Chapter 8
Dental Tool Technology

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Abstract Dental technology is a discipline of dentistry concerned with the custom manufacture of dental devices to meet the prescription of a dentist. From the earliest times missing teeth have been replaced with dentures or crowns made from a wide variety of materials including gold, human or animal teeth, bone and tusks and wood. Natural teeth were used for dentures, collected from battlefields, hospitals or by grave diggers, these were mounted in carved dentures of walrus or hippopotamus ivory or on gold. By the late eightieth century dentures fused porcelain teeth were introduced, dentures could be carved from blocks of ivory or carved fixed to a gold plate by gold pins. In the mid-ninetieth century the first artificial denture base materials were introduced, vulcanite (or hard rubber) and celluloid, superseded in the 1940s with the introduction of polymethyl methacrylate. During the twentieth century base a wide range of new materials and techniques have been introduced to dentistry, including precision lost wax casting for dental alloys, a wide range of precious metal and base metal alloys and dental ceramics. This chapter focuses on advances in dental tool technology.

8.1 Introduction

Dentures were often made by the dentist who extracted the teeth, or their apprentice, sometimes the dentures were made by craftsmen such as jewellers or silversmiths. As clinical dentistry progressed a mechanical assistant specialising in the making of crowns and dentures developed. Dentistry became regulated form the late ninth century onwards and gradually national legislation restricted the practice

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to qualified dentists only. In 1921 the Dentists' Act, which restricted clinical practice to qualified dentists, stimulated the British Army to begin training dental mechanics, the first formal courses in dental technology were offered in London in 1936 [1–3]. Initially known as the dental mechanic, the term 'dental technician' was first used in the 1930s. Dental technology qualifications were generally craft based and gradually progressed to more technically and scientifically based programmes of study from the 1970s onwards, the first-degree programmes were approved in a number of universities in the 1990s. This educational basis of dental technology has resulted in few publications in the scientific literature documenting or evaluating materials and techniques and currently a limited research base.

Dental technology has evolved over the last 100 years from the mechanical assistant to a professional discipline, with an estimated global turnover in the billions of dollars it is, however, still largely unregulated in many countries. Emerging markets such as China are providing competitive challenges to dental laboratories in the west, particularly in the USA. Internationally, the levels of regulation vary, across Europe all dental laboratories must be registered with national medical devices agencies. In the UK statutory registration with the General Dental Council is expected to commence in the summer 2006. There are estimated to be up to 250,000 dental technicians across Europe. In the UK there are approximately 2700 dental laboratories and 8–10,000 people working in dental technology. In the USA there are about 12,000 dental laboratories, which employ about 46,000 technicians. About 40 %, of the laboratories, are single-handed. It is estimated that the laboratory industry in the USA is responsible for about $6 billion to $8 billion of productivity annually with growth expected to increase by about 6 % per year for the next several years [4].

Devices are custom-made, largely by hand and require individual machining with small burs. Before the introduction of lost wax casting, metal crowns and components were made using wire or swaged plate and soldered, filed, polished and buffed using hand files and rotary tools that would be found in jewellery making. The rotary tools will have included bowstring drills using hand cut tools. Power drills for clinical dentistry were slow and difficult to work with were developed from spinning wheels, carpenters drills, jewellers' drills and clockwork mechanisms [5, 6]. James Beal Morrison, who patented the dental chair in 1867, patented the foot-treadle drill in 1871 (possibly influenced by the Singer sewing machine introduced in the 1850s) and in 1875 added a flexible shaft [7]. Later developments included electrically powered motors directly powering the drill, or via belts or flexible drives to the drill handpiece. The flexible shaft invented by James Hall Nasmyth (1808–1890) the Scottish engineer is still used by many dental technicians. The handpiece itself was developed to improve reliability, ease of use and the speed of operation. Air-driven turbines running at very high speeds have been tried but the perceived need of dental technicians for sufficient torque when grinding has limited its appeal. Currently the electric micromotor offering speeds of up to 50,000 rpm with high torque are commonly found in most dental laboratories (Fig. 8.1).

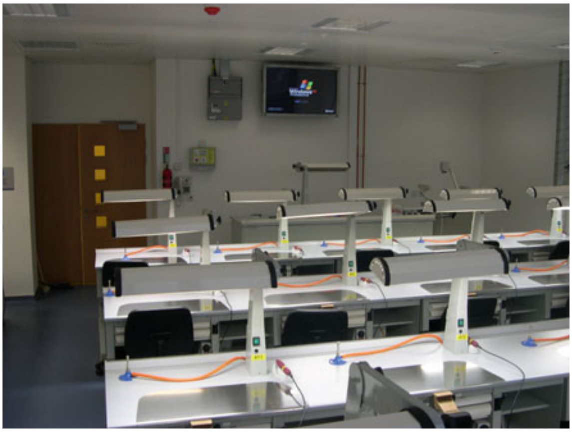


Fig. 8.1 Dental handpieces and drills

8.2 Burs and Abrasive Points

The history of developments in dental burs is limited [8]. The introduction of powered engines stimulated the manufacture and use of dental burs, cutting and grinding tools [6]. Originally hand cut and ground, burs were costly and inconsistent where mass production began in the USA in the 1870s made from carbon steel. The SS White "Revelation Bur" was the first to have a continuous drill edge [9]. Corundum introduced in 1872, which enabled enamel to be worked, was later superseded by silicone carbide (carborundum) stones and discs. Diamond burs were initially produced in the 1890s, and in SS White introduced tungsten carbide (TC) burs to dentistry in 1948 [6]. These burs designed for clinical use will have been used in the dental laboratory for fine work. Most trimming and grinding will have been done using hand files and lathe-mounted wheels.

Almost all devices made in dental laboratories involve the use of a dental laboratory handpiece and burs at some stage. A bur of various abrasive materials, sizes, shapes and cutting characteristics is mounted in a handpiece or on the chuck of a fixed lathe. On a fixed lathe the speed is set and the dental device is held in both hands and manipulated onto the rotating bur altering its position to grind or polish the surfaces. It is commonly used to remove sprues from metal castings, where gross grinding is required. However, some technicians find the use of both hands to secure the dental device whilst grinding beneficial and will undertake all machining on the lathe (Fig. 8.2).

In many laboratories the moveable handpiece is the tool of choice, this may be driven by a flexible drive or by an electric micromotor (Fig. 8.3).

The speed of the handpiece may be fixed by a bench top speed controller, or more normally, a variable speed controller controlled by foot or knee pressure. The speeds vary depending upon the design of the motor but generally range from 0 to 30,000 rpm, however, many machines offer speeds of up to 50,000 rpm. Most machines offer the ability for the operator to set the speed required. They may then

Fig. 8.2 Polishing on the dental lathe

Fig. 8.3 Handpiece and bur being used to grind dental impression tray

operate the motor using a foot or knee controller used either as an on/off switch to the set speed or as a variable speed controller up to the maximum set speed.

When using the handpiece the denture, crown or other device is held in one hand, the handpiece and bur are then brought onto the device varying the position of both hands to enable all surfaces to be trimmed. The pressure used varies during the process, initially for rapid removal of large quantities of material the operator may use heavy pressure and/or high speed. As the device is nearing its required size and shape the operator reduces the pressure and sometimes the speed. The combination of excessive speed and pressure is deprecated in teaching as it generates too much friction which can both damage the tool and the device being trimmed. Acrylic devices can warp and the mechanical properties of metal components can be altered by excessive heat. Pressures in practice together with poor supervision and work-based training can result in misuse of the tools. Complaints of poor performance of burs often relate to use at excessive speed and pressure [10].

The technician uses the drill and bur as a sculptor holding it onto the piece and drawing it along the piece removing the material required. For fine detail such as creating minor texture effects on the surface of a tooth the technician may hold the drill like a pen and gently grind the surface.

The selection of the shape, size and type of bur, cutter or abrasive tool is affected by the material being trimmed, the amount of trimming needed, the nature or form of the trimming being undertaken, the speed of the handpiece or motor and local custom and practice. The range of tool shapes, sizes and materials is very extensive, many of the tools are capable of being used on a wide range of materials and techniques. There are local, regional and national variations in the range of dental rotary tools purchased with no apparent to patterns in usage [10]. Each dental laboratory, or even individual technician in the laboratory, select their own preferences. Large dental laboratories may restrict the choices of tools available to its employees for stock control. In a recent oral survey (unpublished) of 10 laboratories, including three dental schools, each laboratory identified using different burs in the finishing of chromium–cobalt denture frameworks. The bur use varied between lathe and handpiece-mounted tools, course diamond barrels, silicon carbide stones (pink or brown), tungsten carbide burs or mandrel mounted abrasive disks. The costs of diamond or tungsten carbide burs can be 10–20 times the cost of silicon carbide stones, however, the life of the former is greater. One commercial laboratory considered the reduction in production time and longevity as more important that initial cost of the bur. One identified the use of diamond to increase cutting efficiency and reduce friction to avoid overheating of the alloy as the most important [11]. The teaching in schools of dental technology is influenced by available funding, although more expensive burs such as diamond are recommended cost implications on the school or student influence bur selection [11, 12]. The initial pattern of instruction may affect future practice strongly. Responses in the survey from several senior technicians recounted following the instruction they received as an apprentice and had barely changed since as they had adapted their technique to suite the burs they selected. In the teaching of dentists in the USA there is a broad consensus on rotary instrumentation used by dental students with coarser grit burs being used at postgraduate level [13].

8.3 Classification of Dental Burs

The wide range of materials, shapes and cutting surfaces resulted in 20 international standards associated with the manufacture of dental burs these specify aspects of the performance in terms of composition, form, reliability and packaging. BS EN ISO 6360 parts 1, 2, 3, 4, 6, 7 now provides a general numbering system for all types of dental rotary instruments. It was prepared to meet the need for a universal system of

Table 8.1 International standards for dental rotary instruments

BS EN ISO 6360-1:2004	Dentistry. Number coding system for rotary instruments. General characteristics
BS EN ISO 6360-2:2004	Dentistry. Number coding system for rotary instruments. Shapes
BS EN ISO 6360-3:2005	Dentistry. Number coding system for rotary instruments. Specific characteristics of burs and cutters
BS EN ISO 6360-4:2004	Dentistry. Number coding system for rotary instruments. Specific characteristics of diamond instruments
BS EN ISO 6360-6:2004	Dentistry. Number coding system for rotary instruments. Specific characteristics of abrasive instruments
BS 6828-8.1:1987, EN 27787-1:1989, ISO 7787-1:1984	Dental rotary instruments. Cutters. Specification for steel laboratory cutters
BS EN 27787-3:1994, ISO 7787-3:1991	Specification for dental rotary instruments. Cutters. Carbide laboratory cutters for milling machines
BS EN ISO 10323:1996	Dental rotary instruments. Bore diameters for discs and wheels
BS EN ISO 13295:1997	Dental rotary instruments. Mandrels
BS EN ISO 1797-1:1995	Dental rotary instruments. Shanks. Shanks made of metals
BS EN ISO 1797-2:1995	Dental rotary instruments. Shanks. Shanks made of plastic
BS EN ISO 2157:1995	Dental rotary instruments. Nominal diameters and designation code number
BS EN ISO 3823-1:1999	Dental rotary instruments. Burs. Steel and carbide burs
BS EN ISO 3823-2:2003	Dental rotary instruments. Burs. Finishing burs
BS EN ISO 7711-1:1998	Dental rotary instruments. Diamond instruments. Dimensions, requirements, marking and packaging
BS EN ISO 7711-2:1996	Dental rotary instruments. Diamond instruments. Discs
BS EN ISO 7711-3:2004	Dentistry. Diamond rotary instruments. Grit sizes, designation and colour code
BS EN ISO 7786:2001	Dental rotary instruments. Laboratory abrasive instruments
BS EN ISO 7787-2:2001	Dental rotary instruments. Cutters. Carbide laboratory cutters
BS EN ISO 7787-4:2002	Dental rotary instruments. Cutters. Miniature carbide laboratory cutters
BS EN ISO 8325:2004	Dentistry. Test methods for rotary instruments

classification and establishes a comprehensive coding system. They do not, however, specify abrasive/cutting efficiency. The standards are shown in Table 8.1. Although these are current there has been consolidation to create a comprehensive series of standards.

8.4 Coding of Dental Tools

Each item has a 15-digit code, the first 3 numbers identify the materials used in the working part, the next 3 the shank and overall length, the third the shape, the fourth special characteristics, the nominal size of the working part. There are also an optional further 3 numbers for diamond instruments.

The first group is the materials used for the tool, there are 42 materials used for rotary tools of which most are used in the dental laboratory.

8.4.1 Shapes

The shapes are classified in BS EN ISO 6360-2:2004 Dentistry. This standard comprises 5 tables that describe the coding for general shapes and designs of which there are 257 shapes summary information in Table 8.3. In the standard, Table 8.2 describes 70 disk types, Table 8.3 special instruments, Table 8.4 mandrels, and Table 8.5 root canal instruments (these are not used in dental technology).

Table 8.2 Abrasives used in dental technology

Grinding	Polishing
Tungsten carbide	Rubber
Silicon carbide	Natural bristles
Diamond, medium, coarse, very coarse, ultrafine, extra-fine, fine,	Synthetic bristles
Ruby	Brass
High-speed steel	German silver
Normal grade corundum	
High-grade grade corundum, pink	**Buffing**
High-grade grade corundum white	Felt
Tungsten carbide grit	Leather
Titanium	Flannel
Nickel titanium	Muslin
Quartz	Felt cloth
Sapphire	Yarn
Cubic boron nitride	Goat hair
Electrocorundum, red	
Free cutting steel	**Other**
Cold worked steel	Plastic
Spring steel	Quill
Stainless steel	Paper
Stainless spring steel	Gutta percha
	Cuttlefish bone

Table 8.3 Rotary shapes and variants

Basic shape	Example variants
Spherical	With collar, hemispherical
Wheel	End cutting, rim cutting, conical, half circle rim
Cylindrical	Side cut, end and side cut, pointed end, hemispherical end, rounded end, distal end hemispherical proximal end hemispherical, plus others
Conical	Slender, truncated conical, 30 % flatter, side cut only, rounded end
Inverted conical	Side cutting, end cutting, concave collar, rounded conical pointed, others
Bud	Slender, rounded, rounded slender, long, flat end rounded edge
Pear, flame, bullet	
Egg	Long, side cutting
Barrel	
Torpedo	Conical
Lens	

Table 8.4 Summary of coding for toothing burs and cutters

Straight	Right helicoidal
Straight, left cross-cut	Right helicoidal left cross-cut
Straight, sharp cutting angle	Right helicoidal fine left cross-cut
Straight, blunt cutting angle	Right helicoidal, sharp cutting angle left cross-cut
Straight, left cutting	Right helicoidal x-cut, transverse blade at the tip
Straight, left cross-cut	Right helicoidal left cutting
Straight, x-cut	Right helicoidal left cut; right cross-cut
Straight, with grooves	Right helicoidal x-cut
Straight left serpentine cut	Right helicoidal, fine right cross-cut
Left helicoidal	Right helicoidal, right cutting x-cut
Left helicoidal left cross-cut	Right helicoidal, right cutting x-cut right cross-cut
Left helicoidal right cutting	Right helicoidal with grooves
Left cutting x-cut	Right helicoidal, right cutting, 2 cuttings
Left helicoidal right cutting x-cut	Right helicoidal, right and left cutting
Cardia	
Side, finishing bur toothing	
Diamond toothing	
x-cut	

8.4.2 Types of Toothing

Referring to BS EN ISO 6360-3:2005 Dentistry, the number coding system for rotary instruments and specific characteristics of burs and cutters are included in this standard. The standard details the toothing of burs, finishing burs and, very fine, medium, coarse and very coarse cutters. It also includes a Table 8.3 for surgical tools.

Table 8.5 Summary of materials and possible abrasives

Material	Grinding	Polishing	Buffing
Acrylic	• Cold worked steel • High-speed steel • Tungsten carbide • Quartz • Normal grade corundum, white • Silicon carbide • Ruby Sapphire	• Fine sandpaper • Silicone polishers • Goat hair • Natural bristles • Synthetic bristles • Brass wire brushes • German silver wire brushes • Pumice slurry	• Felt • Flannel • Muslin • Felt cloth • Yarn • Whiting • Tripoli
Base metal alloys NiCr, CoCr	• Diamond, coarse or medium • (Fine, ultrafine, extra-fine, very course for fine detail) • Tungsten carbide • Silicon carbide, Pink, brown • Normal grade corundum, pink, white	• Rubber wheels, cylinders, cones • Black • Green	• Synthetic bristles • Felt • Leather • Flannel • Muslin • Felt cloth • Yarn • Chrome oxide
Gold	• Tungsten carbide • Silicon carbide • Normal grade corundum, pink, white • Ruby Sapphire • Cubic boron nitride • Electrocorundum red • High-speed steel • Cold worked steel	• Rubber wheels, cylinders, cones • Black • Green • White • Silicone	• Goat hair • Natural bristles • Synthetic bristles • Leather • Felt • Flannel • Muslin • Felt cloth • Yarn • Tripoli • Rouge
Ceramic	• Diamond, medium fine, • (Ultrafine, extra-fine, coarse, very course) • Silicon carbide green stones	• Diamond paste • Diamond impregnated polishers	

8.4.3 Specific Characteristics of Diamond Instruments

Referring to BS EN ISO 6360-4:2004 Dentistry, the number coding system for rotary instruments and specific characteristics of diamond instruments are included in this standard. The standard describes the additional information that can apply to diamond burs, this is the angle of tapered diamond instruments and the width of diamond-coated discs.

Referring to BS EN ISO 6360-6:2004 Dentistry, the number coding system for rotary instruments and specific characteristics of abrasive instruments, groups

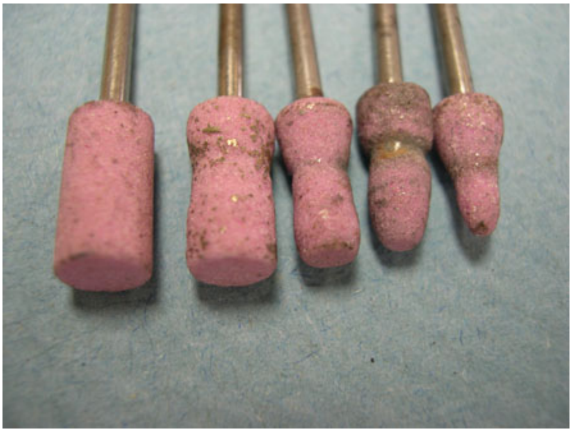


Fig. 8.4 Example of toothing drills

Fig. 8.5 Dental burs

abrasive instruments by the fineness of the grit size: ultrafine, extra-fine, fine, medium, course and very coarse, and within each group it is further subdivided by the hardness of the binding materials very soft, soft, medium, hard, very hard, extra hard. A dental bur will thus be coded as shown in Figs. 8.4 and 8.5.

8.5 Dental Devices

Dental devices may be used for a short term, e.g. removable orthodontic devices, or be in situ for many years, e.g. dental crowns or bridges. All devices are made largely by hand using a variety of equipment and techniques. The techniques are predominantly based on lost wax techniques at some stage in their manufacture whether the devices are made from acrylic, dental alloys or even some ceramics.

Fig. 8.6 Range of devices made by dental technicians

Most newly processed devices normally require trimming, polishing and buffing to make them fit for use in the mouth. As every patient is different, the mouth is a complex three-dimensional structure (Fig. 8.6). The dental technician needs to appreciate the structures and functions of the oral cavity, an understanding of the properties of the materials and their processing and the dexterity and artistic ability to make the device that will fit, function and appear to be natural. The dental handpiece can often be used as a carver to create the lifelike appearance required.

8.6 Dental Laboratory Materials

8.6.1 Gypsum

Gypsum-based products are used for the construction of models or casts of the dental mouth and in refractory investment materials. These may be needed to be ground using dental burs to shape the cast for use, for example to expose the edges of a tooth preparation in the making of a crown. A fine cross-cut of diamond cut tungsten carbide bur is the tool of choice for many technicians for this task. The gypsum used may be modified during its manufacture to increase hardness. Vacuum mixing can enhance its hardness and the surface may be altered by sealants to improve abrasion resistance, with a hardening solution high strength stones the Knoop hardness of a stone was increased to 79 kg/mm^2 [2]. Epoxy resins may also be used for these tasks [2]. Gypsum products will be ground dry under extraction at speeds of under 20,000 rpm due to dust fine burs generate significant amounts of dust, course burs create large particles that can travel in all directions across a laboratory at considerable velocities (Fig. 8.7). Damp gypsum will adhere to the bur and clog the cutting surface.

Fig. 8.7 Dust generated grinding dry plaster cast

8.6.2 Light-Activated Dental Impression Tray Materials

To obtain an accurate cast of a patient's mouth, a clinician will take two impressions. The primary impression is taken using a dental impression material in an impression tray available in a limited range of sizes. The impression is disinfected and then poured in dental plaster upon which a custom-made impression tray can be for the individual patient for greater accuracy. There are many materials for these trays, thermoplastic polymers that are pressure formed onto the cast and then trimmed using dental burs. A common material used is a photopolymerised polymer with high inorganic filler content, up to 76 % [14]. The inorganic filler can be quartz and barium or lithium aluminium silicate glasses, borosilicate glasses, strontium or zinc glasses. These materials are provided as moldable sheet that can be applied to a cast and cured in about 5 min in curing unit using light at about 500 nm [2]. Once cured these materials are trimmed using dental burs. The grinding of these materials creates a very fine dust that many technicians often identified as a nuisance or irritant (Fig. 8.8). Although there is no objective data many dental technicians have reported high wear rates grinding this material. Large tungsten carbide cross-cut burs are the tool of choice for many, some prefer large lathe-mounted abrasive wheels for speed and cost effectiveness.

Fig. 8.8 Grinding of light curing polymer, note method of holding handpiece and dust generated

The particle sizes of some the dust generated is less than 5 μm which is inhalable the particle size varies depending upon the cutting geometry of the bur and the particle size of the filler.

Burs used include ruby abrasives, tungsten carbide and steel burs. The shapes used vary depending upon the form of the tray and the parts that need trimming. Holes are drilled for retention using rose head-shaped burs. There is no published data on wear rates in relation to machining this material, however, many technicians report excessive wear whilst trimming this material as although the matrix of the material will be comparatively soft, the filler content, however, can include quartz (Moh's hardness 7 [14]).

8.6.3 Materials for Dentures

Removable dentures are made on the cast of the oral structures. Teeth are mass-produced in acrylic or porcelain. A trial denture is constructed positioning the teeth into wax that is carved to reproduce the oral tissues. The trial denture is inserted into the mouth to assess the upper and lower jaw relationship, the appearance and tissue support. The wax allows for ease of alteration. When satisfactory the wax trial is returned to the dental laboratory where a mould is made of it embedding it into plaster in a two-part flask, normally metal. The wax is eliminated in boiling water and dental polymers can be inserted either by compression moulding or injection moulding. The polymers are predominantly heat cured or chemically cured polymethyl methacrylate, or alternatively Nylon or other polymers. After curing, the denture is divested from the embedding plaster and trimmed using a dental drill (handpiece) and a range of dental burs. Dentures are polished using pumice slurry with various sizes and shapes of lathe brush or calico mops and buffed to a high lustre using bar compounds of tripoli followed by bar or liquid polishes containing whiting on a wool mop or worn calico mop at high speed.

The grinding of acrylic varies depending upon the type of polymer used or brand. The selection of bur to trim dentures and to prepare them for polishing and buffing is based up the experience of the individual dental technician. The type of bur used, the speed at which it is used and pressure with which it is applied is affected by many factors:

- The skills of the individual, the amount of trimming needed;
- The education and training of the technician;
- The price of the device, this influences the time available and grade of technician undertaking the work;
- The expertise and experience of the dental technician making it; and
- Inexperienced technicians often apply excessive pressure and speed when grinding any device. An acrylic denture can be warped or burnt.

Fig. 8.9 Silicone polishers

The hardness of acrylic resins, Knoop Hardness, 14–17.6 [14], Vickers hardiness 9–23 [15, 16] means that there are a wide variety of burs and stones that can be used. However, excessive speed and pressure must be avoided. Working pressure for laboratory abrasives and tungsten vanadium alloyed tool steel is 1–5 N [17] Tungsten carbide has a recommended pressure of 3.3–7.5 N [17]. The recommended speeds vary depending upon bur material and size of bur.

The burs used for trimming (summarised in Table 8.5) may include:

- Course, medium of fine cut tungsten carbide burs;
- Silicon carbide;
- Ruby abrasives are selected by many for fine grinding of acrylic resin dentures;
- White abrasives; and
- Fine abrading is done using sandpaper of various grit sizes, or abrasive impregnated silicone polishing burs (Fig. 8.9).

Dentures should be trimmed, polished and buffed to a high lustre because surface roughness enhances microbial adhesion and reduces the ability to be cleaned [18–24]. Burs with a threshold surface roughness for bacterial retention of (RA = 0.2 μm) should be used. A number of studies have examined surface finishing techniques [25–29]. The surface lustre produced in the dental laboratory provides the smoothest surface [26–28]. Tungsten carbide burs produce a smoother non-grooved surface than the steel bur on acrylic resins [29].

8.6.4 Metal Components: Crowns, Bridges and Metal Partial Dentures

Metallic crowns, bridges, substructures and partial denture frameworks are made using the lost wax process. Wax forms of either the whole tooth or substructures for the later addition of aesthetic materials are created on casts and dies of high strength dental stone. These wax forms are attached to a sprue, removed from the die and attached to a casting cone former, they are invested in a refractory investment, and placed in a furnace to eliminate the wax and moisture form the investment. Dental alloys are melted and cast into the mould, after cooling they are divested and sand or bead blasted. They will then be cut from the sprue, trimmed, polished and buffed with a range of disks, burs, stones, rubber tools and buffing mops. Metal partial dentures are made in a similar way but are a more complex shape and using a refractory model of the mouth and use multiple sprues.

The alloys used for metal components include high gold alloys (those containing more than 75 % gold), low gold alloys, palladium silver alloys and base metal alloys. The gold alloys have a Vickers hardness from 90 to 230 depending upon alloy type and brand. Low gold alloys and palladium silver alloys will have a Vickers hardness around 140 [14]. Base metal alloys that may be cobalt chromium, cobalt chromium nickel or nickel chromium have a Vickers hardness number of between 320 and 430. Titanium alloys are increasingly being used due to their lightness, they require specialised casting equipment, their Vickers hardness is about 140 and care is needed when finishing not to overheat the alloy.

The selection of the materials for machining and the shape of the tool the crown will depend upon the alloy used, the stage of finishing, the location of the grinding to the size and type of tooth. For example, for the inside of a lower incisor tooth very fine tools will be needed if any adjustment is needed. For optimum performance the device must be as smooth as possible.

8.6.5 Materials for Partial Denture Frameworks

Cobalt chromium alloys are most commonly used, although these may also be made in gold alloys or titanium. The surface finish required is a high lustre to reduce microbial adhesion, surfaces if rough can also rapidly increase the wear of opposing or abutment teeth. There have been few papers evaluating finishing procedures of cobalt chromium denture frameworks. Aydin [30] determined that the best surface finish was obtained using a systematic approach after sandblasting, hard stone, medium silicone carbide disk, second sandblasting, electropolishing, hard rubber point, felt disk and soft brush with polishing paste, although in the study cutting load was not standardised. Xenodimitropoulou and Radford [31] recommended a 6.5 mm aluminium oxide pink stone as the most efficient and consistent due to low costs and cutting efficiency. The tungsten carbide bur was second, however, it lost 70 % of its cutting efficiency over the duration of the machining. The diamond was the less efficient, the diamond bur showed evidence of plucked out grit, being won flat and with the matrix contaminated by the machined sample. Ponnanna et al. [32] determined the roughness generated by sandblasted and identified a systematic approach to finishing similar to Aydin [30]. The amount of dust generated in the finishing of a cobalt chromium framework for a partially dentate patient using silicon carbide abrasives and rubber wheels can be up to 2 g, 1 g of cobalt chromium alloy and 1 g of silicon carbide dust [33].

8.6.6 Titanium Alloys

Cast titanium alloys have excellent biocompatibility and are light, which is particularly useful for upper dentures [34, 35]. The mechanical properties are slightly different to Co–Cr alloys and have to be accounted for during design and in manufacture [36, 37]. In finishing titanium castings the hard brittle reaction layers (α-case) on the cast surface must be removed as these layers are reported to reduce the ductility and fatigue resistance of the framework and clasps. [38]. Ohkubo et al. [38] identified that in comparing Ti-6Al-4V with Co–Cr and type iv gold alloys there was little difference in cutting effectiveness using silicon carbide burs finding no correlation between the hardness of the alloy and volume loss. However, the opposite occurred when suing steel fissure burs. Steel burs will blunt, however, SiC stones will present new abrasives particles as they wear off thus maintaining cutting efficiency, although the diameter of the stone will reduce and thus reduce the cutting velocity unless speed of the motor is increased to compensate. Kikuchi et al. [39] compared different alloys compositions of Ti–Cu alloys assessed by their grindability using SiC burs. Hirata et al. [40] comparing the polishing of Ti and Ag–Pd–Cu–Au alloy with five dental abrasives, carborundum points, and silicone polishers found the Ti more difficult to polish and suggested the development of new abrasives for polishing of Ti. In the CAD/CAM milling of titanium devices Hotta et al. [41] identified that tungsten carbide burs displayed chipping at the bur blade and gradual dulling of the tool and an increase in the average surface roughness on the crown. However, they concluded that the tungsten carbide burs could be used to fabricate up to 50 titanium crowns.

8.6.7 Materials for Metal Inlays, Crowns and Bridges

Crowns and bridges are made in a variety of alloys, including noble alloys varying from high gold soft alloys type I (VHN 60-90) [14]—type IV Extra hard (VHN 220), palladium silver alloys, porcelain fused to metal techniques (base metal or noble metal alloys), low gold alloys Ni–Cr and Ti. The selection of bur type and technique will vary depending upon the alloy and local custom and practice, diamond burs, SiC and tungsten carbide the main options. Siegel and Fraunhofer [42] determined that cross-cut diamond burs should be used for base metal alloys and medium grit diamond burs for high noble alloys. Miyawaki et al. [43] identified the tungsten carbide bur generally superior in cutting effectiveness than diamond when using a dental air turbine to grind Ag–Pd–Cu–Au, Ag–Zn–In–Sn, NiCr or Ti alloys.

After grinding base metal crowns are finished using the same tools as for base metal denture frameworks, however, the tools sizes may include many with finer shapes to characterise teeth or trim inside the fitting surface. Noble alloy crowns being softer can use a wider range of polishers. The hard rubber wheels can be too abrasive for soft gold alloys or silver. Silicone polishers with finer abrasives or bristle brushes with polishing pastes are selected for polishing. Buffing is undertaken using wool, chamois or cloth wheels with rouge or proprietary polishing compounds. A high lustre is developed for oral hygiene and on the occlusal surface to reduce wear on the opposing teeth [44–46].

8.6.8 Ceramics

Porcelain has been used for denture teeth since 1790 [14], it has excellent appearance, durability and biocompatibility. Denture teeth are mainly feldspar with about 15 % quartz and 4 % kaolin [14]. Dental crowns may be all ceramic or ceramic fused to metal for additional strength. The material is supplied as ground glass frits and the technician gradually builds up the crown on a removable die in the cast of the patients' mouth. A core of aluminous porcelain is applied on a platinum foil or metal substructure and fired in a vacuum furnace (Fig. 8.10). Incrementally, small amounts of porcelain are then applied using small spatulas or paintbrushes to form the shape of the tooth, this is over built to allow for shrinkage during firing.

The crown is then trimmed and additional porcelain applied as required. The crown is shaped and characterised using rotary tools. The bur of choice for most ceramists appear to be diamond (although there is no published data on this) alternatively silicon carbide abrasives are used. The selection of the shape of the diamond or silicon carbide points used, their grit size, and the speed used varies with local custom and practice (Fig. 8.11). Finally, the crown glazed this can be a natural or a paint on glaze. Dental ceramics have a Vickers hardness of between about 600 and 700 [14].

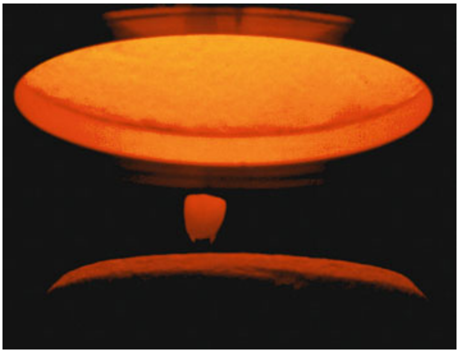


Fig. 8.10 Ceramic crown in furnace

Fig. 8.11 Machining of crown with diamond points

The surface finish of the crown is very important for the dental health of the patient. Rough surfaces increase plaque retention and occlusally can cause considerable damage to the opposing teeth [47–61].

8.6.9 Machinable Ceramic Restorations

In the last 20 years CAD/CAM technology has been introduced in dentistry in some areas replacing lost wax techniques. These systems have been used for the manufacture of inlays, crowns, bridges, substructures and veneers. The tooth, or a cast of the tooth, is scanned with a laser or a probe, the device is milled from tooth coloured ceramics, zirconia or alumina, using computer controlled milling machines. The machines use diamond tools to machine the ceramic. The Cerec system was introduced in the late 1980s [62, 63] a cavity was scanned stereo-photogrammetrically and a precision-fitting restoration milled from a standard ceramic block using a miniature three-axis milling device; driven by a water turbine unit. The CELAY system [64], a copy milling unit, was introduced to the market in 1991. Other systems have been introduced [65–70]. The continual development of more powerful scanners, computing power and software, and improvements in milling technology software milling have increased accuracy [71–83]. Evaluation of enamel wear of these materials has given conflicting results Al-Hiyasat et al.[84] found machinable ceramics were significantly less abrasive yet Ramp et al. [85] and Imai et al. [86] found greater wear. However, the surface roughness of the finished device is an important factor in wear [57].

Yin et al. [87] classified the materials available as machinable dental bioceramics and difficult to machine dental bioceramics. The machinable dental bioceramics had a machinability similar to existing handmade dental ceramics, they could be easily adjusted in the clinic by the use of existing diamond tools. Abrasive damage and edge chipping during finishing procedures can be apparent which can be influenced by grit sizes and abrasive pressure of the diamond tools and is possibly influenced by the microstructure of the materials.

Difficult to machine dental bioceramics include glass-infiltrated alumina, and surgical grade zirconia. Finishing of these materials has been associated with short tool life, grit microfracture, wear flat, grit pullout and matrix abrasion have all been identified in conventional diamond burs [87, 88]. The small size of dental tools required for internal grinding of devices is the most challenging aspect of machining crowns and bridges [89] as in traditional techniques. The number and shape of diamond particles influences cutting rate and resulting surface roughness of the device [89, 90]. The clinical finish of these materials after adjustment is achieved using diamond pastes [91].

8.7 Dental Cutting Tools

8.7.1 Cutting Efficiency

Evaluation of cutting efficiency of burs has largely related to clinical use [92–97] and the recent developments in CAD/CAM with the few studies applied to dental technology. Diamond burs are manufactured in multiple layers by electrodeposition, sintering, or microbrazing to provide continuous cutting surface as they wear [94]. Cutting efficiency is affected by the substrate being ground and can be affected by clogging (adhesive wear) of the bur as well as wear. Diamond burs and abrasives such as silicon carbide retain cutting efficiency as they wear [43] as the wear exposes new surfaces or particles. Particle size and distribution affect cutting performance [89, 90]. Tungsten carbide was found the most effective with Ag–Pd–Cu–Au alloy, Ag–Zn–In–Sn alloy Ni–Cr alloy and Ti, however, the cutting capability of the carbide bur declined whilst the diamond remained quasi-constant [43]. Xenodimitropoulou and Radford [31] identified the silicon carbide bur as the most effective for grinding Co–Cr alloy in the laboratory but tungsten carbide in the surgery. Siegel and Fraunhofer [42] identified that carbide burs sectioned the base metal alloy significantly faster than the diamond burs but the opposite was observed with noble alloys and medium grit diamond burs should be used. Rimondini et al. [98] identified that small particle diamond burs clogged and observed damage to tungsten burs when grinding titanium and that the most effective were 30 and 15 μm diamonds followed by finer grinding with tungsten carbide burs. Watanabe et al. [99] that when machining cast CP Ti and its alloys, carbide fissure burs possessed a greater machining efficiency than the diamond points. The selection of cutting tool material and the size of the cutting particles or edges is a balance between the speed of removal and the level of finish required. Large particles can remove material quickly but can lead to edge chipping of the substrate, greater surface roughness and poorer mechanical properties. Fine particles are slower, can clog more easily but give a smoother surface. The greater pressure and speed used the greater the heat and chance of clogging, however, as these tools are all hand controlled individual custom and practice affects selection and performance.

8.7.2 CVD Dental Burs

Cobalt-cemented tungsten carbide burs used in dental technology are subject to edge chipping and wear reducing their performance. The sintered material is ground to create the cutting edges (Figs. 8.12 and 8.13). Examination of the surfaces (Figs. 8.14 and 8.15) shows edge chipping and the dulling of the surface reducing cutting efficiency.

Conventional diamond burs are manufactured embedding the diamonds into place using various techniques. The cutting efficiency of the diamond particles is related to the effectiveness of the method used to bind them to the bur, grit pullout and matrix abrasion have been identified as factors in the wear of dental diamond burs [94]. Chemical vapour deposition of diamond films offer advantages in their uniformity of coating over complex surfaces and the nature of their bonding to the substrate.

In 1996 Haselton et al. [100] published their work on the production of polycrystalline chemical vapour deposition (CVD) diamond from hot filament-assisted technique onto stainless steel dental burs. Further work using molybdenum as a

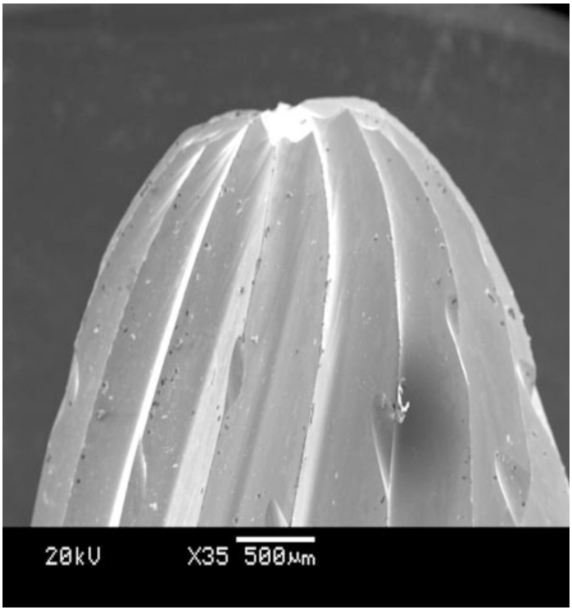


Fig. 8.12 Tungsten carbide bur showing toothing

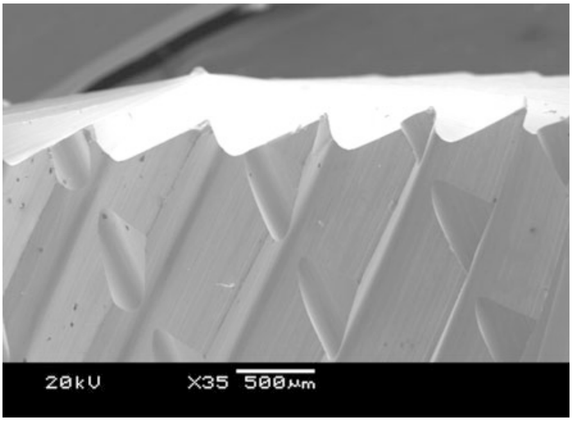


Fig. 8.13 Barrel-shaped tungsten carbide bur

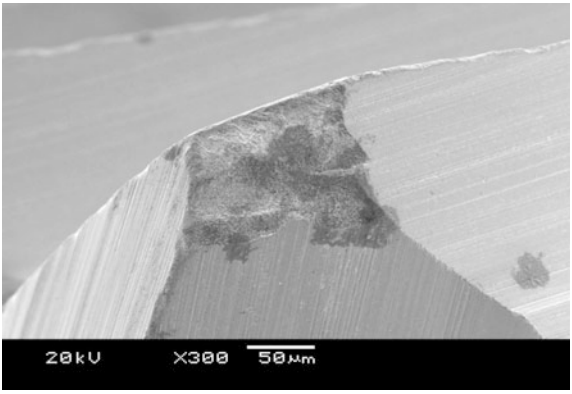
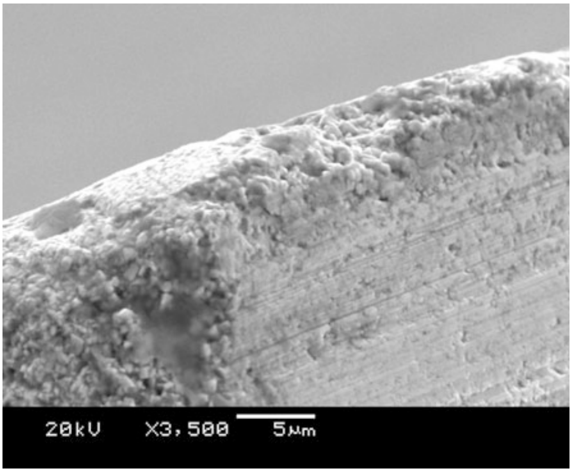


Fig. 8.14 Chip on edge of new tungsten carbide bur

substrate identified better wear characteristics than for a conventional diamond bur [101]. The first report in the dental literature in Borges et al. [102] confirmed greater longevity and identified more efficient cutting ability and the benefit of excluding the risk of metal contamination from the metallic binder used on conventional diamond burs. The unusual combination of housing the Centre for Dental Technology within the Department of Chemistry and Materials Science at Manchester Metropolitan University (MMU) stimulated work on the use of CVD on dental tungsten carbide work. CVD of diamond coatings onto the cemented carbide substrate was poor due to binder materials such as cobalt that can suppress diamond growth [103]. The use of a pre-acid etched substrate surface and a modified HFCVD gave good adhesion [103], further work at MMU developed the CVD techniques for dental burs [104–107].

Studies on the performance of WC–Co CVD diamond-coated burs [108–111] have supported earlier work [102]. Ali et al. [108] identified that the coated WC–Co dental tools remained completely intact after drilling 500 holes into human teeth,

Fig. 8.15 Chip on edge of tungsten carbide bur showing grains and dulling of surface



the conventional bur had lost the majority of its embedded diamond particles. Sein et al. [109] used flank wear to evaluate the wear rates of conventional and CVD diamond-coated burs drilling into a range of substrates. Results show a 300 % improvement with coated burs over conventional burs. Examples of adhesive wear were noted on the bur when grinding acrylic and borosilicate glass. Jackson et al. [110] supported these findings identifying evidence of adhesive and abrasive wear associated with increased rates of abrasion. Polini et al. [111] presented the first quantitative data on the cutting behaviour of uncoated and CVD coated TC burs. They used Co–Cr–Mo dental alloy as the workpiece material grinding at a speed of 20,000 rpm. Some of the uncoated burs failed catastrophically during the tests, the diamond-coated burs exhibited much longer life.

8.7.3 Shanks

The shanks of dental burs may be of the same material as the cutting head or the cutting head will be connected to the head by brazing. The shaft material can be made of metal, e.g. steel or carbide. The type of materials and the treatment given to it is at the discretion of the manufacturer (BS EN ISO 1797-1:1995 Dental rotary instruments. Shanks. Shanks made of metals). The hardness shall be a minimum of 250 HV 5. The shanks are normally 2.35-mm diameter, however, some high-speed laboratory handpieces may require 3.0 mm. If positioned incorrectly in the hand-piece or running at excessive speed the shaft may be liable to deformation, Figs. 8.14 and 8.15 there have been occurrences at MMU of the head separating from the shank. The force in these circumstances lead to the bur head embedding the wall across the laboratory. The implications of this are that ideally grinding occurs in closed chambers, this however is rare practice, then use of bench mounted guards and safety spectacles are normally required.

8.8 Health and Safety

The machining of dental devices exposes dental technicians to several hazards. Impact injuries to the eyes, vibration syndrome and respiratory disease from the dust generated. Eye injuries can be caused by shank failure, abrasive disk failure and debris from the grinding operations. Shields and safety spectacle are required in dental laboratories.

8.8.1 Vibration

The holding of dental handpiece for extended periods with the vibration from the motor itself and the effect of the vibration of the dental bur on the device being ground whilst has been reported to induce vibration syndromes in dental technicians [112–115]. Nakladalova et al. [113] identified damage to both myelinated and unmyelinated fibres in the fingers of subjects exposed to high-frequency vibration. [114] suggested that the usage of high- and low-speed machines may be a cause of vibration syndrome among dental technicians. Mansfield [115] in a study of 120 dental technicians reported paresthesia in the hand fingers (47.4 %) and pain in the joints of upper extremities (elbow 26.6 %, shoulder 10.8 %, wrist 6.6 % and small joints of hand 6.6 %). The EU Physical Agents (Vibration) Directive (2002) came into force 6 July 2005 [116] this requires employers to minimise risk and to address it. Hugonnaud and Lob [117] suggested selection of low vibration handpieces, training in correct usage and recognition of symptoms, health surveillance and periodic reviews. The effect of bur toothing, vibration and its effect has not been investigated, however, increased cutting effectiveness and reduced blunting of tools would benefit. Initial investigations into the performance of CVD coated burs [111] would suggest their benefit in relation to this legislation.

8.8.2 Dust

Since 1967 there have been at least 70 published reports and studies of respiratory conditions associated with dust generated in the making of dental devices [118–129]. The condition dental technicians pneumoconiosis was first specifically described in 1986 by Choudat et al. [124] who described it as complex pneumoconiosis distinct from silicosis, asbestosis, or hard metal disease and that Cr–Co–Mo alloys play a role in its pathogenesis. Since then a number of workers including the Centers for

Disease Control and Prevention in the USA [129] have described a number of respiratory diseases associated with dental laboratory practices including:

- Silicosis (associated with dental ceramics and silica filled polymers);
- Occupational asthma;
- Autoimmune disorders associated with silica;
- Mineral-associated hepatic injury; and
- Sarcoidosis.

8.8.3 Particle Size

The manufacture of dental devices involve numerous techniques and materials and includes significant use of small hand held drills The drills operate at speeds of up to 40,000 rpm. The handpieces hold a range of burs that are used to grind, smooth and polish dental devices. The burs may be made of a range of abrasives including tungsten carbide, silicon carbide (SiC), carborundum (Al_2O_3), rubber, diamond, ruby abrasives or even sandpaper. The materials being ground include precious metal alloys, nickel chromium alloys, cobalt chromium alloys, ceramics, silica/polymer composites, acrylic resins and dental gypsum products. The elements in the dental alloys include, Co, Cr, Cu, Ag, Ni, Sn, Mo.

The dust generated by the processes should be collected by a local dust extractor system. This may be an individual machine or part of a centralised system as in the new development. In use the handpiece and the device being ground are positioned close to the extractor port. The grinding of dental materials generates varying amounts of dust from the materials and the grinding stones. The particle size of these varies depending upon the materials being ground and the grinding tools, Brune and Beltesbrekke identified ranges from 0.6 to 50 µm with a significant proportion below 5 µm that is respirable. This work has been confirmed in a number of undergraduate research projects at MMU. The weight of dust generated in the grinding and polishing of one metal denture base is approximately 1 g. Brune and Beltesbrekke recommended a minimum extraction of 30 l/s (3 m/s) to remove the majority of this dust. Collard et al. reported that a diamond bur created more respirable particles than the carbide bur for each composite tested although this will probably relate to abrasive particle size.

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