

Thermal image analysis of electrothermal debonding of ceramic brackets: an *in vitro* study

Maurice Cummings*, Paul Biagioni**, Philip-John Lamey** and Donald J. Burden*

Divisions of *Orthodontics and **Oral Medicine and Oral Surgery, School of Clinical Dentistry, The Queen's University of Belfast, UK

SUMMARY This study used modern thermal imaging techniques to investigate the temperature rise induced at the pulpal wall during thermal debonding of ceramic brackets. Ceramic brackets were debonded from vertically sectioned premolar teeth using an electrothermal debonding unit. Ten teeth were debonded at the end of a single 3-second heating cycle. For a further group of 10 teeth, the bracket and heating element were left in contact with the tooth during the 3-second heating cycle and the 6-second cooling cycle. The average pulpal wall temperature increase for the teeth debonded at the end of the 3-second heating cycle was 16.8°C. When the heating element and bracket remained in contact with the tooth during the 6-second cooling cycle an average temperature increase of 45.6°C was recorded.

Introduction

Problems have been reported with the clinical use of ceramic brackets; these include attrition of the teeth occluding with the brackets (Douglass, 1989; Viazis *et al*., 1989), bracket failure or breakage (Scott, 1988) and enamel damage caused by traumatic displacement of the bracket (Jeiroudi, 1991). Enamel damage caused during intentional debonding is also a major concern (Joseph and Rossouw, 1990; Viazis *et al*., 1990; Winchester, 1991). With the exception of some one-piece brackets, most metal brackets are ductile and can be peeled from the enamel surface. However, ceramic brackets are brittle and cannot be easily removed by conventional debonding methods. Alternative debonding techniques have been suggested, including debonding with special pliers (Swartz, 1988), ultrasonic debonding units (Bishara and Trulove, 1990a), and grinding the brackets from the tooth surface with a diamond bur (Vukovich *et al*., 1991). Heating ceramic brackets to soften the bonding adhesive with electrothermal debonding devices (Bishara and Trulove, 1990b; Sernetz and Kraut, 1991; Brouns *et al*., 1993) or lasers (Strobl *et al*., 1992; Tocchio *et al*., 1993; Rickabaugh *et al*., 1996) has also been advocated.

Electrothermal debonding (ETD) was first reported as a method of debonding metal brackets (Sheridan *et al*., 1986a,b). ETD units function by heat transference to the bracket and bonding material causing a softening of the composite adhesive allowing debonding without the use of excessive force. Studies have shown that the ETD method provides a reduction in the incidence of bracket fracture, a shorter debonding time, and a decreased risk of enamel damage (Bishara and Trulove, 1990b; Sernetz and Kraut, 1991). One study found that the ETD method produced less patient discomfort compared with mechanical debonding of ceramic brackets (Kraut *et al*., 1991).

Nonetheless, the amount of heat reaching the pulpal chamber and the potential for pulpal damage during electrothermal debonding has received scant scientific evaluation.

Most previous studies of the thermal insult experienced by the pulp as a result of electrothermal debonding of ceramic brackets have used thermocouples to record the rise in pulp chamber temperature (Sernetz and Kraut, 1991;

Brouns *et al*., 1993). The results of these *in vitro* studies indicate that under normal debonding conditions the increase in pulp chamber temperature does not exceed the commonly accepted safe limit described by Zach and Cohen (1965). However, when the ceramic brackets failed to debond successfully at the first attempt and the heating element remained in the bracket slot, temperature increases above the safe threshold were noted.

When a thermocouple is used to measure changes in pulpal wall temperature a conducting medium is required to transfer heat from the pulpal wall to the thermocouple (Sernetz and Kraut, 1991; Brouns *et al*., 1993). The development of thermal imaging techniques means that it is now possible to use a non-contact form of temperature analysis.

The present study investigated thermal debonding of ceramic brackets using thermal imaging techniques.

Materials and methods

Brackets

Fascination ceramic premolar brackets with a 0.022-inch slot size (Dentaurum Co., Pforzheim, Germany) were used in this study. These comprise a polycrystalline aluminium oxide which uses chemical retention to achieve attachment to the buccal surfaces of the teeth.

Preparation of teeth

Sound human premolar teeth extracted from adolescent patients for orthodontic reasons were collected and stored in 10 per cent formalin solution immediately after extraction. The teeth were sectioned vertically through the contact area of the proximal surfaces in a mesio-distal direction. Minimal overhanging dentine was removed from around the edges of the exposed pulp chamber. This was performed conservatively to ensure little interference with the original morphology of the pulp chamber. Initial pilot studies had revealed that this manner of preparation provided the best access for thermo-imaging of the pulpal wall.

The buccal surfaces of the teeth were polished using a pumice and water slurry in a rubber cup. The teeth were then cleaned, dried, and etched for 30 seconds using a 37 per cent orthophosphoric acid gel (3M Corp., St Paul, Mn, USA). The teeth were washed with water for 20 seconds and air dried. The ceramic brackets were then bonded onto the buccal surfaces of the teeth in a standardized manner using Concise (3M Corp.) and any excess material extruding beyond the bracket base was removed before polymerization. The specimens were stored in distilled water at 37 degrees for 24 hours to ensure complete polymerization. The apical third of each tooth section was then embedded in a cylinder of dental stone to facilitate handling.

Thermal debonding unit

The Ceramic Bracket Debonding Unit (Dentaurum Co.) was used to debond the brackets. This device functions by warming the bracket and bonding material through heat transference. An arched metal heating element, situated at the tip of the hand-piece is inserted into the bracket slot and then activated. The unit has a heating cycle of 3 seconds which has been shown to heat the tip of the heating element to 1140°C (Brouns *et al*., 1993). The manufacturers recommend that the heating element should not be activated until it is inserted into the bracket slot. The heating cycle is followed by a cooling cycle of 6 seconds. The manufacturers also recommend that a light turning force is applied to the bracket via the heating element during the heating cycle.

Thermographic analysis

The Thermovision 900 (Agema Infra-red Systems, Danderyd, Sweden) thermographic imaging system was used in this study. The system consists of a modular unit, a long-wave scanner, a visual graphic monitor, and an enhanced keyboard with specialized system controls. Infrared radiation is focused onto a cryogenically cooled mercury cadmium telluride detector which has a sensitivity of 0.1°C. The detector output is digitized and transmitted to the system controller, and can be viewed on a monitor or stored in 12-bit format for subsequent analysis with real time accuracy. The thermal image achieved is a visual representation of the temperature distribution on the object surface. The thermographic analysis was performed within a temperature controlled environment at 20°C free from external radiation sources, convective air currents, and extremes of humidity. The thermographic technique recorded the temperature change over the entire tooth section. However, only the maximum temperature recorded on the pulpal wall was used in the subsequent analysis.

Each tooth/bracket specimen was clamped firmly to a bench top and the lens of the thermographic imaging system was placed perpendicular to the exposed pulpal wall at a distance of 5 cm. The heating element of the Ceramic Bracket Debonding Unit was then placed in the bracket slot. The experimental set-up is illustrated diagrammatically in Figure 1.

Initially, ceramic brackets were debonded from 10 bracket/tooth specimens in the normal manner, i.e. a 3-second heating cycle followed by a light turning force. The manufacturers recommend that a gentle turning force of 70–100 g (corresponding to a turning moment of 0.07–0.1 Nm) should be applied throughout the entire heating cycle. In the present study, this light turning force was not applied until after the 3-second heating cycle. Although the turning moment was not measured directly, the operator used only gentle force as recommended by the manufacturers.

For a further group of 10 tooth/bracket specimens the temperature rise provoked at the pulpal wall when the ceramic brackets failed to debond was assessed. No turning moment was applied at the end of the 3-second heating cycle and the heating element was left in the bracket slot until the end of the 6-second cooling cycle.

At the end of the cooling cycle the ceramic bracket was removed from the tooth using a gentle turning force.

Results

Normal debond group

Figure 2 represents the thermographic image recorded on the pulpal wall at the end of the

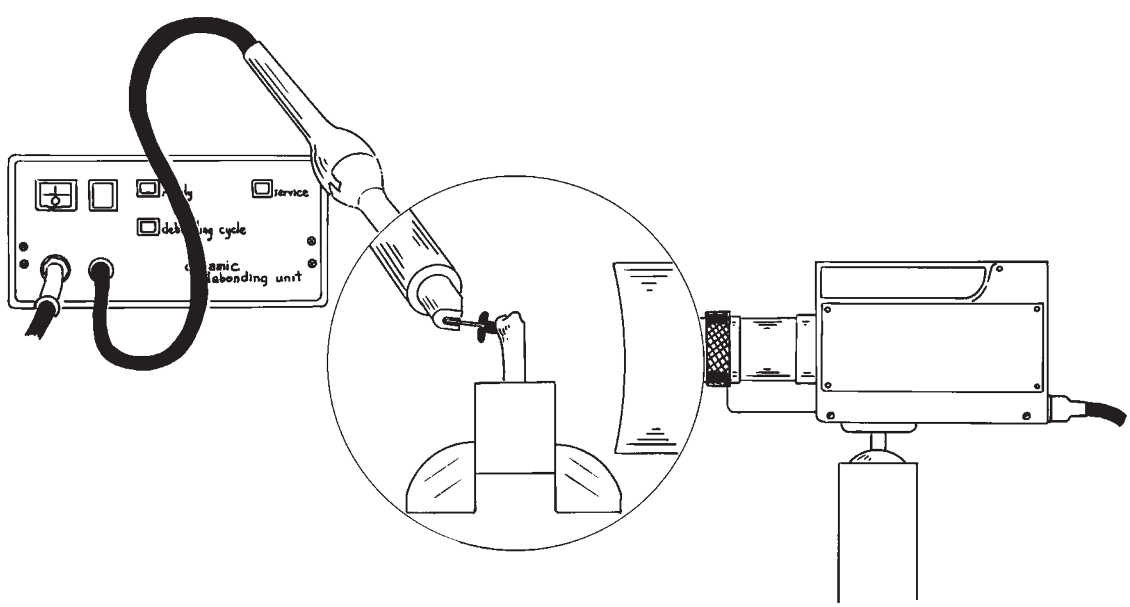

Figure 1 Diagrammatic illustration of the experimental set-up: the thermal debonding unit, the sectioned tooth with ceramic bracket bonded to the buccal surface, and the thermal imaging machine aimed at the pulpal wall (left to right).

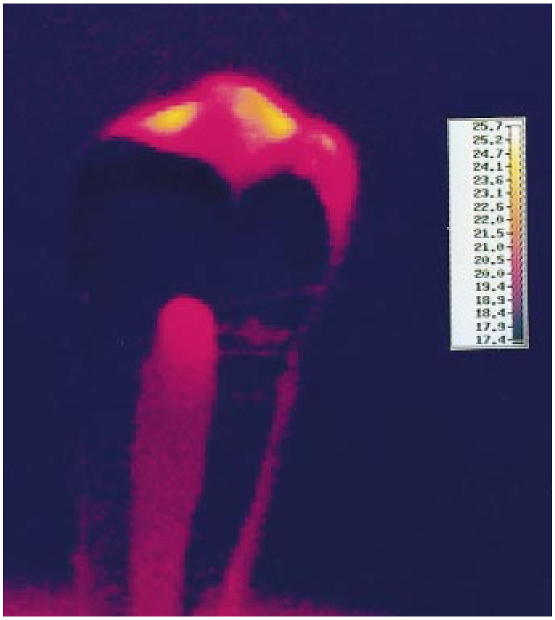

Figure 2 Thermographic image recorded on the pulpal wall at the end of the 3-second heating cycle.

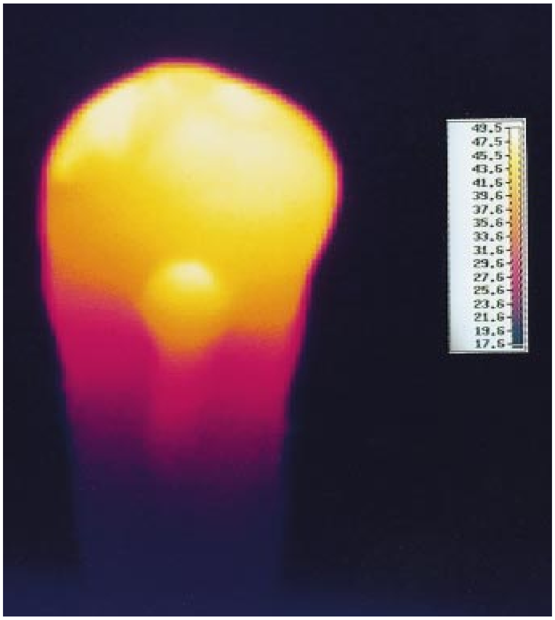

Figure 4 Thermographic image recorded on the pulpal wall at the end of the 6-second cooling cycle with the heating element remaining in contact with the bracket.

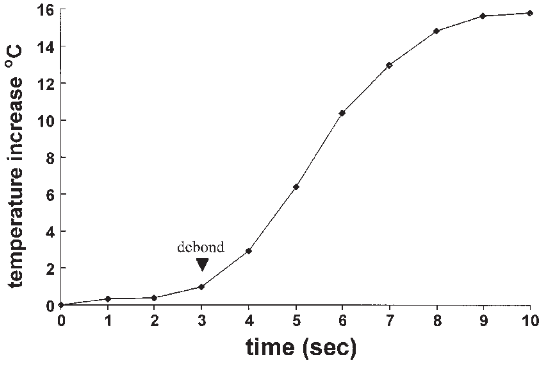

Figure 3 The average pulpal wall temperature increase plotted against time during normal debond at 3 seconds.

3-second heating cycle. The mean pulpal wall temperature increase recorded for the 10 tooth/bracket specimens debonded in the normal manner at the end of the 3-second heating cycle was 16.2°C (SD 3.2). This gradually reduced to the starting level over a period of 2–3 minutes.

Figure 3 shows the average pulpal wall temperature change plotted against time. There was a minimal temperature rise prior to debonding of the ceramic bracket. However, following removal of the bracket the pulpal wall temperature continued to rise for a further 7–8 seconds. The thermographic analysis revealed that heat was initially conducted to the area of pulpal wall directly subjacent to the bracket base. The subsequent spread of heat involved a larger portion of the pulpal surface, but the maximum temperature rise was found in the area below the bracket.

In all cases the debonding of the ceramic bracket was successful at the first attempt.

Simulated failure to debond group

Figure 4 represents the thermographic image recorded at the pulpal wall at the end of the 6-second cooling cycle with the heating element remaining in contact with the bracket. The average increase in pulpal wall temperature was 45.6°C (SD 7.0). Again, this gradually reduced to the starting level over a period of 2–3 minutes. Statistical analysis revealed that significantly

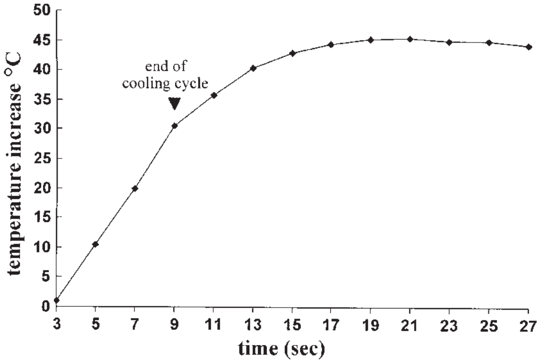

Figure 5 The average pulpal wall temperature increase plotted against time during failure to debond. The heating element remained in contact with the bracket during the 3-second heating cycle and the 6-second cooling cycle.

higher increases in pulpal wall temperature were recorded in the simulated failure to debond group (*t*-test, $P = 0.0001$). Figure 5 shows the average pulpal wall temperature rise plotted against time. The pulpal wall temperature continued to rise and began to level off some 17 seconds from the beginning of the heating cycle.

There was no clinical evidence of enamel or bracket fracture during the debonding procedure for any of the specimens used in this study.

Discussion

In the experiment where the ceramic brackets were removed at the end of the 3-second heating cycle the maximum pulpal wall temperature was recorded some 7–8 seconds later and returned to baseline level after 2–3 minutes. These findings are similar to those of Sernetz and Kraut (1991) who also noted a short delay (5–10 seconds) before the maximum temperature was attained, and a return to the baseline temperature over 2–3 minutes. This time delay probably reflects the time taken for heat conductance from the enamel surface through dentine to the pulpal wall.

A much larger mean temperature rise was noted if failure to debond was simulated. This appears to indicate that after the heating cycle is complete, the heat remaining in the ceramic bracket and the heating element continues to be transferred to the pulpal wall. Here, again, the maximum temperature was noted some 7–8 seconds after removal of the bracket with the heating element.

Investigations which aim to establish the potential harmful effects of heat-generating dental procedures are hampered by the absence of accurate data on the tolerance limits of human pulpal tissue. The maximum temperature rise that human pulp can withstand before irreversible pulpal damage occurs is unknown. In the absence of such data, most investigators have used the guidelines established by Zach and Cohen (1965) on primate teeth. In their study, varying external heat applications were correlated against intra-pulpal temperature recorded by means of a thermocouple placed in the pulp chamber. No histological evidence of pulpal reaction was found if the pulpal temperature increase remained below 2°C. The thermal injury was reversible in the majority of cases if the pulpal temperature increase did not exceed 5.5°C. When the intra-pulpal temperature increased by 11.1°C, abscess formation occurred in 60 per cent of the teeth and an increase of 16.6°C provoked pulpal necrosis in all teeth examined.

Since most previous studies of electrothermal debonding of ceramic brackets have used thermocouples to record pulpal temperature changes it is difficult to directly compare previous work with the present investigation. In one study, a thermocouple inserted into the pulpal chamber and immersed in a conducting medium of sodium chloride solution recorded an average pulp chamber temperature rise of 3.6°C (Brouns *et al.*, 1993). However, the maximum pulpal temperature increase recorded was 13.0°C, which is above the critical threshold of 5.5°C established by Zach and Cohen (1965).

Sernetz and Kraut (1991) used a thermocouple embedded in a thermal conductive paste to record the pulpal wall temperature following electrothermal debonding of ceramic brackets. When the brackets were removed in under 3 seconds, the pulpal temperature increase did not exceed 5°C. However, when the debonding time exceeded 3 seconds a pulpal temperature rise of 10–15°C was noted.

The thermocouple technique relies on the use of a fluid or semi-fluid conducting medium which is likely to dissipate some of the heat reaching the pulpal wall. *In vivo* pulpal blood flow is also likely to dissipate heat from the pulpal wall. However, the temperature rise recorded by the thermocouple is likely to be influenced by the composition of the conducting medium, and the distance between the thermocouple tip and the pulpal wall. Since thermal injury will initially affect the pulpal tissue in direct contact with the pulpal wall, it could be argued that the temperature rise on the pulpal wall surface is of most interest. However, difficulties are likely to be encountered in accurately placing the thermocouple tip at the site of maximum temperature rise. The advantage of the thermographic technique used in the present study is that it provides an accurate measure of the temperature on the surface of the pulpal wall which is not influenced by the presence of a conducting medium. The higher temperature rises recorded in the present study compared with previous thermocouple studies reflect this different method of recording temperature changes.

Since the tolerance limits of pulpal tissue were established by Zach and Cohen (1965) in primates using thermocouples in the pulp chamber, it would also be inappropriate to judge the present thermographic study against these previous thresholds. It is likely that the pulpal wall temperature increase *in vivo* would be less than that recorded in the present investigation. The heat capacity of a complete tooth is greater than a sectioned tooth and pulpal blood flow is also likely to have a cooling effect. The experimental model also differed from the clinical situation in that the roots of the teeth were fixed in plaster not bone, and blood flow in the periodontal ligament and surrounding bone is also likely to reduce the temperature increase recorded clinically.

Only one previous report could be found in the literature where thermography was used to assess pulpal temperature increases associated with electrothermal debonding of ceramic brackets. Ruppenthal and Baumann (1992), using infra-red thermography, found the temperature rise for successful debonding to be between 1 and 3°C. Even when failure to debond was simulated and multiple heating cycles of the electrothermal debonding unit were administered, the pulpal temperature did not rise by more than 6.5°C. However, the teeth used were sectioned horizontally, apical to the bracket position, and viewed with a measurement field of only 1 mm^2. Arguably, this approach does not provide optimal access to the surface of the pulpal wall adjacent to the centre of the ceramic bracket where heat transmission is greatest. The use of such a small recording zone may also compound the difficulties in locating the area of maximum temperature increase. In the present study the teeth were sectioned vertically allowing direct access to the pulpal wall subjacent to the ceramic bracket and a recording zone encompassing the whole pulpal wall was used.

Some researchers have concluded that the amount of heat injury exhibited by teeth subjected to thermal insult largely depends on the individual recovery capacity of the pulpal tissue (Spierings *et al*., 1985). A histological study carried out by Kraut *et al*. (1991) found no evidence of pulpal necrosis or inflammation 2 weeks after electrothermally debonding ceramic brackets. However, an *in vivo* histological investigation of the human pulp after thermodebonding of ceramic brackets found localized damage to the pulp in several teeth where more than one heating cycle was used (Jost-Brinkmann *et al*., 1992).

There is some evidence that the recovery capacity of pulpal tissue following orthodontic tooth movement may be reduced. Radiospirometric investigations of human pulpal tissue after orthodontic force application have found that the mean pulpal respiration rate was depressed as a result of orthodontic force application (Hamersky *et al*., 1980; Unsterseher *et al*., 1987). It has been suggested that further pulpal insult may compromise pulpal vitality (Unsterseher *et al*., 1987). Longitudinal clinical studies are therefore required to establish the maximum temperature which can be safely administered to the enamel surface, and whether recent orthodontic movement influences the thermal tolerance of the pulp. The length of time the pulpal wall temperature is elevated is also likely to be a critical factor. In addition, teeth with thinner pulpal walls, such as lower incisors, may transmit more heat to the pulp than premolars and molars with thicker pulpal walls.

The results of this study provide important baseline data on the pulpal wall temperatures following ETD using thermographic techniques. In this study, only one type of ceramic bracket (polycrystalline) and one adhesive (Concise) were used. Although different ceramic brackets and adhesives may vary in their heat transfer capacity it is unlikely that they would differ markedly from those noted in the present study.

The results also reveal that larger temperature rises occur when ceramic brackets fail to debond and the heating element remains in contact with the bracket during the 6-second cooling cycle.

In view of the fact that the thermal tolerance limits of human pulp are unknown, it would appear prudent to allow the tooth to cool when a ceramic bracket fails to debond before repeating the heating cycle. The manufacturers do not recommend the use of air or water to encourage cooling due to increased pain and sensitivity experienced by the patient. They also recommend that if a ceramic bracket fails to debond during the 3-second heating cycle, the heating element should be removed from the bracket, and no further heating cycle should be applied for at least 5 minutes. Since this study found that the pulpal wall temperature returned to normal within 2–3 minutes this would appear to be an appropriate interval to allow cooling to occur. Removing the heating element from the bracket slot is likely to facilitate this cooling.

Conclusions

Thermal image analysis revealed an average pulpal wall temperature increase of 16.2°C when the ceramic brackets were removed at the end of one heating cycle. A much larger mean pulpal wall temperature increase was noted when failure to debond was simulated and the heating element was left in the bracket slot until the end of the cooling cycle. It is recommended that clinicians should follow the manufacturers' instructions and remove the heating element from the bracket if it fails to debond. It also appears sensible to allow the tooth to cool for 5 minutes before re-inserting the heating element in the bracket.

Address for correspondence

Donald J. Burden
Orthodontic Division
School of Clinical Dentistry
The Queen's University of Belfast
Royal Victoria Hospital
Grosvenor Road
Belfast BT12 6BP
UK

Acknowledgements

The authors gratefully acknowledge the helpful assistance of Dentaurum (Pforzheim, Germany) who provided the electrothermal debonding unit used in this investigation.

References

Bishara S E, Trulove T S 1990a Comparisons of different debonding techniques for ceramic brackets: an *in-vitro* study. Part I. Background and methods. American Journal of Orthodontics and Dentofacial Orthopedics 98: 145–153

Bishara S E, Trulove T S 1990b Comparisons of different debonding techniques for ceramic brackets: an *in-vitro* study. Part II. Findings and clinical implications. American Journal of Orthodontics and Dentofacial Orthopedics 98: 263–273

Brouns E, Schopf P, Kojancic B 1993 Electrothermal debracketing of ceramic brackets: an *in vitro* study. European Journal of Orthodontics 15: 115–237

Douglass J B 1989 Enamel wear caused by ceramic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 95: 96–98

Hamersky P A, Weiner A D, Taintor J F 1980 The effect of force application on the pulpal tissue respiration rate in the human premolar. American Journal of Orthodontics 77: 368–378

Jeiroudi M T 1991 Enamel fracture caused by ceramic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 99: 97–99

Joseph V P, Rossouw E 1990 The shear bond strengths of stainless steel and ceramic brackets used with chemically cured and light activated composite resins. American Journal of Orthodontics and Dentofacial Orthopedics 97: 121–125

Jost-Brinkmann P G, Stein H, Miethke R R, Nakata M 1992 Histological investigations of human pulp after thermodebonding of metal and ceramic brackets. American

Journal of Orthodontics and Dentofacial Orthopedics 102: 410–417

Kraut J, Radin S, Trowbridge H I, Emling R C, Yankell S L 1991 Clinical evaluations on thermal versus mechanical debonding of ceramic brackets. Journal of Clinical Dentistry 2: 92–96

Rickabaugh J L, Marangoni R D, McCaffrey K K 1996 Ceramic bracket debonding with the carbon dioxide laser. American Journal of Orthodontics and Dentofacial Orthopedics 110: 388–393

Ruppenthal T, Baumann M A 1992 Zur Temperaturerhöhung in der Zahnpulpa während elektrothermischer Abnahme von Keramikbrackets. Fortschritte der Kieferorthopädie 53: 111–116

Scott G E 1988 Fracture toughness and surface cracks. The key to understanding ceramic brackets. Angle Orthodontist 58: 3–8

Sernetz F, Kraut J 1991 Laboratory evaluations on thermal debonding of dental brackets. Journal of Clinical Dentistry 2: 87–91

Sheridan J, Branley D, Hastings J 1986a Electrothermal debracketing—Part I: an *in-vitro* study. American Journal of Orthodontics 89: 21–27

Sheridan J, Branley D, Hastings J 1986b Electrothermal debracketing—Part II. An *in vivo* study. American Journal of Orthodontics 89: 141–145

Spierings T A, Peters M C, Plasschaert A J 1985 Thermal trauma to teeth. Endodontics and Dental Traumatology 1: 123–129

Strobl K, Bahns T L, Willham L, Bishara S E, Stwalley W C 1992 Laser-aided debonding of orthodontic ceramic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 101: 152–158

Swartz M L 1988 A technical bulletin on the issue of bonding and debonding ceramic brackets. Ormco Corporation, California #070-5039

Tocchio R M, Williams P T, Mayer J, Standing K G 1993 Laser debonding of ceramic orthodontic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 103: 155–162

Unsterseher R E, Nieberg L G, Weimer A D, Dyer J K 1987 The response of human pulpal tissue after orthodontic force application. American Journal of Orthodontics 92: 220–224

Viazis A D, DeLong R, Bevis R R, Douglas W H, Speidel T M 1989 Enamel surface abrasion from ceramic brackets: a special case report. American Journal of Orthodontics and Dentofacial Orthopedics 96: 514–518

Viazis A D, Cavanaugh G, Bevis R R 1990 Bond strength of ceramic brackets under shear stress. An *in-vitro* report. American Journal of Orthodontics and Dentofacial Orthopedics 98: 214–221

Vukovich M E, Wood D P, Daley T D 1991 Heat generated by grinding during removal of ceramic brackets. American Journal of Orthodontics and Dentofacial Orthopedics 99: 505–512

Winchester L J 1991 Bond strengths of five different ceramic brackets. An *in vitro* study. European Journal of Orthodontics 13: 293–305

Zach L, Cohen G 1965 Pulp response to externally applied heat. Oral Surgery, Oral Medicine, Oral Pathology 19: 515–530