Shear Bond Strengths of Orthodontic Brackets Cemented to Bovine Enamel With Composite and Resin-modified Glass Ionomer Cements

Keith C. Titley, BDS, MScD Raj-Deep Mahal, DMD, MSc
P. Emile Rossouw, BChD, PhD Gajanan V. Kulkarni, BDS, PhD

Dr. Titley is professor and Dr. Mahal was master's candidate, Department of Pediatric Dentistry, University of Toronto, Toronto, Canada, and is private practitioner, Ottawa, Ontario; Dr. Rossouw was associate professor, Department of Orthodontics and Dr. Kulkarni is assistant professor, Department of Pediatric Dentistry, University of Toronto, Toronto, Canada. Correspond with Dr. Titley at k.titley@utoronto.ca

Abstract

Purpose: The purpose of this in vitro study was to determine the effects of short- and long-term storage on the shear bond strength of metal, polycarbonate, and ceramic orthodontic bracket bases using autopolymerizing resin composite and resin-modified glass ionomer cements (RMGIC). The glass ionomer cement was applied in both a wet and a dry environment.

Methods: With a method developed in the authors' laboratory, orthodontic brackets were cemented under constant pressure to embedded bovine incisor enamel. All cements were mixed and applied in accordance with the manufacturer's instructions. The specimens were stored in water at 37°C for 24 hours, 7 days, or 180 days. After the lapse of each time interval, they were shear tested to failure. The shear bond strengths (SBSs) were converted to megapascals (MPa). An adhesive remnant index (ARI) was used to record the site of the residual cement.

Results: There were no precipitous increases or decreases in SBS over a lapsed time of 180 days, although some variations occurred between 24 hours and 7 days. Similar findings were recorded for ARI.

Conclusions: The bracket base-cement combinations produce clinically sustainable SBSs over time. Selection of the cement may be important in patients who exhibit a high risk for caries. (*Pediatr Dent*. 2003;25:263-269)

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The direct bonding of orthodontic brackets to enamel became a routine clinical procedure[1] following the introduction of the acid-conditioning technique by Buonocore.[2] The acid-conditioning technique showed that the adhesion of autopolymerizing resins to the surface of enamel could be considerably enhanced.[2] This resulted in the introduction of the direct bonding of brackets to teeth and provided an esthetic alternative to orthodontic banding.[3] The added advantages were that appliances were easier to clean, there was no encroachment on arch length due to interproximal band thickness, and partially erupted and irregularly shaped teeth could be included in the active appliance.[3-5]

Factors that must be taken into consideration when direct-bonded orthodontic appliances are used include enamel conditioning agents, bracket base materials, base designs, and cement luting agents.[6] To meet the demands of modern orthodontic treatment, these bracket base-cement- enamel bonds should not only reach sufficient strength to resist fracture within 1 hour of bracket and arch wire placement, but also retain it over the time required for the case to be completed.[7] Brackets that debond during the course of treatment are an inconvenience to both the orthodontist and the patient and result in prolongation of treatment.

The brackets and cements that are currently at the orthodontist's disposal are extensive and varied. The brackets may be composed of metal, plastic, ceramic, or a combination of these materials, and their respective bases have a variety of configurations and surface treatments that are designed to enhance bonding.[7] There are 2 categories of cement that are commonly used to attach any of these bracket bases to either a conditioned or nonconditioned enamel surface.[5,8] They are either resin composites or resin reinforced glass ionomers. The former cements require conditioning of the enamel surface and a dry bonding environment, whereas the latter may bond to a conditioned or nonconditioned surface in a wet or dry environment.[8] Both of these categories of cement may be autopolymerized or photopolymerized, or both modes of curing may be incorporated into the same product.[6]

The debonding of a bracket base from the tooth has the potential to result in iatrogenic damage to the surface of the enamel. The sites of failure within the bracket-cement-enamel complex can occur within the bracket, between the bracket and the cement, within the cement, and between the tooth surface and the cement.[9] An adhesive remnant index (ARI) has been developed to quantify the amount of cement that remains on the enamel surface following a bracket base debond.[10] This index has a 4-point scale which ranges from "no adhesive being left on the tooth" to "all of the adhesive remaining on the tooth." The index appears to be dependent upon both the type of cement and the material from which the bracket is manufactured, although no clear relationships have been established between them.[6-8]

The purpose of the present in vitro study was to determine the effects of short- and long-term storage on the shear bond strength of metal, polycarbonate, and ceramic orthodontic bracket bases bonded to bovine incisor enamel using autopolymerizing resin composite and resin-modified glass ionomer cements (RMGIC).

Methods

Tooth material

Bovine incisor teeth were obtained ex-abattoir, and their crowns were removed from their roots. The coronal pulps were extirpated with a dental excavator, and the crowns were then stored in distilled water in a freezer at -20°C until used.[11] Prior to experimental preparation, the crowns were allowed to thaw, and cotton pellets moistened with distilled water were placed in their pulp chambers. Each crown was embedded in an autopolymerizing polymethyl methacrylate (PMMA, Esschem Co, Pa) cylinder 25 mm in diameter and 20 mm in depth, with its labial surface exposed and parallel to the horizontal plane. The embedded teeth were then refrigerated in distilled water at 4°C until required.

Brackets, cements, and conditioners

Maxillary left central incisor brackets of 3 different types were used in this study. They were:

1. the metal Speed bracket with a 60-gauge microetched foil mesh base (Strite Industries, Cambridge, Ontario, Canada);
2. the polycarbonate Spirit MB bracket (Ormco Corp, Glendora, Calif);
3. ceramic Transcend Series 6000 bracket (3M/Unitek Corp, Monrovia, Calif).

Two autopolymerizing cements were used to cement these brackets to bovine enamel. They were:

1. Phase II sealant and resin composite (Reliance Orthodontic Products Inc, Itasca, Ill);
2. GC Fuji Ortho resin reinforced glass ionomer (GC Corp, Tokyo, Japan, US Distributor GC America Inc, Chicago Ill).

The enamel surface for resin composite cement was conditioned with a 37% orthophosphoric gel (Reliance Orthodontic Products Inc, Itasca, Ill) and the resin-reinforced glass ionomer was conditioned with 10% polyacrylic acid (GC Corp, Tokyo, Japan, US Distributor GC America Inc, Chicago, Ill). A hair dryer was used to dry the enamel surface where appropriate (120 V Handi Dri, Lancer Pacific, Carlsbad, Calif).

Bracket base surface area

A morphometric computer program (Digitek Image Processing System, series 100, Digitek Co, Brooklyn, NY) was used to digitize the base areas of 25 randomly selected brackets of each bracket type, and the mean base surface area for each bracket type was calculated.

Experimental protocol

The experimental protocol used for each of the 3 bracket types and the 2 cements is displayed in Table 1. For each bracket type and its cement, 36 specimens were prepared and then randomly divided into 3 groups of 12. Each group was stored in distilled water at 37°C for either 24 hours, 7 days, or 180 days, after which time interval they were shear tested to failure. Wherever storage of the specimens was concerned, crystals of thymol were added to the distilled water to inhibit bacterial growth.[12] The solutions were changed every 2 weeks. The resin composite cement groups were designated the control groups.

Enamel conditioning and cements

Resin composite cement: the enamel surface was conditioned for 30 seconds, rinsed with running distilled water for 30 seconds, and dried with the hair dryer. Phase II sealant was mixed in a 1:1 catalyst-to-base ratio, and a thin layer was brushed on to the conditioned enamel surface. The Phase II resin composite cement was mixed in accordance with the manufacturers' instructions and applied to the bracket base.

Table 1. Experimental Protocol Followed for the 3 Bracket Types and 2 Cements

Group no.	N	Bonding material	Acid etchant	Storage duration
1	12	CR*	37% H_3PO_4	24 h
2	12	CR	37% H_3PO_4	7 d
3	12	CR	37% H_3PO_4	180 d
4	12	GIC† (dry)	10% polyacrylic acid	24 h
5	12	GIC (dry)	10% polyacrylic acid	7 d
6	12	GIC (dry)	10% polyacrylic acid	180 d
7	12	GIC (wet)	10 % polyacrylic acid	24 h
8	12	GIC (wet)	10% polyacrylic acid	7 d
9	12	GIC (wet)	10% polyacrylic acid	180 d

*CR=resin composite cement.
†GIC=glass ionomer cement.

Resin-modified glass ionomer cement in a dry environment: the enamel surface was conditioned for 30 seconds, with 10% polyacrylic acid, rinsed with running distilled water for 30 seconds and dried with the hair dryer. GC Fuji Ortho was mixed in accordance with the manufacturers' instructions and applied to the bracket base.

Resin-modified glass ionomer cement in a wet environment: the enamel surface was conditioned for 30 seconds with 10% polyacrylic acid, rinsed with running distilled water for 30 seconds, and dried with the hair dryer. A wet environment was created by the application of distilled water to the enamel surface with a water-soaked cotton swab. GC Fuji Ortho was then mixed in accordance with the manufacturers' instructions and applied to the bracket base.

Bonding the brackets

Just prior to surface conditioning and bonding a bracket, the middle one-third of the labial enamel surface was ground flat using water irrigated no. 600 grit SiC paper on a rotating grinding wheel. The embedded teeth were then rinsed in running distilled water and dried with the hair dryer. The bracket base with its applied cement was placed on the enamel surface with its slot parallel to the incisal edge.[13] A cylinder of dental stone 610 grams in weight was attached to the upper member of a semiadjustable Hanau articulator, and its guide pin was then lowered to engage the bracket slot. This both ensured that each bracket was seated under constant pressure and the investigators' hands were free to remove any extraneous cement that was extruded around the periphery of the bracket. This cement was initially removed with a sharp dental explorer. After allowing to bench set for 5 minutes, the cemented bracket was examined under a light microscope at a magnification of ×25, and any extraneous cement remaining was removed with a fine sandpaper disc on a straight handpiece. The bonded teeth were then stored in distilled water as described earlier until it was time for shear bond strength testing.

Table 2. The Criteria for Scoring the Adhesive Remnant Index[10]

Score	Description
0	No adhesive left on the tooth
1	Less than 50% adhesive left on the tooth
2	More than 50% adhesive left on the tooth
3	All of the adhesive left on the tooth

Table 3. Shear Bond Strengths Recorded for Brackets and Cements after 24 Hours, 7 Days, and 180 Days*

Bracket	Cement	24 hours	7 days	180 days	*P* values
Speed	CR	15.8±1.51	17.6±0.56	18.4±2.65	.003†
Spirit MB	CR	12.2±0.34	13.4±0.52	12.0±0.41	.0001†
Transcend	CR	25.0±1.14	23.6±1.12	23.5±0.82	.001†
Speed	GIC (dry)	12.0±1.08	11.2±0.65	12.5±1.63	.03†
Spirit MB	GIC (dry)	10.4±0.74	12.3±0.53	10.2±1.06	.0001†
Transcend	GIC (dry)	13.8±1.18	14.8±0.67	14.2±0.95	.1
Speed	GIC (wet)	11.1±0.77	11.1±0.80	12.0±0.98	.03†
Spirit MB	GIC (wet)	11.2±0.59	12.0±0.65	11.7±0.91	.04†
Transcend	GIC (wet)	14.2±1.37	14.8±0.78	15.3±1.02	.04†

*Note that Speed, Spirit, and Transcend are respectively made of metal, polycarbonate, and ceramic materials.
†Denotes significance at the 5% level.

Shear bond strength testing

The embedded teeth with their attached brackets were positioned in a Universal Testing Machine (Instron 4301, Instron Corporation, Canton, Mass) so that the incisal edge of the bracket base was parallel to a sharpened chisel blade. They were then shear tested to failure using a 1 kiloNewton (kN) load cell and a crosshead speed of 0.5 mm/min. The maximum force required to debond the bracket was recorded in Newtons and then converted to megaPascals (MPa).

Adhesive Remnant Index (ARI)

Following debonding, each enamel surface was examined under a light microscope at a magnification of ×35. The amount of cement left adhering to the surface was scored according to the criteria outlined by Artun and Bergland[10] (Table 2). A selection of 3 groups of teeth was made at random, and ARI scores were recorded by a single investigator (R-D.M.). One month later, the ARI scores were recorded for a second time by the same investigator. A second investigator also examined these same groups of teeth and recorded the ARI scores (P.E.R.). This enabled the completion of inter- and intraoperator error studies in the scoring of the ARI using an unweighted kappa statistic.

Statistical analysis

The mean shear bond strength (SBS) and standard deviation was calculated and recorded for each group. For each cement, a 1-way ANOVA was used to determine the effect of storage on SBS for each bracket type, and an unweighted kappa statistic was calculated to determine inter- and intrareliability when assigning ARI scores. If long-term storage had a significant effect on SBS, then Duncan's multiple range test was used to determine which groups of mean SBS (24 hours, 7 days, or 180 days) were significantly different from the others. The Fisher exact test was used to assess the association between mode of failure as judged by ARI scores and the different storage times.

Results

Long-term storage

The mean shear bond strengths (SBS) and their respective standard deviations are shown in Table 3. The results in general showed there were no precipitous increases or decreases in SBS from 24 hours to 7 days or from 7 days to 180 days, and that Speed and Transcend brackets cemented with resin composite (CR) cement produced consistently higher SBSs over the storage periods.

Resin composite cement: The SBS of the Speed bracket significantly increased from 24 hours to 7 days (*P*=.003) but remained unchanged at 180 days. The Spirit MB bracket reacted in a similar manner but at a lesser magnitude (*P*=.0001). On the other hand, the Transcend bracket showed a significant reduction in SBS from 24 hours to 7 days (*P*=.002) but remained unchanged at 180 days.

RMGIC dry environment: The SBS of the Speed bracket showed no significant changes from 24 hours to 7

Table 4. Frequency of ARI Scores and their Corresponding Shear Bond Strengths after 24 Hours, 7 Days, and 180 Days

			Frequency of ARI scores (%)					Mean SBS±SD corresponding to ARI score			
Bracket	Cement	Storage	0	1	2	3	*P* values	0	1	2	3
Speed	CR	24 h	25	17	17	42	.03*	15.6±1.28	16.1±1.93	17.5±0.59	15.1±1.52
		7 d	17	17	67	0		17.6±0.42	17.4±0.95	17.6±0.57	0
		180 d	42	8	0	50	.0003*	18.2±3.27	20.0	0	18.2±2.51
Speed	GIC (dry)	24 h	8	17	17	58	.50	13.9	12.7±1.51	11.6±0.28	11.6±0.83
		7 d	0	8	42	50		0	10.1	11.5±0.50	11.2±0.63
		180 d	0	17	25	58	.73	0	10.6±0.42	13.5±1.41	12.7±1.57
Speed	GIC (wet)	24 h	42	8	25	25	.003*	10.6±0.78	10.9	11.7±0.49	11.5±0.58
		7 d	0	50	50	0		0	11.1±0.72	11.1±0.95	0
		180 d	17	8	25	50	.002*	11.8±1.93	10.9	11.2±0.48	12.6±0.46
Spirit MB	CR	24 h	0	0	8	92	.48	0	0	11.7	12.3±0.32
		7 d	17	0	0	83		13.7 ± 0.06	0	0	13.4±0.55
		180 d	0	0	0	100	.48	0	0	0	12.0±0.41
Spirit MB	GIC (dry)	24 h	50	17	0	33	.03*	10.5±0.77	9.8±0.18	0	10.5±0.93
		7 d	0	33	0	67		0	12.1±0.30	0	12.4±0.60
		180 d	0	0	0	100	.09	0	0	0	10.2±1.06
Spirit MB	GIC (wet)	24 h	33	8	17	42	.03*	11.0±0.47	11.8	11.8±0.57	11.1±0.64
		7 d	0	0	8	92		0	0	11.3	12.1±0.64
		180 d	0	8	8	83	1.00	0	12.4	11.6	11.7±0.97
Transcend	CR	24 h	25	8	0	67	.78	26.1±0.97	25.6	0	24.5±0.97
		7 d	8	8	8	75		24.1	24.3	22.4	23.5±1.21
		180 d	8	0	0	92	.73	22.6	0	0	23.6±0.80
Transcend	GIC (dry)	24 h	0	0	33	67	.08	0	0	14.0±0.83	13.7±1.37
		7 d	8	17	50	25		14.1	15.6±0.01	14.7±0.56	14.8±0.92
		180 d	0	25	8	67	.07	0	14.9±0.75	14.5	13.9±0.96
Transcend	GIC (wet)	24 h	0	25	8	67	.2	0	15.0±2.29	15.0	13.8±0.93
		7 d	8	8	42	47		15.4	15.7	14.6 ± 0.77	14.6±0.85
		180 d	0	17	0	83	.03*	0	15.1±0.60	0	15.3±1.10

*Denotes significance at the 5% level.

days, but showed a significant increase after 180 days (*P*=.03). The Spirit MB bracket showed a significant increase in SBS from 24 hours to 7 days (*P*=.0001), followed by a significant decrease after 180 days (*P*=.0001). Over all 3 storage periods, the Transcend bracket showed no significant changes in SBS (*P*=.13).

RMGIC wet environment: The SBS of the Speed bracket showed no significant changes in SBS from 24 hours to 7 days, but showed a significant increase after 180 days (*P*=.03). The Spirit MB bracket showed a significant increase in SBS from 24 hours to 7 days (*P*=.04), followed by a significant decrease after 180 days (*P*=.04). The Transcend bracket showed increases in SBS over the 3 storage periods, with the increase from 7 to 180 days being significant (*P*=.04).

Intra- and interinvestigator reliability, ARI

Unweighted kappa statistic values of 0.96 were recorded for both intra- and interinvestigator reliability in the recording of ARI scores. On the kappa scale, values below 0.40 indicate poor agreement, 0.40 to 0.75 fair agreement, and values above 0.75 excellent agreement. The results in this investigation reflect excellent agreement and consistency in the assignment of ARI scores.

Long-term storage and ARI scores

The results showing the distribution of ARI scores and the mean SBSs associated with each bracket/cement combination at 24 hours and at 7 days and 180 days are shown in Table 4. The 2-tail Fischer exact test indicated that some significant shifts occurred in some of the ARI scores over time. In the 24-hour to 7-day period, a significant shift in ARI scores for Speed brackets bonded with RMGIC in a wet environment was recorded after 7 days of storage, indicating an increased tendency for cohesive fracture to occur within the cement (*P*=.004). This shift was independent of SBS. A similar shift was recorded for Speed brackets bonded with resin composite cement (*P*=.03). In contrast, significant shifts in which more residual cement was left adhering to the tooth surface were recorded for Spirit brackets cemented with RMGIC in either a dry (*P*=.9) or a wet (*P*=.03) environment. These shifts were also associated with an increase in SBS. No significant shifts were recorded for Transcend brackets for any of the cements during the 24-hour to 7-day periods.

For the 7- to 180-day period, ARI scores were generally unaffected by the passage of time. There were exceptions, however, and these included Speed brackets bonded with resin composite cement or RMGIC in a wet environment and Transcend brackets bonded with RMGIC in a wet environment. Speed brackets bonded with resin composite cement (*P*=.0003) or glass ionomer cement in a wet environment (*P*=.003) showed similar shifts in which less cement was left adhering to the tooth surface. In the former instance, the ARI shift was independent of SBS, and in the latter it was associated by an increase in SBS. The shift in ARI scores for Transcend brackets bonded with RMGIC in a wet environment showed a shift in ARI (*P*=.03) that resulted in more cement left adhering to the tooth surface, and this shift was associated with an increase in SBS.

Discussion

There appears to be no general consensus on the effects of long-term storage on the SBS of bonded orthodontic brackets.[14-18] The present study has shown that, although SBS may increase from 24 hours to 7 days, long-term storage over a 180-day period does not result in a precipitous deterioration of the bonds. This study indicates that the effect of long-term storage is dependent on both the type of bracket as well as the luting cement. In this study, long-term storage generally resulted in an increase in mean SBS of Speed brackets bonded with an autopolymerizing resin composite or RMGIC applied in a wet or a dry environment. In contrast, Spirit and Transcend brackets behaved differently with the same cements and under the same conditions. The Spirit brackets demonstrated an initial increase in SBS over the 7-day period, and this was followed by a decrease over 180 days. This finding was independent of the luting cement.

On the other hand, long-term storage resulted in a significant decrease in SBS for Transcend brackets bonded with resin composite cement. The exact opposite was true, however, for Transcend brackets bonded with RMGIC in a wet environment because SBS was found to significantly increase over the 180-day period.

These results find some support from other long-term studies and further reinforce the contention that the effects of long-term storage on SBS are equivocal. Studies have shown that both resin composites and glass ionomer cements continue to polymerize over time and, in consequence, increase in strength.[19,20] This provides support for the results obtained in this study for the Speed backets and, to a lesser extent, the Spirit brackets. Other studies, however, have concluded that there are no significant changes in SBS of directly bonded orthodontic brackets over the long term.[17,18] In fact, it has been speculated that resin composite cements absorb and desorb water over time, causing hydrolytic degradation of inorganic fillers and resulting in a decrease in bond strength.[18]

It has been speculated that the amount of cement adhering to either the tooth surface or the bracket base following debonding is not related to the SBS of the separate interfaces, but rather to the configuration of the bracket base and the physical properties of the cement used.[21] The results of this study provide an equivocal amount of support for these findings. After 7 days of storage, the ARI scores of Speed brackets bonded with RMGIC in a wet environment shifted from the majority of the cement remaining on the tooth to being principally retained on the bracket. This shift was also found to be independent of SBS. The fact that maturation and strength of RMGIC increases over time is probably a factor in these findings.[20] By way of contrast, although a similar ARI shift was recorded with Speed brackets cemented with resin composite cement, this shift was associated with an increase in SBS. Other studies support this latter finding in which an inverse relationship was shown to exist between mean SBS and ARI where the cementing medium was a resin composite cement.[7] Polymerization of resin composite cements has been shown to continue over time, and this probably is the contributing factor to the increase in SBS and ARI shift.[19]

The observation that the configuration of the bracket base may also be a contributing factor[21] is provided by the results recorded with Spirit brackets bonded with RMGIC in both wet and dry environments. In both instances, the ARI shift over the 7-day period resulted in the majority of the cement being left on the tooth surface rather than the bracket base after debonding. This was associated with an increase in SBS. Since RMGIC matures and gains strength over time, the weakest link was at the cement-Spirit bracket base interface.

The long-term storage from 7 to 180 days was shown to generally have no effect on ARI scores. Among the exceptions were Speed brackets bonded with resin composite or RMGIC in a wet environment where less cement was left adhering to the tooth surface after 180 days. The ARI shift recorded for the Speed bracket-resin composite combination was independent of SBS while the Speed bracket-RMGIC wet environment was associated with an increase in SBS. This finding is a complete reverse of the results recorded from the 24-hour to 7-day period.

In clinical orthodontics, treatment success is predicated upon the retention of attachments over time and the easy and efficient removal of residual cement without iatrogenic damage to the underlying enamel when the attachments are debonded. Bonded appliances must resist the displacement forces that are present in the oral cavity, and it has been estimated that for directly bonded brackets these are tensile and shear forces in the range of 2.86 to 8 MPa in magnitude.[5,22,23] Previous results have shown that 5 of 6 bracket-resin composite cement combinations achieve acceptable SBS within 1 hour of placement, enabling the clinician to be reasonably confident that immediate placement of an archwire is possible without causing a debond.[7]

The results obtained with all bracket base-cement combinations used in the present study indicate that more than adequate bond strengths are achieved within 24 hours, and, although they may fluctuate over a 7-day and 180-day period, they remain well above 8 MPa. In all probability, adequate bond strengths could be expected within 1 hour of placement. As a result, the bracket base-cement combinations used in this study may be expected to perform well clinically over the lifetime of the bonded orthodontic appliance.

When bonded appliances are removed and if all of the cement is detached from the tooth surface, clean up is easier for both the clinician and the patient rather than when the majority of the cement is left adhering to the tooth. Iatrogenic damage to the underlying enamel during debonding, however, is always a concern for clinicians. The ARI index presents a method of assessing where the residual cement is situated but does not record if damage to the enamel has occurred during the debonding process. The more deeply the enamel surface is penetrated by the conditioning agent, the greater the penetration of the cement and the greater the risk of damage to the enamel during debonding.[6] It has been shown that 10% polyacrylic acid presents less of a risk for damage to enamel than 37% orthophosphoric acid since it produces a much milder etching pattern.[8] As a result, if debonding a resin composite-phosphoric acid combination results in an ARI score of 0 (no resin left on the tooth), the possibility of removal of fluoride-rich, surface-enamel crystals and resin tags exists. The use of a glass ionomer cement-polyacrylic acid combination reduces the risk of this damage.

A further advantage of glass ionomer cements is that, when desiccated by air drying, they become friable and can be more easily removed, further reducing the possibility of damage to enamel.[24-26] Glass ionomer cements also have the ability to both release and absorb fluoride and prevent the demineralization of enamel.[27-31] It has also been reported that less cariogenic flora is found in plaque deposits adjacent to glass ionomer cements.[32,33] Thus, glass ionomer cements should be used for patients who exhibit a high caries risk.

Conclusions

It may be concluded that the bracket base-cement combinations used will produce SBS that are sustainable over time. As a result, these bracket base-cement combinations may also be expected to perform well clinically over the lifetime of a bonded orthodontic appliance. The selection of glass ionomer containing cements may be important in those patients who exhibit a high risk for caries.

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