Wire friction from ceramic brackets during simulated canine retraction

By Kazuo Tanne, DDS, DDSc; Susumu Matsubara, DDS; Tatsuya Shibaguchi, DDS; and Mamoru Sakuda, DDS, DDSc

Technical advances in orthodontic materials research have led to the manufacture of ceramic brackets for use in orthodontic treatment. Ceramic brackets are especially popular among adult patients who have expressed a desire for more esthetic appliances. Unfortunately, ceramic brackets move teeth less efficiently than their metal counterparts.

Investigations into the nature of the friction between orthodontic wires and metal brackets have examined the effects of bracket width, wire size and wire material.[1-7] These studies indicated that frictional resistance becomes greater with an increase in bracket width and wire size, and that nickel-titanium alloy wires generally produce greater friction than stainless steel and cobalt chromium alloy wires.

Although a few experimental studies have been reported,[8-10] the frictional resistance between orthodontic wires and ceramic brackets during actual or simulated tooth movement has not been fully investigated.

The purpose of this study was twofold: (1) to investigate the efficiency of tooth movement with ceramic brackets in comparison to metal brackets; and (2) to examine microscopically the morphological changes of wire surfaces produced by experimental tooth movement with ceramic brackets.

Materials and methods

Distal movement of a metal mandibular canine, fitted with one type of metal bracket and three types of ceramic brackets was measured. Two of the ceramic brackets in the study were polycrystalline alumina and throughout this report will be called "ceramic brackets A and B." The third ceramic was made of zirconia and will be represented as "ceramic bracket C" (Figure 1).

All the brackets used in this experiment were standard 0.018" x 0.025" brackets. Bracket width

Abstract

The present study was designed to investigate the nature of friction between orthodontic wire and various ceramic brackets. The amount of tooth movement with metal and ceramic brackets was measured, and the wire surfaces were examined microscopically immediately after artificial tooth movement.

The amount of tooth movement produced by the ceramic brackets was significantly less than that produced by metal bracket. The wire surfaces were scratched more obviously by ceramic brackets than by metal bracket. Slot surfaces and edges of the ceramic brackets were substantially more porous and rougher than those surfaces of the metal bracket.

These material differences between metal and ceramic brackets significantly affect the efficiency of orthodontic tooth movement.

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Key Words

Ceramic bracket • Friction • Orthodontic tooth movement

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Figure 1A-D
Brackets used in this study.
A: Metal bracket
B: Ceramic bracket A (polycrystalline alumina)
C: Ceramic bracket B (polycrystalline alumina)
D: Ceramic bracket C (zirconia)

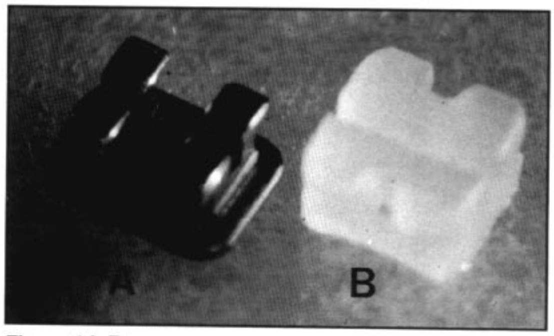

Figure 1A-B

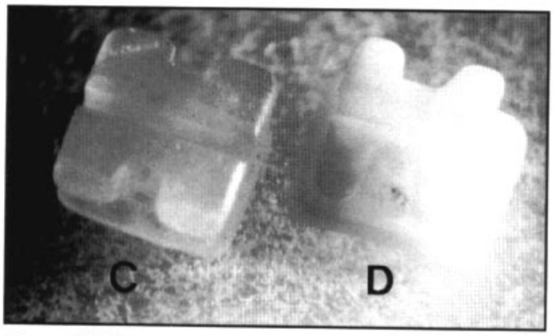

Figure 1C-D

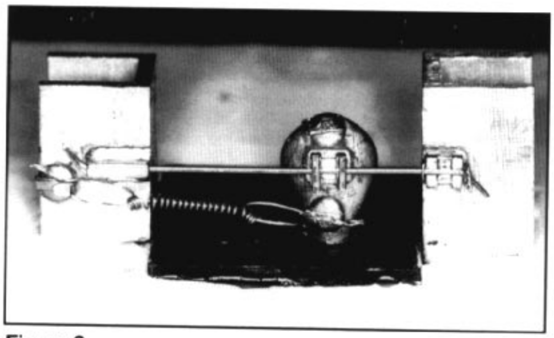

Figure 2

Figure 2
An experimental system for simulated canine movement in the distal direction. Retraction of the canine is carried out by closed coil spring.

was 3.2 mm for the metal bracket, 3.5 mm for ceramic bracket A, 3.6 mm for ceramic bracket B and 3.4 mm for ceramic bracket C. The orthodontic wires tested were 0.018″ round, 0.016″ x 0.022″ and 0.017″ x 0.022″ cobalt-chromium (Co-Cr) alloy wires (Elgiloy blue, Rocky Mountain Co., Denver, Colo.).

The metal tooth was fixed firmly with two types of wax (Base plate paraffin wax 50% and Utility wax 50%, GC Dental Industrial Co., Tokyo, Japan). This allowed the metal tooth to move in the water bath (50°C). Duration of the experimental tooth movement was 5 minutes.

The original distance distal to the bracket was 14 mm, simulating a first premolar extraction case. Instead of ligating the wire into the bracket, two pieces of 0.022″ x 0.028″ wire were bonded to cover the bracket wings occlusogingivally to eliminate the influence of wire ligation on tooth movement (Figure 2). An initial force of 250 gf was produced by closed coil springs (Elgiloy closed coil spring 0.009″ x 0.036″, Rocky Mountain Co., Denver, Colo.) in a distal direction. The retraction force was applied at a point on the crown, i.e. 4 mm cervical to the bracket position (Figure 2).

The experiment was repeated five times for each of the four brackets and three wires. The amount of tooth movement was measured by digital calipers (Mitsutoyo Co., Tokyo, Japan). These measured values were subjected to Student's t-test to compare the amount of tooth movement produced by ceramic brackets with that of the metal bracket.

Figure 3
The amount of tooth movement with the metal and ceramic brackets. * significant at 5% level of confidence. ** significant at 1% level of confidence.

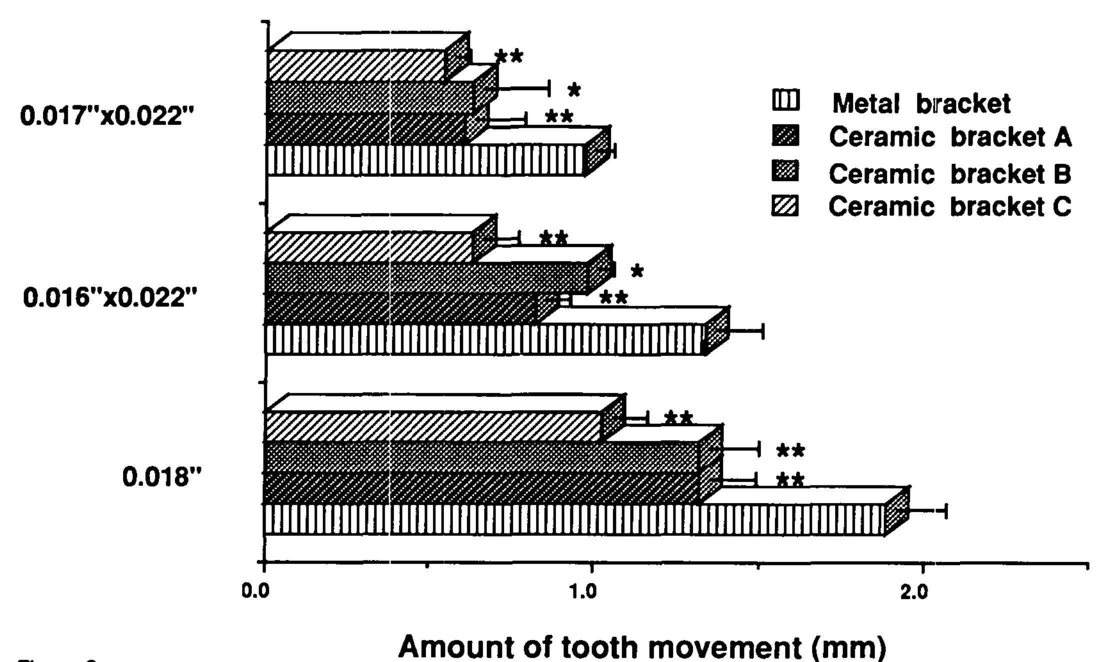

Figure 3

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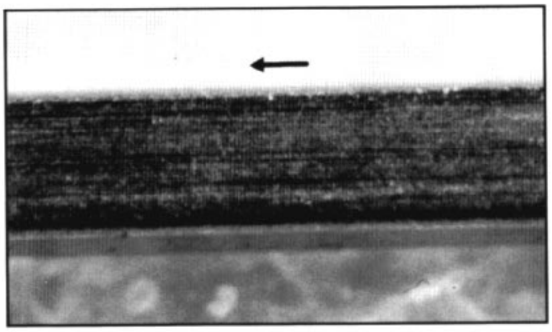

Figure 4A

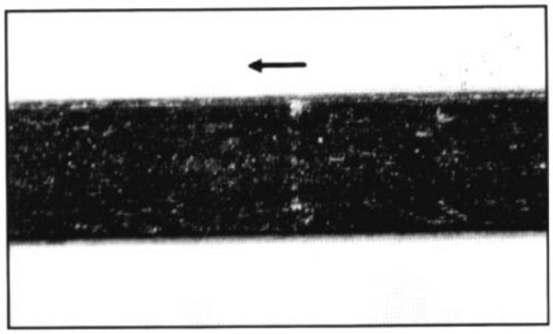

Figure 4B

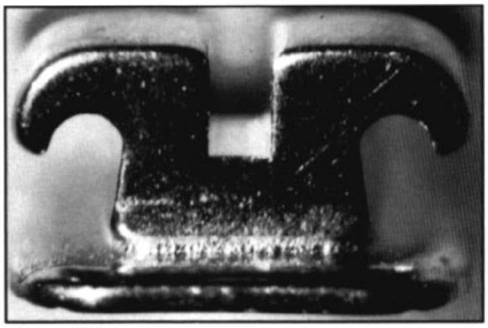

Figure 4C

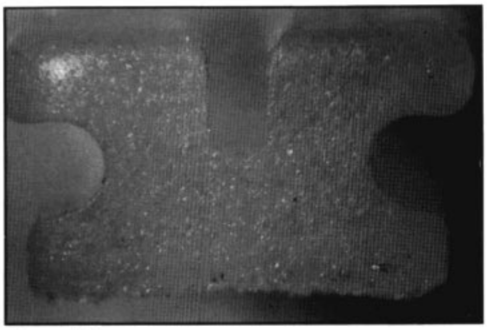

Figure 4D

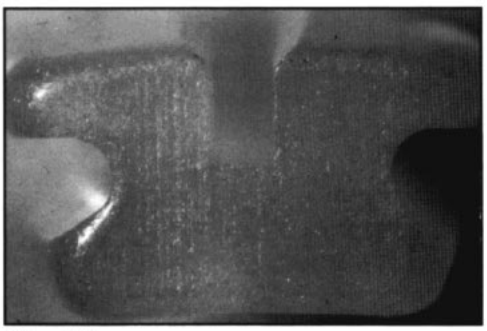

Figure 4E

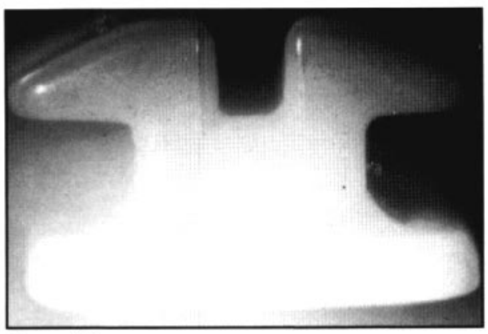

Figure 4F

Figure 4A-F
Wire surface and dista édge of the brackets observed by stereoscopi microscope. Solid ar rows indicate the direc tion of canine retraction
A: Wire surface with th metal bracket
B: Wire surface with th ceramic bracket A
C: Edge of the meta bracket
D: Edge of the cerami bracket A
E: Edge of the cerami bracket B
F: Edge of the ceram bracket C

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After the experimental tooth movement, wire surfaces were examined by stereoscopic microscope and scanning electron microscope (S.E.M.). Further, the distal edges and the slot surfaces of the metal and ceramic brackets were examined by stereoscopic microscope and S.E.M., respectively.

Results

The amounts of tooth movement with the metal and ceramic brackets are shown in Figure 3. For the 0.018" round wire, the amount of tooth movement was 1.89 mm for the metal bracket, 1.32 mm for ceramic brackets A and B, and 1.02 mm for ceramic bracket C. When the 0.016" x 0.022" and 0.017" x 0.022" rectangular wires were used, the amounts of tooth movement were 1.34 mm and 0.97 mm for the metal bracket, 0.82 mm and 0.60 mm for ceramic bracket A, 0.98 mm and 0.63 mm for ceramic bracket B and 0.63 mm and 0.54 mm for ceramic bracket C, respectively (Figure 3). The values for the ceramic brackets were significantly less than those for the metal bracket at 1% or 5% level of confidence, as shown in Figure 3.

The decreased rates in the amount of tooth movement with ceramic brackets ranged from 30% to 50% of the rates observed with metal bracket.

The amount of tooth movement also decreased substantially as the wire size became larger in the following order: 0.018", 0.016" x 0.022" and 0.017" x 0.022" (Figure 3).

Examples of the wire surface, bracket slot and edge observed by stereoscopic microscope and S.E.M. are shown in Figures 4 and 5. The slot surfaces of the ceramic brackets were more porous and rougher than those of the metal bracket (Figure 5E-H). The distal edges of the brackets exhibited similar findings to the slot surfaces (Figure 4C-F). The remarkable scratch was not observed on the wire surface when the metal bracket was used (Figure 4A). The wire surfaces with three types of ceramic brackets exhibited remarkable and deep scratches, irrespective of the wire size (Figure 4B).

Figure 5A-H
Scratches (▶) on the wire surface and the surface of the bracket slot observed by S.E.M. Solid arrows indicate the direction of tooth movement.
A: Scratches on the wire surface with the metal bracket
B: Scratches on the wire surface with the ceramic bracket A
C: Scratches on the wire surface with the ceramic bracket B
D: Scratches on the wire surface with the ceramic bracket C
E: Slot surface of the metal bracket
F: Slot surface of the ceramic bracket A
G: Slot surface of the ceramic bracket B
H: Slot surface of the ceramic bracket C

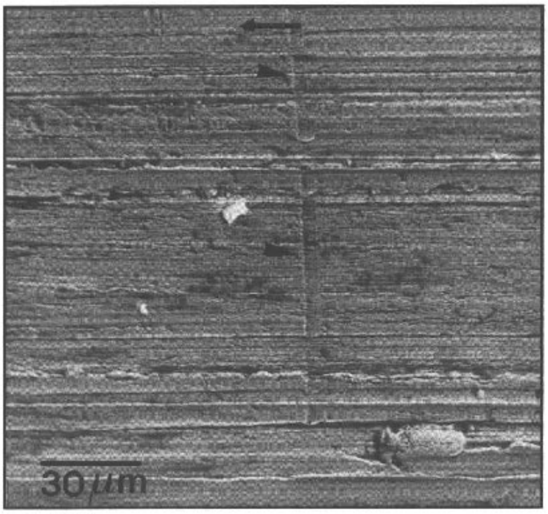

Figure 5A

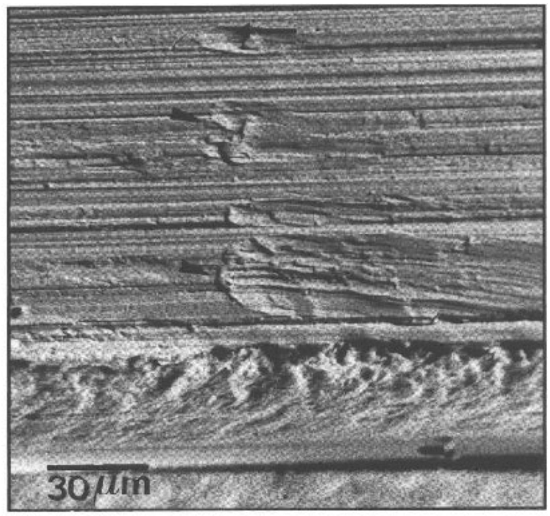

Figure 5B

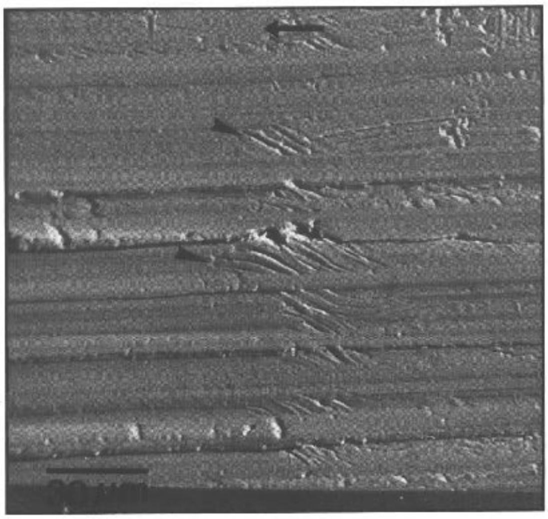

Figure 5C

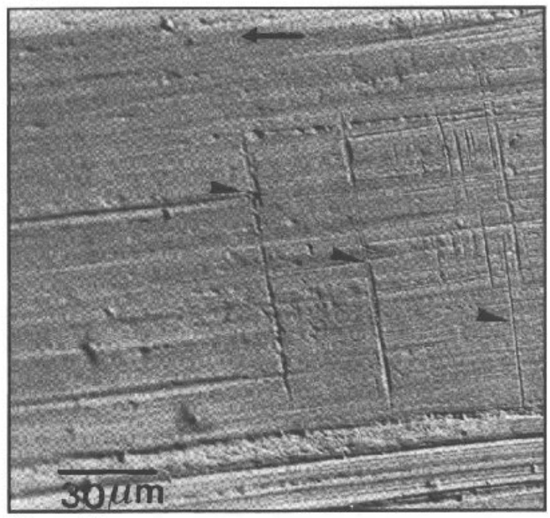

Figure 5D

S.E.M. examination revealed that the wire surface was slightly damaged even when the metal bracket was used, although this phenomenon was not detected by stereoscopic microscope (Figure 5A). On the other hand, remarkable scratches were observed on the wire surface when ceramic brackets A and B were used (Figure 5B,C). Deep linear scratches were observed clearly on the wire surface with ceramic bracket C (Figure 5D).

Discussion

In clinical orthodontics, various multi-bracket techniques are used to achieve desired tooth movement. In these techniques, sliding mechanics are frequently employed for mesio-distal tooth movement. Frictional resistance between wire and bracket is indicated as a shortcoming during sliding movement of a tooth.

In order to elucidate the nature of friction between wire and bracket, variables such as bracket width, wire size and wire material have been investigated.[1-7]

With respect to the frictional resistance with different bracket widths, Kamiyama et al.,[1] Tidy et al.[2] and Dresher et al.[3] showed that wire friction decreased as the bracket width increased. To the contrary, Frank et al.[4] and Kapila et al.[5] reported an increase of friction associated with a wider bracket, and Andreasen and Quevedo[6] described no relationship between these quantities. In this study, the mesio-distal widths of the metal and three ceramic brackets were similar, ranging from 3.2 mm to 3.6 mm, hence the effect of bracket width on the amount of tooth movement was supposed to be slight, or negligible.

Friction did increase with greater size of wire. Garner et al.,[7] Dresher et al.,[3] Tidy et al.[2] and Kapila et al.[5] clarified that various Ni-Ti wires produced greater friction than stainless steel wires.

These studies have provided a variety of clinical implications for multi-bracket techniques in terms of friction between wire and bracket. However, it is not clear the degree to which ceramic

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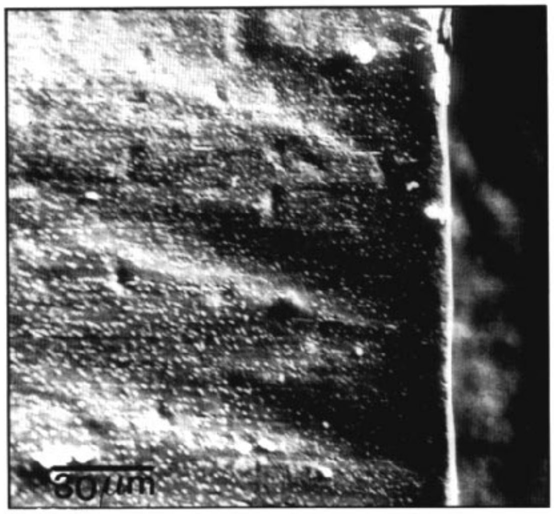

Figure 5E

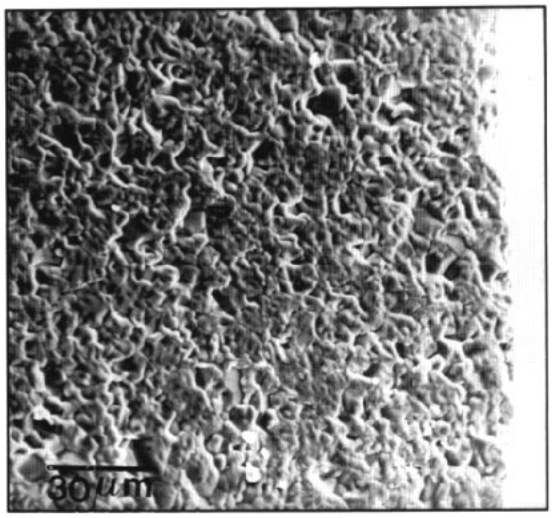

Figure 5F

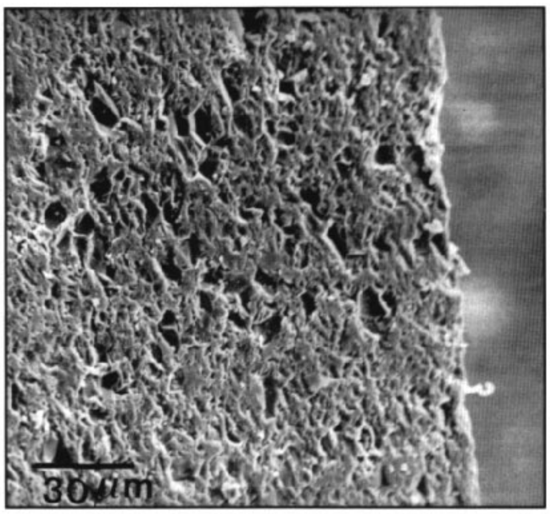

Figure 5G

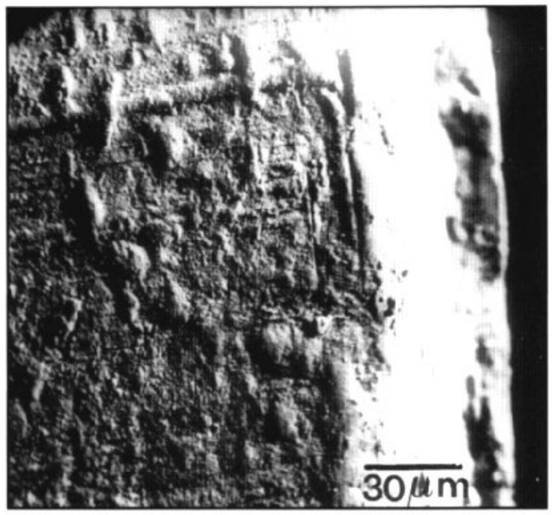

Figure 5H

brackets affect frictional resistance with orthodontic wires. Riley et al., however, has reported that plastic brackets reduce the amount of tooth movement.[11] Thus, greater friction between ceramic brackets and wire was speculated to affect the amount of tooth movement.

The present study has the following clinical implications: (1) the amount of tooth movement was significantly affected by ceramic brackets; and (2) scratches on the wire produced by ceramic brackets were indicated as a cause of reduced tooth movement. These findings confirm that the slot surfaces and edges of ceramic brackets strongly hit the wire surface and may interfere with smooth sliding between bracket and wire.

In orthodontic tooth movement, the amount of tipping of a tooth is altered according to the application point of force.[12] Consideration should be given to applying force at a point more apical to the bracket position so that the bracket slot does not hit the wire surface.

Furthermore, ceramic brackets should be improved in many aspects for solving the problems indicated in the present and previous studies.[8-10,13,14]

Because fracture of ceramic brackets is observed frequently[14] during orthodontic tooth movement, their strength must be improved.

In addition, bracket edge and slot surfaces should be refined, i.e. the edge of a ceramic bracket should be smooth and round, and the surface of the bracket slot should be smooth to prevent wire damage.

These refinements would provide more efficient and desired tooth movement . . . the ultimate goal in clinical orthodontics.

Conclusions

The amount of distal movement of a mandibular canine was measured using a metal tooth, one metal bracket and three types of ceramic brackets (polycrystalline alumina x 2, zirconia x 1). The wires used in this experiment were 0.018" round, and 0.016" x 0.022" and 0.017" x 0.022" rectangular.

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Each bracket slot and wire surface was examined by means of stereoscopic microscope and S.E.M. The following results were obtained.

1. The amount of tooth movement with three ceramic brackets was significantly less than that with the metal bracket at 1% or 5% level of confidence.
2. The decreased rate of tooth movement with three types of ceramic brackets ranged from 30% to 50% when compared with the metal bracket.
3. The amount of tooth movement decreased with an increase in wire size.
4. Slot surfaces and edges of the ceramic brackets were more porous and rougher than those of the metal bracket.
5. The wire surfaces were obviously scratched by the ceramic brackets, whereas slight scratches were observed on the wires used with the metal bracket.

It was shown that efficiency of tooth movement was significantly reduced by the ceramic brackets when compared to the metal bracket. This loss of efficiency seems to be caused by frictional resistance between the wire and ceramic bracket, as indicated by microscopic findings of the wire surfaces. Refinement of ceramic brackets, slot edges and surfaces in particular, should one day produce more efficient and desired tooth movement.

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Commentary: Ceramic brackets

By Robert Kusy, PhD

When I sat down to write this commentary, I thought that a snappy title would be a logical place to begin. But what title — "Improving the Strength of Ceramic Brackets?" Hardly, since I don't believe that this is the fundamental problem. Well then, how about something like "Reducing the Hardness of Ceramics?" Hmmm... Given the chemical structure, it might be easier to get water out of a stone. Well, let's forget that for a moment and get to the point: today's ceramic brackets are inferior to stainless steel brackets in many ways, except with regard to esthetics, and little can be done to improve ceramic brackets without a major material breakthrough. Here's why...

Ceramic materials are formed by combining metal and non-metal atoms into regular arrays or lattices (for alumina) in which charge neutrality must be maintained. Because of the somewhat ionic and covalent nature of the bonds, deformation via dislocations and slip can only occur if the positive and negatively charged ions can slide past one another. Such slip is difficult to achieve because the positively or negatively charged ions provide additional energy barriers to deformation that metals (those so-called positive ions in a sea of promiscuous electrons) don't have to overcome. The very strong bonding energy of ionic bonds results in a bonding force versus bond stretch diagram that is very steep, although the bond itself is nondirectional.

So, what does this mean to the manufacturer in terms of the future of ceramic brackets in orthodontics? It means that ceramics have intrinsic properties that are unique and not easily changed without modifying the nature of the very bonding itself. Strong bonding forces make for high elastic stiffnesses, and the energy barriers provided by charged ions make for brittle structures. In orthodontic terms strength is high, but range is woefully low. And formability... Well, let's forget it and talk about hardness instead. There is in materials science a general correlation between strength and hardness, and ceramics are very hard. Therefore, if hardness could be reduced, it would likely be done at the expense of strength. Because notches such as those found in rough surfaces tend to increase the localized stress state by factors of three or more in a material that generally hasn't the capacity to blunt a surface step or a crack tip, the surfaces are prone to mechanical fracture. Moreover, static fatigue can cause failure without any apparent warning, when water chemically reacts with the surface of certain ceramics. These same problems plague engineers in the national defense, aerospace, and automotive industries who are constantly striving to make superior impact-, heat-, and chemically-resistant ceramics for body armor, turbines, and high performance engines. The problems that confront orthodontic manufacturers are not unique, and if overcome would have global impact in the general field of ceramics.

Given the limitation of today's technology, where should ceramic brackets rank within the scheme of life in the typical orthodontic practice? Unquestionably, ceramics are superior to stainless steel alternatives from an esthetic viewpoint. As long as they are not used in contact with opposing teeth they will not have an adverse effect on tooth structure via wear. Because of their intrinsic chemical structure and not because of their roughness, they have higher coefficients of static and kinetic coefficients of friction than stainless steel brackets. More specifically, no significant difference exists between the frictional coefficients in monocrystalline sapphire versus polycrystalline alumina brackets. With regard to other mechanical characteristics, fracture toughness ranges from 3 to 5 $MPa \cdot ^{1/2}$ for both alumina bracket types versus 50 to 154 $MPa \cdot m^{1/2}$ for high strength steels. By comparison, even the most sophisticated partially stabilized zirconia, which undergoes a stress-induced phase transformation that ultimately squeezes the crack tip shut, has a fracture tough-

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ness of only 9 MPa·$m^{1/2}$. The fracture toughness values of ceramics provide a clear message to the practitioner: namely, that stainless steel brackets are going to be more deformable or forgiving than alumina brackets for a long time to come.

So, what to do to mitigate the deficiencies of ceramic brackets? In the short-term, reduce the sources of stress concentrations in the bracket slots in general and at the corners of the slots in particular. Place a glaze on the surface to further help reduce these problems as well as any possible effects of static fatigue. Ion implant the near surface to reduce the coefficients of friction, amorphosize its chemical structure, and place the surface in compression. In the long-term, increase studies on phase transformation toughening of ceramics, seek techniques to optically transform stainless steel surfaces to a white hue, and seek new composite materials and processing techniques that combine esthetics with favorable mechanical properties. Here lies a problem of great importance to the orthodontist in which the dental scientist can steal the initiative away from the mainstream of the ceramics profession.

About that title again... How about "Alumina for Esthetics, but Stainless Steel for Sliding?" No... But maybe, "Limitations and Future Directions of Ceramic Bracket Research?" Hmmm... Ah, what's in a title anyway; you've got the point of this commentary.

—Robert P. Kusy, PhD
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The author welcomes your comments — or titles:

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