax-up. The diagnostic wax-up will be completed at the new increased OVD with mutually protected occlusion from which the bonded interim prosthesis with bis-acryl composite resin will be fabricated (Figs. 14.7a, 14.7b, and 14.7c).

Fig. 14.6 The first set of diagnostic casts articulated with a facebow record. Casts remain untouched throughout the treatment

Fig. 14.7a Second set of diagnostic casts. Cross-articulated with initial set of casts in centric relation and minimally invasive wax-up completed with mutually protected occlusion. Protrusive movement

Fig. 14.7b Right laterotrusion with mutually protected occlusion

Fig. 14.7c Left laterotrusion with mutually protected occlusion

14.5.1.6 Hygiene Instructions

During this initial phase of treatment, the patient should complete a hygiene visit and be instructed on good oral hygiene practices. If the patient is a high-caries-risk patient, preventative measures must be taken from the initial visit. Educating the patient of lifestyle changes and dietary habits and prescribing high-fluoride toothpaste and mouth rinses are all ways in which the caries risk can be minimized. Prevention is essential when rehabilitating a worn dentition patient with multiple bonded restorations. Wear patients must demonstrate that they will be able to maintain good oral hygiene habits prior to investing in such an extensive treatment.

14.5.2 Phase II: Auxiliary Preparation

14.5.2.1 Caries Control

When the worn dentition patient first presents for treatment, any active caries that is present must be treated. The etiology of the caries must also be addressed to prevent future reoccurrences. The caries rate must remain under control for patients undergoing comprehensive oral rehabilitation with adhesive dentistry.

14.5.2.2 Interdisciplinary Specialty Referral

Should the patient require any adjunct services (i.e., crown lengthening, extraction, root canal therapy, orthodontic treatment), this is the time to refer patients to the appropriate specialty for treatment.

14.5.2.3 Transitional Prosthetic Treatment

During phase I treatment, preliminary impressions were made of the patient, and a diagnostic wax-up was completed in centric relation at the new occlusal vertical dimension (OVD) with mutually protected occlusion. Studies have shown that increasing the OVD with fixed provisional restorations has more predictable outcomes than with removable appliances [25, 26]. Hence, it is recommended to transition patients undergoing oral rehabilitation with a fixed interim prosthesis (Figs. 14.8a, 14.8b, and 14.8c).

The interim prostheses are used to test the patient functioning with the new OVD. During this transition period, the patient's muscles of mastication have time to adapt as it lengthens and relaxes over time [27]. Studies have shown that the muscles are amenable to increases in the OVD within a 1-month timeframe [25–28]. Hence, if the patient is asymptomatic with the new OVD after a period of 1-month, the operator may proceed with the definitive esthetic restorations (Figs. 14.9a, 14.9b, 14.9c, 14.9d, and 14.9e).

Fig. 14.8a Bis-acryl composite resin interim prosthesis at the new increased OVD. One week post interim prosthesis delivery. Patient exhibited good oral hygiene habits and was asymptomatic to the new OVD. Patient demonstrates a good prognosis for definitive treatment. Frontal view in new centric relation position

Fig. 14.8b Right view in new centric relation position

Fig. 14.8c Left view in new centric relation position

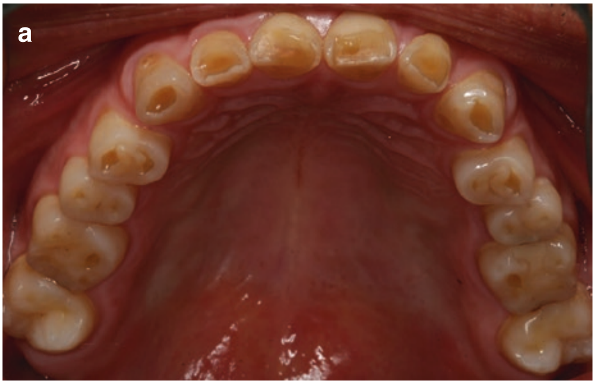

Fig. 14.9a Patient initial presentation of the worn dentition on the maxillary arch

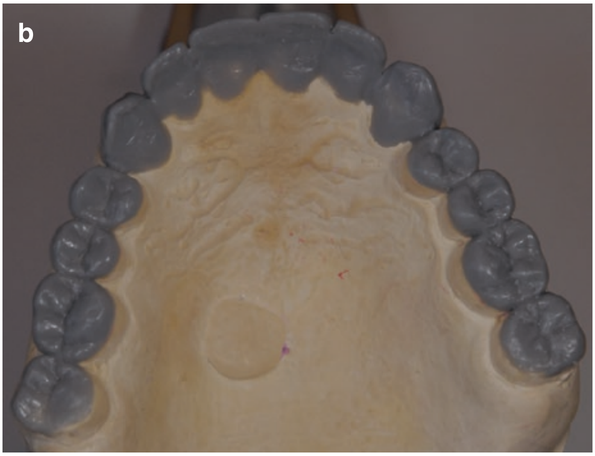

Fig. 14.9b Diagnostic wax-up at the new occlusal vertical dimension

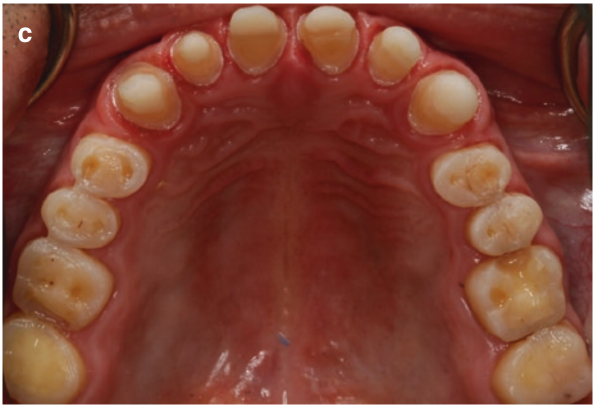

Fig. 14.9c Definitive preparations of the maxillary arch. Full-coverage preparations on the anteriors with minimally invasive preparations on the posterior teeth

Fig. 14.9d Definitive restorations fabricated based on the diagnostic wax-up

Fig. 14.9e Definitive restorations delivered utilizing adhesive dentistry and following anterior-guided occlusion principles

14.5.3 Phase III: Definitive Prosthetic Treatment.

Once the patient has demonstrated that they are able to function at the new, increased occlusal vertical dimension (OVD) and is happy with the esthetics, the patient is ready for the definitive ceramic restorations. With the advent of technology and new materials, the teeth can now be prepared with minimally invasive procedures utilizing adhesive dentistry at the time of delivery [5, 11, 12]. The goal is to preserve as much tooth structure as possible versus over preparation of teeth relying on retention and resistance forms while maintaining the fundamentals of occlusion [5–12, 22]. Teeth are minimally prepared, and the definitive restorations are to solely replace the worn dentition portions of the teeth with sufficient room for the restorative material (Figs. 14.10a, 14.10b, 14.10c, and 14.10d).

Once the restorations have been definitively cemented, new diagnostic records must be made in order to fabricate an occlusal guard. The occlusal guard will help protect the newly delivered restorations and preserve them for longevity.

14.5.4 Phase IV: Maintenance

14.5.4.1 Occlusal Guard

The patient has invested a tremendous amount of time and finances at this point to rehabilitate their worn dentition. Hence, an occlusal guard must be fabricated to help protect the integrity of the restorations, particularly for bruxers [41] (Fig. 14.11).

A maxillary occlusal splint fabricated with a hard, acrylic outer shell and soft intaglio lining is recommended. The soft inner surface helps to protect the porcelain from any damages, while the hard outer shell helps to maintain the harmonious balanced occlusion (Figs. 14.12a, 14.12b, and 14.12c). The occlusal guard must follow the same principles of occlusion: even posterior centric stops with anterior guidance during excursive movements. As the mandible functions in excursive movements,

Fig. 14.10a Minimally invasive preparations of worn posterior dentition

Fig. 14.10b Master cast of worn posterior dentition from definitive impression

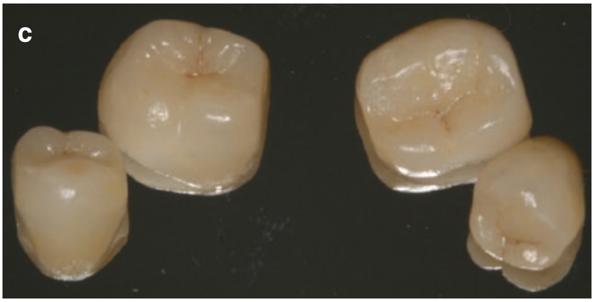

Fig. 14.10c Definitive lithium disilicate restorations

Fig. 14.10d Delivery of the posterior esthetic restorations maintaining ideal occlusion

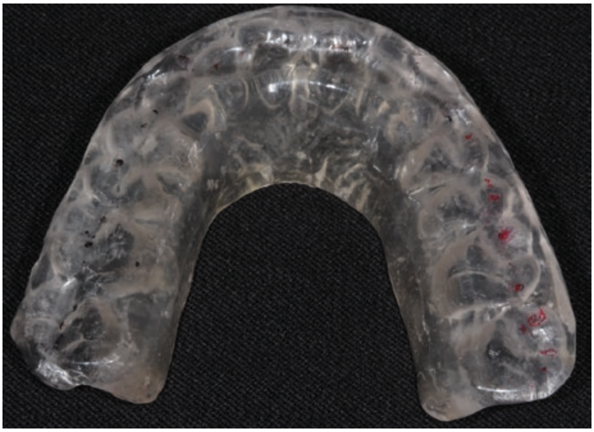

Fig. 14.11 Maxillary hard outer and soft inner occlusal guard with anterior guidance

Fig. 14.12a Occlusal guard following anterior-guided occlusion. The posterior teeth dis-occlude as the mandible functions in excursive movements. Right laterotrusion with occlusal guard in place

Fig. 14.12b Protrusive movement with occlusal guard in place

Fig. 14.12c Left laterotrusion with occlusal guard in place

the anterior teeth must guide the posterior teeth away from working and nonworking interferences. By following the same occlusal philosophies with the maxillary guards, the definitive restorations can be maintained for long-term success.

14.5.4.2 Recall Visits

The patient must see the dentist regularly for recall appointments, at least every 6 months unless otherwise indicated. During these appointments, the patient will have a thorough cleaning and an overall oral and head and neck examination. Radiographs can be taken, as warranted, and existing restorations will be evaluated for any chips, fractures, and marginal integrity.

14.5.4.3 Occlusal Equilibration

During each consequent visit, the occlusion must be examined. The restorative dentist must check for even posterior contacts and evaluate the patient's excursive movements for any interferences. If there are any discrepancies with regard to the centric stops and excursive movements, an occlusal equilibration must be completed chairside until harmonious occlusion is once again achieved.

Patients must also be advised to bring their occlusal guards with them to every recall visit. The longevity of the guards depends on how it is maintained; however, if there are signs of wear or cracks on the appliances, it is a sign that it is time for it to be replaced.

In the meanwhile, the occlusion on the night guards must be equilibrated just as it is done so on the patient's dentition. The guards must have even posterior contacts in centric and mutually protected occlusion in all excursive movements. If there are any interferences that are present, they must be eliminated for the longevity and integrity of the restorations.

14.6 Conclusion

With the advent of dental technology and the production of modern dental materials, new techniques are continually being introduced in the field of dentistry. Minimally invasive procedures utilizing adhesive dentistry have become extremely beneficial for the worn dentition patients, particularly the youth, to help preserve natural tooth structure [5, 11, 12, 14]. However, learning techniques only makes the dentists good technicians. As healthcare providers, dentists must not only be skillful at delivering the treatment but also need to be able to discern the need and proper treatment of care.

When treating the worn dentition patients, the restorative dentist must comprehend gnathology [6]. Gnathology is the "study of biology of the masticatory mechanisms and the kinematic recording of mandibular position" [43]. Care must be taken to follow the patient's condylar movements and to provide proper anterior guidance to achieve a harmonious occlusion. When restoring the worn dentition, it is imperative to stay within the confines of the envelope of function in efforts to prevent chipping or fractures of the restorations.

Patients tend to seek dental treatment when the esthetics of their "social six" is compromised and are unaware of the contributing risk factors [3, 4]. However, in order to achieve both functional and esthetic success, sufficient space must be made available for the restorations to be placed as to not interfere with the functional mandibular movements. Restoring worn down dentition with ceramic restorations will only last so long if the proper diagnosis is not made and the functional issues are not addressed accordingly [44]. As a healthcare provider, it is the duty of the dentist to diagnose and eliminate the recurrence of the disease. It is also the goals of the dentist to select appropriate dental materials and deliver appropriate treatment planned to minimize long-term risks.

Like the American architect Louis Henry Sullivan stated in 1896, "form follows function" [1]. The mandibular movements of the patient must be understood and applied appropriately to provide a mutually protected occlusion. Esthetic form follows occlusal function. Regardless of new technology or new materials being introduced, the fundamentals and principles of a harmonious occlusion remain the same in the field of dentistry. Ultimately, the goal of the dentist is to restore occlusion, esthetics, and function for long-term success with the worn dentition patients.

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