Chapter 2

Ceramic Brackets Revisited

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Additional information is available at the end of the chapter

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Abstract

Increasing demand for esthetics during fixed appliance therapy has led to a significant increase in the demand for and use of ceramic brackets. This comprehensive review covers the physical properties as well as rebonding and debonding of polycrystalline and monocrystalline ceramic brackets. Furthermore, this review aims to present the advantages and disadvantages as well as the refinements these brackets underwent since their introduction in the late 1980s. Interestingly, the introduction and development of these brackets were a part of a quickly expanding ceramic technology in many industries. The authors strongly believe that the novice will particularly benefit from this review presenting up-to-date knowledge.

Keywords: review, ceramic brackets, monocrystalline alumina brackets, polycrystalline alumina brackets, rebonding, debonding

1. Introduction

It is interesting to note that ceramic braces entered orthodontics via an indirect route. Translucent polycrystalline alumina (TPA) was developed by NASA (National Aeronautics and Space Administration) and Ceradyne, a leader in advanced ceramics for aerospace, defense, electronics, and industrial use. In 1986, a dental equipment and supply company contacted Ceradyne for an esthetic material to be used in orthodontics. Ceradyne recommended TPA. Shortly, after this contact, namely in 1987, ceramic brackets were introduced. In the same year, i.e., 1987, the production of ceramic brackets reached 300,000 pieces a month [1]. To clarify, 300,000 pieces would translate into 15,000 nonextraction patients per month! Ceramic brackets have progressed substantially since their first introduction over 30 years ago. This article aims to present an up-to-date review of the physical and clinical characteristics, i.e., properties, of ceramic brackets.

2. Ceramic bracket production: a short overview

Most ceramic brackets are produced from aluminum oxide (alumina) particles, and these brackets are available in polycrystalline and monocrystalline forms [2].

Nowadays, the majority of polycrystalline (multiple crystals) brackets are produced by ceramic injection molding (CIM). An outline of CIM is as follows: the aluminum oxide (Al_2O_3) particles are mixed with a binder. This mixture is rendered flowable through heat and pressure application and injected into a bracket mold. The binder is removed, i.e., burned out. Subsequently, sintering—the production of a coherent mass by heating without melting—is carried out. The advantage of CIM is that this technology can manufacture complex and precise items with smooth surfaces in large quantities at fast rates [3].

The production process for monocrystalline (single crystal) ceramic brackets, also referred to as sapphire brackets, is completely different. Here, the Al_2O_3 particles are melted. The resultant mass is slowly cooled to permit a controlled crystallization, leading to the production of a large, single crystal. This large, single crystal in rod or bar form is then milled into brackets with ultrasonic cutting techniques and/or diamond cutting tools. After milling, the monocrystalline brackets are heat-treated to eliminate surface imperfections and to relieve the stress caused by the milling procedure. The production of these brackets is more expensive when compared to the production of polycrystalline brackets. This increased expense is mainly due to the difficulty of milling, i.e., the cutting process [2].

3. Properties of ceramic brackets

3.1. Hardness

Ceramic brackets are known for their hardness. They are notably harder than enamel [4–7]. Thus, contact between enamel and ceramic brackets has to be avoided by all means. This type of contact can lead to severe enamel damage [8]. Particular care has to be exercised with deep bite and/or class II canine relationship patients. If required, bite opening applications must be performed to prevent enamel damage.

3.2. Tensile strength

The ultimate tensile strength, often shortened as tensile strength, is defined as the maximum stress that a material can withstand while being stretched or pulled before failing or breaking [9]. When stress is placed on a ceramic material, its unyielding atomic structure makes the redistribution and the relief of stress close to impossible [2]. Ductile materials, such as metals and polymers, experience plastic deformation before failure [10]. In other words, the elongation of ceramics at failure (brittle fracture) is less than 1%, yet the elongation of stainless steel at failure (ductile fracture) is approximately 20% [11]. Hence, ceramic brackets do not flex. This implies that ceramic brackets are much more likely to fracture than metal brackets under identical conditions [11].

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3.3. Fracture toughness

Fracture toughness is a property which describes the ability of a material containing a crack to resist fracture [6, 12]. This is an important material property since the presence of imperfections, such as microscopic scratches, cracks, voids, and pores are not completely avoidable during the fabrication of materials. These microscopic imperfections may or may not be harmful to the material, depending on a number of factors such as the fracture toughness of the material examined, the stress on the material, length of the crack, and resistance of the material to crack propagation as well as the environment of the material [6].

The higher the fracture toughness, the more difficult it is to propagate a crack in that material [12]. The fracture toughness of polycrystalline alumina brackets is higher than the fracture toughness of monocrystalline alumina brackets. This implies that crack propagation is relatively easier in single-crystal alumina brackets when compared with polycrystalline alumina brackets [12]. Polycrystalline brackets have a higher resistance to crack propagation due to crack interaction with grain boundaries (GBs). A GB is the interface between two “grains” (crystals) in a polycrystalline (multiple crystals) material (**Figure 1**). Cracks are impeded at these GBs [10]. Clinical applications that may scratch the surfaces of ceramic brackets may greatly reduce the fracture toughness, thereby predisposing ceramic brackets to eventual fracture [12]. Thus, utmost care has to be taken not to scratch ceramic bracket surfaces with instruments and stainless steel ligature wires during treatment. Also, the clinician should not overstress when ligating with steel ligature wires. This might initiate crack growth and propagation, leading to the eventual fracture of the bracket. Careful ligation is mandatory, and elastomeric modules (ligatures) or coated ligatures are advised to prevent ceramic bracket fractures, particularly tie-wing fractures [6, 13, 14]. Arch wire sequencing also has to be performed carefully. The use of resilient full-size arch wires before the placement of full-size stainless steel arch wires is recommended [7]. Furthermore, the patient has to be advised to restrain from chewing and/or biting on any hard substances [6] as well as from intraoral/lip piercings. A prudent choice is to avoid ceramic brackets with orthognathic surgery patients as well as with patients involved in contact sports.

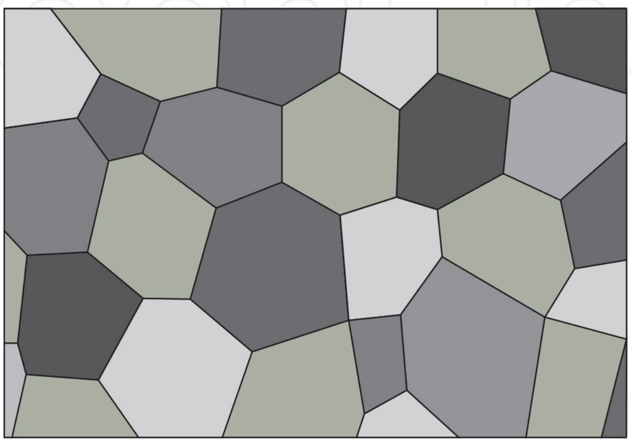

Figure 1. Schematic presentation of “grains” and GBs.

Finally, it should be noted that the exposure of alumina to water or saliva decreases fracture toughness [10]. This characteristic is important to remember when the clinician attempts to extrapolate in vitro results to the clinical setting, i.e., the oral environment.

3.3.1. Tie-wing fracture

Figure 2 pictures a tie-wing fracture of the lower second premolar bracket. Most likely this tie-wing was damaged with pliers during arch wire insertion into the molar tube.

Complete fragmentation of a damaged bracket might occur during arch wire ligation or during the course of treatment. Thus, the removal of an impaired bracket and its replacement with a new bracket is a prudent risk management strategy. The risk of ceramic fragment penetration into the patient's oral soft tissues, inhalation or swallowing by the patient does exist. Ceramics are radiolucent, i.e., ceramic bracket fragments are not visible on radiographs [15].

An interesting in vitro study [16] tested tie-wing fracture strength of polycrystalline and monocrystalline brackets after being exposed to fluoride prophylactic agents (Prevident 5000 and Phos-flur gel; Colgate Pharmaceuticals, Canton, Mass, USA). The researchers stated that the fluoride-alumina surface interaction most likely caused strain in the surface bonds of both types of brackets. Yet, this presumed bond strain only affected the fracture strength of the monocrystalline alumina brackets. The results of this study imply that the use of topical fluoride agents may increase the susceptibility of tie-wing fractures of monocrystalline brackets under clinical conditions and that polycrystalline brackets might be the appropriate choice for poor oral hygiene patients that require fluoride prophylactic agents. The authors [16] pointed out that this outcome was most likely related to the inhibition of cracks at the GBs of the polycrystalline microstructure.

The tie-wing complex of polycrystalline ceramic brackets can be manufactured as either semitwin or true twin. Semitwin differs from true twin by having an isthmus of ceramic joining the mesial and distal tie-wings, i.e., the mesial and distal tie-wings are not four independent projections from the bracket base as with the true twin configuration (**Figure 3**). This semitwin configuration has been stated to possess a better tie-wing fracture strength. It has been proposed that such a ceramic connector produces a cross-stabilizing effect [13, 17].

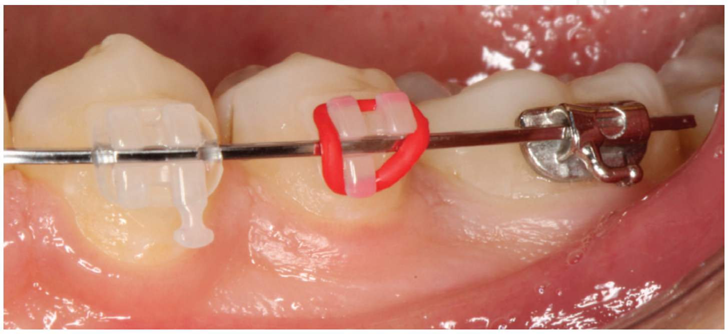

Figure 2. Distogingival tie-wing fracture (the red elastic ligature was used to accentuate this fracture).

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Figure 3. The semitwin tie-wing complex.

3.4. Friction

When polycrystalline ceramics were compared with monocrystalline ceramics, it was concluded that polycrystalline ceramics have a higher coefficient of friction. In fact, more than a decade ago, it was pointed out that monocrystalline brackets have frictional characteristics close to metal brackets [4].

To overcome the problem of frictional resistance of polycrystalline brackets, manufacturers carried out numerous modifications. Polycrystalline ceramic brackets with metal inserts in the arch wire slot (metal slots) were developed [18]. Nevertheless, it was reported that the sharp edges of the metal insert may "dig into" the softer arch wire material, thus increasing resistance to sliding and thereby reducing the efficiency of tooth movement [7, 19]. Another modification was the addition of bumps along the floor of the polycrystalline ceramic bracket slot. Nevertheless, these bumps were not effective in reducing frictional resistance [20].

A recent study, including ceramic and metal brackets that were manufactured by different production methods, including CIM and metal injection molding (MIM), concluded that the manufacturing technologies do not present a critical difference regarding friction [3]. It was reiterated that the complex phenomenon of friction depends on a multitude of factors, such as the bracket/ligature/arch wire combinations, the surface quality of the arch wire/bracket slot, the bracket design, and the force exerted by the ligature on the arch wire [3].

3.5. Optics

The optical properties of ceramic brackets provide an attractive option for a great number of patients. As previously mentioned, polycrystalline ceramic brackets possess a microstructure of crystal GBs. This microstructure reflects light, resulting in some degree of opacity. In contrast, single-crystal brackets lack GBs, thus permitting the passage of light, making these brackets basically clear [2, 10, 21].

As mentioned above, monocrystalline brackets have more optical clarity than polycrystalline brackets (**Figure 4**). Whether this difference is of essential importance from an esthetic point of view is a decision to be made by the orthodontist as well as the patient [2].

Apart from esthetics, the optical properties of ceramic brackets have been shown to affect the amount of light transmitted through these brackets during photocuring. The amount of light transmitted through ceramic brackets affects the curing efficiency of the light-cured adhesive. Polycrystalline brackets and polycrystalline brackets with a polymer mesh base were found to block direct light transmittance to a greater extent than monocrystalline brackets. It was pointed out that the color-coded holders designed for identification and handling of ceramic brackets also hinder light transmittance. The use of clear holders with colored edges has been suggested [22].

3.6. Color stability

The color stability of ceramic brackets throughout orthodontic treatment is an important characteristic. It has been stated that ceramic brackets, both monocrystalline and polycrystalline, undergo a color change when subjected to coffee, black tea, coke, and red wine [21, 23, 24]. It has to be pointed out that these are in vitro findings. In vivo studies concerning the color stability of ceramic brackets are lacking.

3.7. Plaque accumulation

Limited information is available about which bracket material (ceramic versus metal brackets) is less prone to the adhesion of bacteria and plaque accumulation. A clinical study performed by Lindel et al. [25] concluded that ceramic brackets exhibit less long-term biofilm accumulation than metal brackets. It was emphasized that future research should aim to determine whether the difference in biofilm accumulation between ceramic and metal brackets has a clinically significant effect on the development of decalcifications. Lindel et al. [25] pointed out that the results obtained from this type of future research might have a strong effect when choosing bracket material in patients with insufficient oral hygiene habits.

Figure 4. Intraoral image of monocrystalline (A) and polycrystalline (B) ceramic brackets.

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3.8. Biocompatibility

Biocompatibility is the ability of a material to provide successful service in a host while causing minimal response [9]. It has been stated that conventional ceramic brackets are chemically stable (inert) in the oral environment and that they exhibit excellent biocompatibility with oral tissues [5].

In 2012, Retamoso et al. [26] carried out an in vitro cytotoxicity study evaluating various orthodontic brackets. These researchers reported that monocrystalline ceramic brackets had good biocompatibility. On the other hand, polycrystalline ceramic brackets with metal slots demonstrated some toxic effects. It was pointed out that the metallic slot was the essential factor responsible for a decrease of cell viability due to nickel ion release. They [26] concluded that it is essential to continue with studies evaluating cytotoxicity. If toxicity of any material is proven, alternative materials have to be used.

3.9. Magnetic resonance imaging (MRI) compatibility

Orthodontists are often asked to remove fixed orthodontic appliances prior to an MRI scan—a diagnostic tool that does not expose the patient to radiation—particularly when looking for pathology in the head and neck region or when information regarding the articular disc is required [10, 27].

Beau et al. [27] provided a detailed flowchart concerning the indications for the removal of fixed orthodontic appliances prior to MRI scans of the head and neck region. According to this flowchart, ceramic brackets do not have to be removed prior to an MRI scan. They are MRI-safe. However, ceramic brackets with any metal components, such as stainless steel slots, have to be removed if the region under examination is adjacent to these brackets. Stainless steel causes extensive artifacts, which may degrade image quality beyond clinical acceptability. The authors [27] pointed out that they did not include arch wires or removable appliances in their research, since these can be easily removed prior to an MRI scan.

4. Characteristics of ceramic bracket bases

Several retention mechanisms were developed for the attachment of ceramic bracket bases to the adhesive. These are chemical retention, mechanical retention, and a combination of both methods [21, 28]. The first developed method was the chemical retention method. This method, now obsolete, used a coating of glass on the flat ceramic bracket base and then a silane coupler to achieve a chemical bond between the glass-coated bracket base and the adhesive. The silane molecule is a bifunctional molecule; that is, one end reacted with the glass coating on the bracket base, while the other end reacted with the adhesive [11, 29]. It was pointed out that the chemical retention mechanism produced very strong bonds that harmed the tooth surface in the form of cracks and enamel tear-outs during debracketing [4, 7, 11, 29–32].

Almost three decades ago, Ghafari and Chen [33] compared the performance of chemical retention ceramic brackets to silane-treated grooved base ceramic brackets (a combination of chemical and mechanical retention). They [33] concluded that mechanical retention might reduce the negative side effects of debracketing by favoring failure within the adhesive, thus protecting the integrity of the enamel surface, i.e., the health of the tooth, as well as the integrity of the ceramic bracket.

The reports about iatrogenic tooth damage during debracketing impelled manufacturers to make changes in the base designs of ceramic brackets, relying more on mechanical retention for bond strength. In fact, the majority of ceramic brackets available today are purely mechanically retained brackets [4, 30, 34]. Mechanical retention is achieved by creating undercuts or grooves in the base of the bracket. These undercuts make a mechanical interlock with the adhesive bonding agent possible [28].

Currently, many different mechanical base designs are available, such as microcrystalline base design with a stress concentrator, button-structured base design, ball-base design with gingival ball reduction, dovetail base design, laser-structured base design, and "portal" bonding base design [4, 15, 35, 36].

An additional, interesting base design is the application of a thin layer of polymer onto the ceramic bracket base [19]. Thus, bonding takes place between the enamel and the flexible polymer mesh base. Encouraging in vitro results concerning the enamel surface after debracketing were obtained [30, 37, 38].

At this point, only two published clinical studies [14, 39] with a purely mechanical retention mechanism were encountered. There is a need for clinical studies, particularly randomized clinical studies, i.e., the gold standard for evaluating clinical procedures.

5. Rebonding of ceramic brackets

Although some major orthodontic supply companies explicitly state in their instruction sheets that their ceramic brackets are for single use only, several laboratory studies suggested various techniques for the reuse, i.e., the rebonding, of ceramic brackets [40–44]. For reuse, the bracket has to be intact in the first place.

It has been pointed out that the appropriate term is "reuse" or "recondition" instead of "recycle," since the term "recycled" implies the manufacturing of new brackets from the raw material of the original, failed brackets [12]. Nevertheless, the literature usually refers to these brackets as "recycled."

An in vitro study [43], carried out in 2016, investigated the "recycling" of polycrystalline ceramic brackets with a microcrystalline base via the following three methods: first is the erbium-doped yttrium aluminum garnet (Er:YAG) laser, and the other two are traditional methods, i.e., flaming and sandblasting. Sandblasting (50 μm Al_2O_3 particles) damaged the delicate bracket base structure and demonstrated significantly less bond strength than new

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brackets. The flaming procedure yielded a bond strength that was similar to that of new ceramic brackets. However, flaming affected the esthetics of these brackets, i.e., these brackets ended up faded and dark. Er:YAG lasers completely removed the adhesive remnants from the ceramic bracket bases without damaging the base structure. Furthermore, the shear bond strength of Er:YAG laser "recycled" brackets was similar to that of new brackets. It was pointed out that the laser method may be preferred over other "recycling" methods.

Yassaei et al. [44] also concluded that the Er:YAG laser presents an efficient way for "recycling" ceramic brackets. These researchers used polycrystalline ceramic brackets with a dovetailed base in their in vitro study.

6. Debonding of ceramic brackets

Debonding usually refers to the removal of orthodontic brackets and the residual adhesives from the tooth enamel at the end of fixed appliance treatment [45].

Ceramic brackets lack flexibility. In other words, the rigid ceramic and the rigid enamel have little ability to dissipate stress when exposed to debracketing forces at the end of treatment. Thus, bracket fracture and/or enamel damage may occur during debracketing [2, 11].

Several approaches aiming to minimize the side effects associated with the debracketing of ceramic brackets exist. These are the conventional (mechanical), ultrasonic, electrothermal, and laser techniques [11, 21].

6.1. Mechanical debracketing

Three mechanical debracketing techniques have been described. These are lift-off, wrenching, and delamination [46]. The first technique uses a lift-off debracketing instrument (LODI). This pistol-grip plier is placed over the bracket, and a debracketing force is applied to the tie-wings of the bracket. It has been pointed out that the LODI cannot be used with ceramic brackets due to their brittleness [39]. The wrenching technique uses a special tool that produces a wrenching or torsional force at the base of the bracket [46]. This approach, providing a rotational shear force, can be likened to the turning of a door knob.

The delamination technique was the first technique introduced and is still reported to be the most widely accepted ceramic bracket removal technique [11, 15]. This technique involves the application of a slow squeezing force with the sharp blades of the debracketing pliers placed on the enamel surface and within the adhesive, thereby producing a wedging effect (**Figure 5**).

It has been stated that such a force—produced by a slow, gradual compression—would seem to offer the best chance for inducing crack propagation within the adhesive, leading to a cohesive failure, thus minimizing the risk of enamel damage as well as the risk of bracket fracture. A cohesive bond failure is a failure through a single material, where cohesive forces between the same atomic species are present [2, 11, 21, 46].

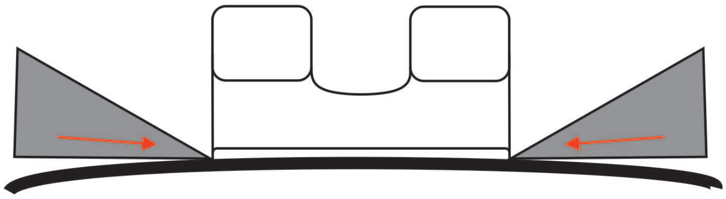

Figure 5. Schematic presentation of the delamination technique.

In 1993, Bishara and Fehr [47] evaluated the force levels produced with wide and narrow blades during ceramic bracket removal from human maxillary molar teeth. The wide blades and narrow blades were 3.2 and 2 mm, respectively. Polycrystalline ceramic brackets relying on a combination of mechanical and chemical retention were used. The findings of this in vitro study indicated that the narrow blades produced a significantly lower mean debracketing force, namely 120 kg/cm^2 than the wider blades (150 kg/cm^2). Bishara and Fehr [47] concluded that such a significant reduction (20%) in the debracketing force places less stress on the enamel surface, thereby reducing the risk of enamel damage. It has been reported and reiterated that debracketing forces larger than 138 kg/cm^2, i.e., 13.53 MPa should be avoided [11, 48, 49].

In 2000, Arici and Minors [50] carried out an in vitro study with four different methods of debracketing. They pointed out that reducing the contact area, i.e., contact area between the plier blades and the adhesive, to a minimum reduces the force necessary to initiate ceramic bracket removal. Macroscopically, no enamel damage and no bracket fractures were reported. Arici and Minors [50] used primary bovine mandibular incisor teeth and polycrystalline ceramic brackets with chemical retention. They concluded that their findings basically corroborate the findings of Bishara and Fehr [47].

Following the introduction of ceramic brackets, more than 30 years ago, serious complications during debracketing were encountered [4, 7, 11, 13, 51, 52]. Many in vitro studies, to assist in the development of more reliable and clinically safe ceramic brackets, followed. The reduction of ceramic debracketing forces, thereby protecting enamel integrity as well as bracket integrity, was the aim of these studies [11, 47, 48, 50].

Nowadays, the majority of ceramic bracket manufacturers present detailed debracketing instructions. In fact, many manufacturers have introduced debracketing instruments specifically designed for their bracket brand. These manufacturers claim that their brackets can be removed as easily and as safely as metal brackets as long as the orthodontist meticulously follows these instructions [4, 11, 13, 15]. As a risk management strategy, ceramic brackets that are not accompanied by detailed instructions for bonding and debracketing should definitely not be used.

Any shortcomings related to ceramic brackets should be reported immediately to the manufacturer [7]. "First, do no harm" should serve as the fundamental guiding principle for anyone engaged in health care [53].

6.2. Precautions for mechanical debracketing

Bonding a ceramic bracket to a compromised tooth, such as a brittle, nonvital tooth (endodontically treated tooth), a tooth with developmental defects, a tooth with demineralized enamel, a tooth with enamel cracks and/or a large restoration, should be avoided as much as possible. This type of tooth is under greater risk for enamel damage when compared with a healthy tooth during mechanical debracketing [21, 39]. Care also has to be exercised with porcelain restorations, such as crowns and veneers [51].

During the bonding procedure, excess adhesive flash (EAF) must be removed with an explorer before the adhesive has set or with burs after setting. Only meticulous EAF removal allows the sharp-edged plier blades of the debracketing instrument to be fully seated on the enamel during ceramic bracket removal. This produces a safe force transmission and crack propagation through the adhesive, resulting in a cohesive failure within the adhesive, thereby protecting enamel as well as bracket integrity [2, 11, 21]. Furthermore, EAF removal improves esthetics by providing a clean and neat appearance.

It should be noted that a flash-free adhesive-coated appliance system was introduced. This innovative technology does not necessitate flash removal [54].

Unfortunately, debracketing may lead to bracket fracture. Bracket fragments may detach (loose fragments) or remain attached on the enamel surface. Low-speed or high-speed grinding of the bracket fragments with no water coolant may bring forth permanent damage and necrosis of the dental pulps. Therefore, water cooling is absolutely necessary during the grinding/removal of ceramic bracket fragments [10, 55]. Furthermore, high-volume suction next to the area of grinding has been emphasized in order to minimize the spreading of ceramic particles [10, 55]. These particles have been reported to cause irritation of the eyes as well as itching of the hands [55]. After the removal of these fragments, the clinician can proceed with adhesive remnant removal.

Loose, fractured ceramic bracket fragments may create serious problems, such as aspiration or ingestion of these radiolucent fragments. Furthermore, during debracketing, the "popping off" of fragments may occur. This may subject the patient as well as the orthodontist to eye injury. The use of protective eyewear and a mask is indispensable for the orthodontist. The patient should be given protective eyewear as well [21, 34, 56].

The force applied during debracketing may cause discomfort. Therefore, the orthodontist should always support the teeth with his or her fingers or make the patient bite firmly into a cotton roll during debracketing. Biting firmly into a cotton roll and/or gauze not only minimizes discomfort but also minimizes the risk of brackets and/or fragments from getting displaced into the oral cavity [21, 34]. Colored cotton rolls may facilitate the detection of fractured ceramic bracket fragments.

If pliers are used for debracketing, Bishara and Fehr [21] advised the renewal of the plier blades after the removal of 50 brackets. Pliers with nonexchangeable blades should be sharpened on a regular basis [21]. Sharp-edged plier blades are required for safe debracketing, i.e., for the induction of crack propagation within the bonding adhesive rather than the enamel or the ceramic bracket. The orthodontist should never delegate ceramic bracket debracketing to auxiliaries [21, 56].

It has been emphasized that every informed consent form signed by the patient/parents (and the orthodontist) should specifically outline the potential risks of ceramic brackets, particularly in an ever-increasing litigious society [56]. Also, the brand of the ceramic bracket should always be recorded on the patient's file. This is of particular importance in the case of transfer to another orthodontist.

6.3. Adjunctive methods proposed for mechanical debracketing

Larmour and Chadwick [57] evaluated the ability of a commercial debonding agent, post-debonding agent (P-de-A) (Oradent Ltd., Eton, Berks, UK). This green gel, containing a derivative of peppermint oil, was claimed to facilitate ceramic bracket debracketing and adhesive residue removal. The manufacturer of P-de-A advised an application time of 1–2 min to soften the resin. Nevertheless, the P-de-A research results did not support these claims [57, 58].

In 1997, Arici et al. [59, 60] proposed the use of a crushable porous ceramic lamella as a means of facilitating debracketing. These porous lamellae were attached to the bracket base with adhesive resin. Subsequently, these bracket/lamella assemblies were bonded to the enamel of the experimental teeth (bovine incisor teeth). The authors [60] of this in vitro study reported the safe removal of these ceramic bracket/lamella assemblies, i.e., no fractures of the ceramic bracket or any evidence of enamel damage was observed. Commercial production of this type of ceramic bracket/lamella assembly was not undertaken.

In 1998, Larmour et al. [61] evaluated the possibility of reducing the complications of ceramic bracket debracketing by introducing a notch in the composite bond layer. A section of Mylar® matrix strip (0.01 mm thick and 0.75 mm wide) was placed within the bonding agent in this ex vivo investigation. After the bonding agent had set, the matrix strip was removed creating a "notched" bond layer. Larmour et al. [61] concluded that notching the bonding agent does facilitate ceramic bracket removal. Nevertheless, they emphasized that this modification is not feasible in a clinical setting due to the time needed and the technical difficulty of creating a "notched" bond layer. Furthermore, they cautioned that such a "notched" adhesive layer may lead to plaque accumulation.

In 2003, Carter [62] suggested that a hot-water bath might facilitate ceramic bracket debracketing. Patients were given a cup of hot water, supplied from a coffeemaker, and were asked to hold this water in their mouths for 1 min without swallowing. Subsequently, debracketing with suitable pliers was performed. Carter [62] emphasized that since 1986 no enamel fracture or any other iatrogenic damage occurred with this application in his clinic. Unfortunately, the exact temperature of this "hot-water bath" was not stated.

6.4. Ultrasonic debracketing

It was reported that the ultrasonic debracketing technique presents a decreased probability of enamel damage as well as a decreased probability of bracket fracture. Also, the residual adhesive remaining after debracketing can be removed with the same ultrasonic tip. Nevertheless, the debracketing time is the longest when compared with the mechanical or electrothermal debracketing techniques. It was reported that the debracketing time of the ultrasonic debonding technique is 38–50 s per bracket, when compared with 1 s per bracket with the mechanical debracketing technique. Furthermore, the contact between the "hard" ceramic bracket and the ultrasonic tip has been reported to cause wear of this expensive tip. During the ultrasonic debracketing procedure, water spray is mandatory to prevent pulp damage. This method requires further testing and is not yet recommended for clinical use [11, 21]. No clinical studies were encountered upon a literature search.

6.5. Electrothermal debracketing

In 1986, Sheridan et al. [63] were the first who described electrothermal debracketing (ETD) for the removal of metallic brackets.

With ceramic brackets, ETD has been reported to cause a reduced incidence of bracket fracture. The reduced incidence of bracket fracture is ascribed to the small amount of force needed to break the bond after the heat-induced tip has promoted bond failure by softening/weakening the adhesive material. A relatively short debracketing time per bracket (2 ± 1 s) was reported. The possibility of pulp damage has been mentioned. Fortunately, no signs of irreversible pulp damage with ETD were described [11, 64–66]. Patient acceptance was generally positive [64].

6.6. Laser debracketing

Different types of lasers have been used for the debracketing of ceramic brackets [67]. The application of laser irradiation causes the softening of the adhesive material. This seems to be quite similar to ETD; however, with laser-assisted debracketing, the amount of thermal energy delivered to the ceramic bracket can be carefully controlled, thereby preventing the possibility of overheating [21, 68]. The time spent for ceramic bracket removal with the laser-based technique is 1–5 s. Debracketing forces are significantly reduced with lasers. As a result, enamel damage and bracket fracture risks are significantly reduced [67, 69]. The high cost of this device may be a disadvantage for the orthodontist [11, 21].

7. Last but not least

The physical properties as well as rebonding and debonding of monocrystalline and polycrystalline alumina ceramic brackets were reviewed. Ceramic brackets fabricated from polycrystalline zirconium oxide (zirconia) were not mentioned. Thus, we would like to add a short paragraph about these brackets for the interested reader.

Zirconia ceramic brackets, manufactured in Japan and Australia, have attracted interest in the past [12]. Nevertheless, problems concerning color (yellowish tint) and opacity (nontranslucency) were reported approximately three decades ago [12, 70]. Furthermore, no significant advantage of zirconia brackets over alumina brackets with regard to their frictional characteristics were reported [71]. Limited published research on zirconia (zirconium oxide) brackets exists [72].

8. Conclusion

In an increasingly demanding and litigious society, it is mandatory for the orthodontist to use carefully designed ceramic brackets. As a simple risk management strategy, ceramic brackets that are not accompanied by detailed instructions for bonding and bracket removal should definitely not be used. These products might not have been exposed to appropriate, detailed testing procedures prior to their sale. Thus, be alert and keep updated!

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† I, Selma, dedicate this chapter to the memory of my grandmother, Anna Kirschner (1915–2004). My heart will always miss you....

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