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Frictional properties of aesthetic brackets

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SUMMARY The purpose of this study was to compare the frictional properties of two self-ligating aesthetic brackets, Opal (Ultradent Products) and Oyster (Gestenco Int.), with those of four conventionally ligated aesthetic brackets, Transcend (3M Unitek), Inspire (Ormco), Allure (GAC Int.), and Image (Gestenco Int.). Friction was tested with different wire dimensions and qualities [stainless steel (SS) wire 0.017 × 0.025 inches; SS 0.019 × 0.025 inches; TMA 0.019 × 0.025 inches] using a Zwick testing machine. All brackets had a 0.022-inch slot and the prescription of an upper first premolar of the Roth system (tip: 0 degrees, torque: –7 degree). Each bracket/archwire combination was tested 10 times and each test was performed with a new bracket/wire sample that was pulled through twice. Additionally, two sets of 30 Opal brackets each were aged with an ageing machine under standardized conditions for 9–10 and 18–20 months, respectively. Friction of the aged brackets was tested with identical wire dimensions and qualities using the same testing procedure. All data were statistically analysed with unsigned comparisons of all bracket/wire combinations using GLM and the Games–Howell *post hoc* test.

The results showed Opal brackets to have the lowest frictional forces for all wire dimensions and qualities. Furthermore, friction was lower at a significant level ($P \leq 0.05$) compared with all other brackets. Only the Oyster bracket had similar values in combination with a 0.019 × 0.025 inch SS wire. Aged Opal brackets showed higher values than new ones, but still lower frictional forces than the four conventional aesthetic brackets. Friction was comparable with the new Oyster bracket.

Introduction

The appearance of fixed orthodontic appliances has always been of particular concern in orthodontic treatment. In the 1970s, attempts to produce brackets from different aesthetic materials included the use of plastic brackets that were injection moulded from the aromatic polymer polycarbonate. Problems reported included crazing and deformation (Dobrin *et al.*, 1975) as well as stains and odours. Even alternative composite brackets made of chopped glass fibres did not change these problems. It was nearly 10 years before ceramic brackets became available for orthodontic applications. The ceramic brackets available nowadays are made of alumina (Al_2O_3) either in polycrystalline or monocrystalline forms. The manufacturing process of monocrystalline brackets results in a purer structure, a smoother surface, and a considerably harder substance than the fabrication of polycrystalline brackets.

Most studies carried out on ceramic brackets not only confirmed the problems of colouring and early fracture in torquing (Holt *et al.*, 1991) but also showed increased friction of ceramic brackets compared with metal brackets (Angolkar *et al.*, 1990; Pratten *et al.*, 1990; Kusy and Whitley, 1997).

The increased use of sliding mechanics that followed the development of the pre-adjusted edgewise systems has focused interest on the effect of friction between bracket and archwire and its contribution to the resistance to tooth movement. Friction is defined as the resistance to motion when one object moves tangentially against another. Drescher *et al.* (1989) calculated, in an *in vitro* experiment, that friction accounts for 60 per cent of the force required to produce tooth movement in several bracket/archwire combinations. The search for a bracket system with a low frictional resistance resulted in the development of self-ligating brackets.

Although the first self-ligating bracket was the Russell lock (Stolzenberg, 1935), manufacturers and orthodontists have shown renewed interest in the development of self-ligating brackets since the mid-1970s. Two different types of self-ligating brackets were produced: those with a spring clip that pressed actively against the archwire, such as the Speed bracket, and self-ligating brackets, e.g. the Activa bracket whose self-ligating clip did not press against the wire.

The attempt to combine the benefits of both types of brackets, i.e. an acceptable aesthetic appearance for the patient as well as low friction for adequate clinical performance, resulted in the development of self-ligating aesthetic brackets such as the Opal, a new glass-filled, nickel-free, polycrystalline, self-ligating aesthetic bracket. A further product is the self-ligating Oyster bracket, that is based on a fibreglass-reinforced composite (FRC).

However, previous studies have mainly focused on the friction of conventionally ligated aesthetic brackets in comparison with metal or self-ligating metal brackets. Thus, the following question arises: how do the frictional properties of self-ligating aesthetic brackets compare with those of conventionally ligated aesthetic brackets in different bracket/archwire combinations?

Therefore, the purpose of the present study was to compare the frictional properties of four conventionally ligated aesthetic brackets with those of two self-ligating aesthetic brackets. This comparison necessitated the determination of the force required to pass three standard clinical archwires through these brackets *in vitro*. In addition, to determine the effects of ageing on friction, two further sets of Opal brackets were aged and tested.

Materials and methods

Bracket systems

Four conventionally ligated aesthetic brackets, i.e. Allure (GAC Int., Bohemia, New York, USA), Image (Gestenco Int., Gothenburg, Sweden), Inspire (Ormco, Orange, California, USA), and Transcend (3M Unitek, Monrovia, California, USA), as well as two self-ligating aesthetic brackets, Opal (Ultradent Products, South Jordan, Utah, USA) and Oyster (Gestenco Int.), were tested. While Inspire is a monocrystalline ceramic bracket, Allure and Transcend are made of polycrystalline ceramic and Image is made of FRC. The new self-ligated Opal bracket is made of a glass-filled, nickel-free polycrystalline resin, while Oyster is a self-ligating aesthetic bracket produced from a FRC polymer. Both Opal and Oyster are passive self-ligating brackets. The bracket specifications are given in Table 1. All brackets used in this study had a 0.022 × 0.028 inch slot and the prescription of an upper first premolar bracket of the Roth system with 0 degrees tip and −7 degrees torque.

Ten brackets of each type were ligated to rectangular archwires that came from plain strands of wire, with different dimensions and qualities. The archwires used were made of either 0.017 × 0.025 inch stainless steel (SS), 0.019 × 0.025 inch SS, or 0.019 × 0.025 inch TMA and produced by the same manufacturer (Ormco). The conventional brackets were ligated with elastic modules in order to prevent individual differences in forces resulting from the ligature wires. All brackets were treated under identical standardized conditions.

Experimental set-up

In order to simulate the effects of moisture and temperature corresponding to conditions in the oral cavity, the brackets with fixed wires were placed into SS containers with artificial saliva (SR 90, AMH Niemann, Barleben, Germany). The composition of the artificial saliva is shown in Table 2. They were kept in an oven at 37°C for 28 days.

The bracket bases were then dried and centrically bonded onto a round metal base that had been sandblasted to improve retention. To ensure correct positioning of the wire-bracket couples on the metal base, the following technique was used: Two identical standard edgewise 0.022 inch brackets (tip = 0 degrees; torque = 0 degrees) were bonded onto a flat aluminium plate in a straight line. This position was secured by ligating these brackets to a straight piece of a 0.022 × 0.025 inch SS wire before bonding. The plate was mounted centrically to the model table of the milling machine 'Degussa F2' (Degudent, Hanau, Germany). Each round metal base was fixed in the milling machine and adjusted in such a way that its centre corresponded with the centre of the tested bracket. Bracket bases were supplied with primer Transbond MIP (3M Unitek) and light curing composite, Tetric Flow (Ivoclar Vivadent, Ellwangen, Germany). The metal base-holding part of the milling machine was then lowered vertically towards the bracket base, ensuring parallelism between the metal base surface and bracket/wire couple. Finally, the composite was cured for 1 minute.

Friction was tested with a universal testing machine (Model 1446, Zwick, Ulm, Germany) by simulating the continuous tipping–uprighting sliding movement of bonded teeth (Figure 1). This set-up consisted of a metal framework that allowed rotation of the metal base bonded to the bracket/wire unit. A 12mm metal piece was attached to this metal base, from which a 250g weight was suspended to increase

Table 1 Bracket characteristics and prescription.

	Bracket system					
	Allure	Image	Inspire	Transcend	Oyster	Opal
Manufacturer	GAC Int.	Gestenco Int.	Ormco	3M Unitek	Gestenco Int.	Ultradent Products
Type	Conventional	Conventional	Conventional	Conventional	Self-ligating	Self-ligating
Material	Polycrystalline ceramic	FRC	Monocrystalline ceramic	Polycrystalline ceramic	FRC	Glass-filled polycrystalline resin
Bracket width (mm)	3.7	3.5	3.1	3.5	4.0	3.4
Slot size (inches)	0.022	0.022	0.022	0.022	0.022	0.022

FREC, fibreglass-reinforced composite.

wire binding at the edges of the bracket during sliding. Two guide rollers were placed above and below the metal base to guide the movement of the wire.

Each of the rectangular wires was pulled through twice with the crosshead moving at a velocity of 12.7 mm/minute. The maximum frictional force was then measured. According to a study using a similar experimental set-up (Bednar *et al.*, 1991), this velocity was chosen as standard. Different studies using speeds from 0.5 to 50 mm/minute (Ireland *et al.*, 1991; Taylor and Ison, 1996) showed no significant differences in friction measurements. Using this procedure, each bracket/wire combination was tested 20 times, thus 60 tests were carried out for each type of bracket.

Ageing simulation

In the present study, only Opal brackets were aged because they showed the best frictional qualities. Two sets of 30 Opal brackets each were aged under standardized conditions simulating either 9- to 10-month or 18- to 20-month duration using a chewing masticator, (type Regensburg, EGO, Regensburg, Germany; Rosentritt *et al.*, 2006).

For the 9- to 10-month simulation, the brackets were left in the chewing simulator for 3 days, during which they were exposed to alternating cycles of 55°C warm and 5°C cold water 1100 times. The ageing period of 18–20 months included 2200 cycles of 55°C warm and 5°C cold water with the brackets remaining in the chewing simulator for 6 days. The brackets were then placed on the wires, bonded, and fixed into the testing apparatus in the same way as the new brackets. Prior to ligation to the brackets, the wires had been placed in containers with artificial saliva and kept in an oven at 37°C for 28 days in order to create comparable experimental conditions to the wires used in the comparative set-up described above. Ten brackets per wire dimension were tested and each wire was pulled through twice. The maximum frictional force of the aged Opal brackets was measured as described above.

Table 2 Composition of artificial saliva used in the study (SR 90, AMH Niemann).

Component	Per cent
$MaCl_2$	0.01
$CaCl_2$	0.02
NaH_2PO_4	0.07
NaCl	0.08
KCl	0.12
Sorbitol	3.1
Water	96.6

Statistical analysis

Statistical analysis was carried out with the Statistical Package for Social Sciences, Version 12.0 for Windows (SPSS Inc., Chicago, Illinois, USA) and the results were considered as significant at $P \leq 0.05$. With the chosen sample size of $n = 20$ per unit of analysis (bracket/archwire combination), a minimum statistical power of 0.80 was estimated for each two-sided comparison. The

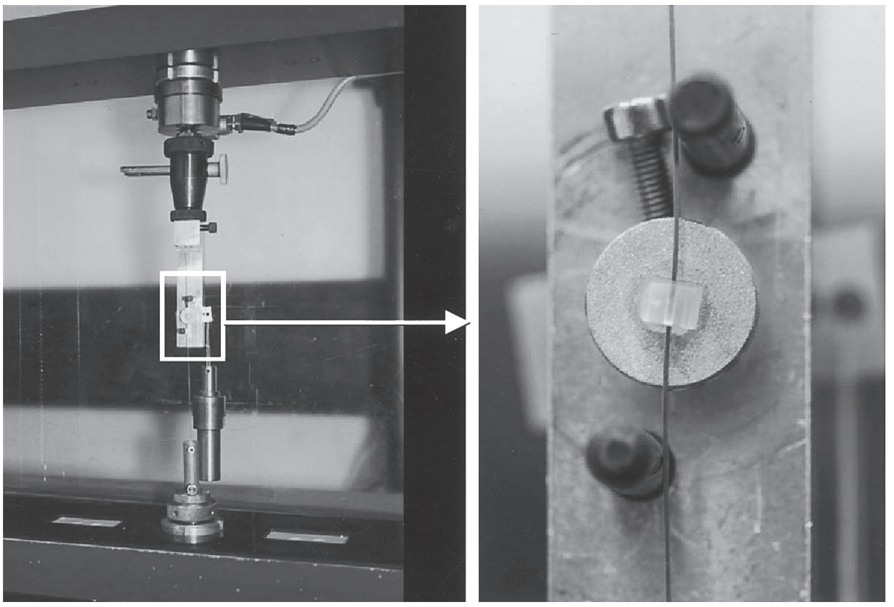

Figure 1 Experimental set-up fixed in the Zwick testing apparatus. The metal framework allowed rotation of the metal base bonded to the bracket/wire unit. An attached weight of 250 g simulated angulation by increasing wire binding at the edges of the bracket during sliding. The magnified detail shows the wire fixed in the bracket with two rollers guiding the wire movement.

data were presented graphically by box and whisker-plots using SigmaPlot 10.0 (Systat Software GmbH, Erkrath, Germany). Normal distribution of the data was tested using the Kolmogorov–Smirnov test, and the homogeneity of variances with Levene's test. Since the data showed normal distribution but no homogeneity of variance, frictional forces were evaluated with unsigned comparisons of all bracket/wire combinations using Mann–Whitney's *U*-test and *post hoc* analysed using the procedure of Games–Howell for control of the multiple comparisons.

Results

For each bracket/wire unit tested, the two self-ligating brackets showed lower frictional forces than the four conventional brackets (Figure 2, Table 3). For each wire used, the Opal bracket displayed significantly lower frictional forces ($P \leq 0.05$) for all wire dimensions and properties than any of the conventional ligated brackets.

The Opal bracket showed even lower frictional forces than the Oyster bracket. This difference was significant ($P \leq 0.001$) for both the 0.017 × 0.025 inch SS and 0.019 × 0.025 inch TMA wires, but insignificant with regard to the

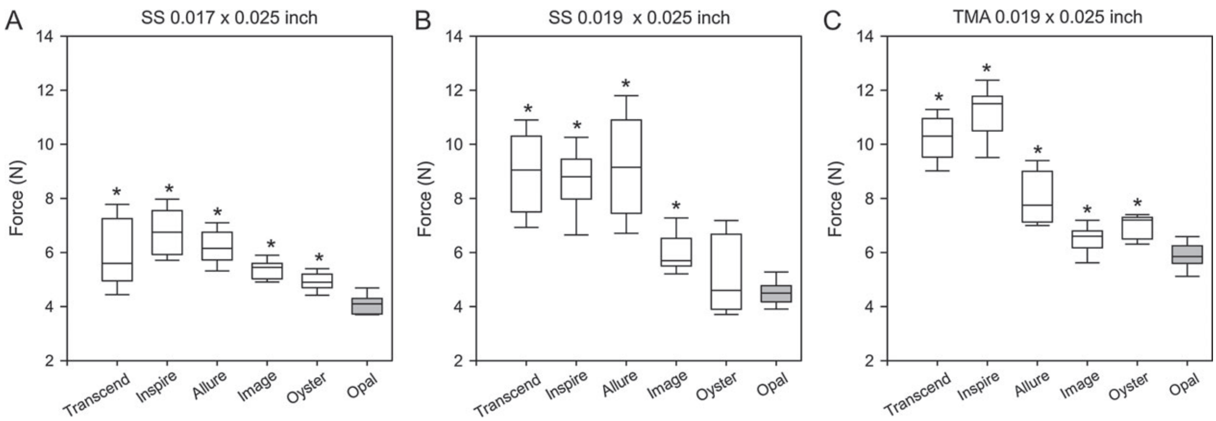

Figure 2 Box-plots showing the maximum frictional forces of the bracket systems Transcend, Inspire, Allure, Image, Oyster, and Opal depending on the wire dimensions and qualities used: (A) Stainless steel (SS) 0.017 × 0.025 inch, (B) SS 0.019 × 0.025 inch, and (C) TMA 0.019 × 0.025 inch. The significance of testing in pairs is given using the Opal system as the reference (*$P \leq 0.05$; $n = 20$ for each configuration).

Table 3 Statistical summary of friction data for all bracket/archwire combinations (N).

Bracket system	Archwire	Archwire size (inches)	Ageing	*n*	Mean	SD	Median	IQR	Minimum	Maximum
Allure	SS	0.019 × 0.025	None	20	9.3	1.89	9.2	3.4	6.6	12.3
Allure	TMA	0.019 × 0.025	None	20	8.0	1.00	7.8	1.9	6.4	9.7
Allure	SS	0.017 × 0.025	None	20	6.2	0.61	6.2	1.0	5.1	7.2
Image	SS	0.019 × 0.025	None	20	6.0	0.75	5.7	1.0	4.7	7.5
Image	TMA	0.019 × 0.025	None	20	6.5	0.52	6.6	0.6	5.5	7.3
Image	SS	0.017 × 0.025	None	20	5.4	0.34	5.5	0.6	4.9	5.9
Inspire	SS	0.019 × 0.025	None	20	8.7	1.14	8.8	1.5	6.3	10.4
Inspire	TMA	0.019 × 0.025	None	20	11.15	0.95	11.50	1.3	9.4	12.5
Inspire	SS	0.017 × 0.025	None	20	6.8	0.84	6.8	1.6	5.2	8.1
Opal	SS	0.019 × 0.025	None	20	4.6	0.44	4.5	0.6	3.9	5.5
Opal	TMA	0.019 × 0.025	None	20	5.9	0.47	5.9	0.7	5.0	6.6
Opal	SS	0.017 × 0.025	None	20	4.1	0.35	4.1	0.6	3.5	4.7
Opal	SS	0.017 × 0.025	9–10 month	20	4.4	0.37	4.5	0.7	3.8	5.1
Opal	SS	0.017 × 0.025	18–20 month	20	5.2	0.32	5.2	0.5	4.7	5.9
Opal	SS	0.019 × 0.025	9–10 month	20	4.9	0.49	4.8	0.8	4.3	5.9
Opal	SS	0.019 × 0.025	18–20 month	20	5.0	0.32	5.0	0.4	4.3	5.6
Opal	TMA	0.019 × 0.025	9–10 month	20	6.1	0.45	6.1	0.7	5.5	7.0
Opal	TMA	0.019 × 0.025	18–20 month	20	6.2	0.68	6.0	1.1	5.3	7.7
Oyster	SS	0.019 × 0.025	None	20	5.2	1.40	4.6	2.8	3.5	7.7
Oyster	TMA	0.019 × 0.025	None	20	6.9	0.47	7.2	0.8	5.8	7.5
Oyster	SS	0.017 × 0.025	None	20	4.9	0.36	4.9	0.5	4.2	5.6
Transcend	SS	0.019 × 0.025	None	20	8.9	1.47	9.1	2.8	6.8	11.0
Transcend	TMA	0.019 × 0.025	None	20	10.2	0.82	10.3	1.4	8.9	11.8
Transcend	SS	0.017 × 0.025	None	20	6.0	1.26	5.6	2.3	4.1	8.4

SD, standard deviation; SS, stainless steel; IQR, interquartile range.

0.019 × 0.025 inch SS wire ($P = 0.565$). Nevertheless, the Oyster bracket showed excellent friction values. With regard to the two SS wire dimensions used in the study, the Oyster bracket showed less friction than any of the conventional ligated brackets. This difference was significant ($P \leq 0.001$). The only exception was for the comparison between Oyster/SS 0.019 × 0.025 inch wire and Image/SS 0.019 × 0.025 inch wire, showing an insignificant difference ($P = 0.072$).

In comparison with the TMA wire, the Oyster bracket resulted in significantly ($P \leq 0.001$) less friction than the Transcend, Inspire, and Allure brackets, and significantly ($P \leq 0.05$) more friction than the Image bracket.

Ageing

In comparison with new Opal brackets, the ageing procedure of Opal brackets resulted in a greater frictional force for all dimensions and archwire qualities (Figure 3). This increase was significant for both SS wire dimensions 0.017 × 0.025 inches and 0.019 × 0.025inches ($P \leq 0.05$), but not for TMA 0.019 × 0.025inches for the ageing period of 9–10 months. It was also significant ($P \leq 0.001$) for the ageing period of 18–20 months for the two SS wire dimensions 0.017 × 0.025inches and 0.019 × 0.025inches, but again not for the 0.019 × 0.025inch TMA wire.

Comparison of the Opal brackets aged for 9–10 and 18–20 months showed an increase in frictional forces with ageing. This increase was not significant for the SS 0.019 × 0.025 inch and TMA 0.019 × 0.025 inch wires, but significant for the SS 0.017 × 0.025 inch wires ($P \leq 0.001$).

Nevertheless, friction of the aged Opal bracket was lower than that of the new brackets Transcend, Inspire, Allure, and Image, and thus, comparable with the new Oyster bracket.

Discussion

This laboratory study was designed to compare the friction produced by self-ligating and conventionally ligated aesthetic brackets. The results show that conventionally ligated aesthetic brackets produce higher friction than aesthetic self-ligating brackets. In general, the Opal bracket produced the lowest frictional force (Figure 2). Both self-ligating aesthetic systems consistently produced low levels of friction.

Frictional resistance between archwire and brackets is caused by many factors and varies according to archwire size and material (Angolkar *et al.*, 1990; Ireland *et al.*, 1991), mode of ligation (Bednar *et al.*, 1991; Sims *et al.*, 1993), angulation of the wire to the bracket (Andreasen and Quevedo, 1970; Dickson *et al.*, 1994), and saliva (Kusy *et al.*, 1991; Downing *et al.*, 1995). Drescher *et al.* (1989) regarded bracket width to play an inferior role in frictional forces.

In this study, friction was tested under dry conditions. The effect of lubrication by saliva on friction is controversial. Kusy *et al.* (1991), for example, regarded artificial saliva as inadequate replacement for human saliva and hence such experiments as invalid. Andreasen and Quevedo (1970) claimed that saliva played an insignificant role, while Read-Ward *et al.* (1997) concluded that the presence of human saliva had an inconsistent effect on static friction and sliding mechanics. Baker *et al.* (1987) found that saliva acted as a lubricant, while Stannard *et al.* (1986) and Downing *et al.* (1995) reported that saliva increased friction. Thus, in the present investigation the wire/bracket couples were tested under dry conditions.

In this study, all four conventionally ligated aesthetic brackets were ligated with elastomeric modules. Prior to friction testing, the wires were incubated in artificial saliva at 37°C for 28 days to simulate the effect of temperature and humidity in the oral cavity on elastic ligatures. The duration chosen for the experiments corresponded to the amount of time that ligatures are supposed to hold an archwire in place. This method was selected on the basis of a study by Taloumis *et al.* (1997), who found that elastics ligatures, which had been stored in artificial saliva as described above, lost 43–66 per cent of their pressure in the first 24 hours. After

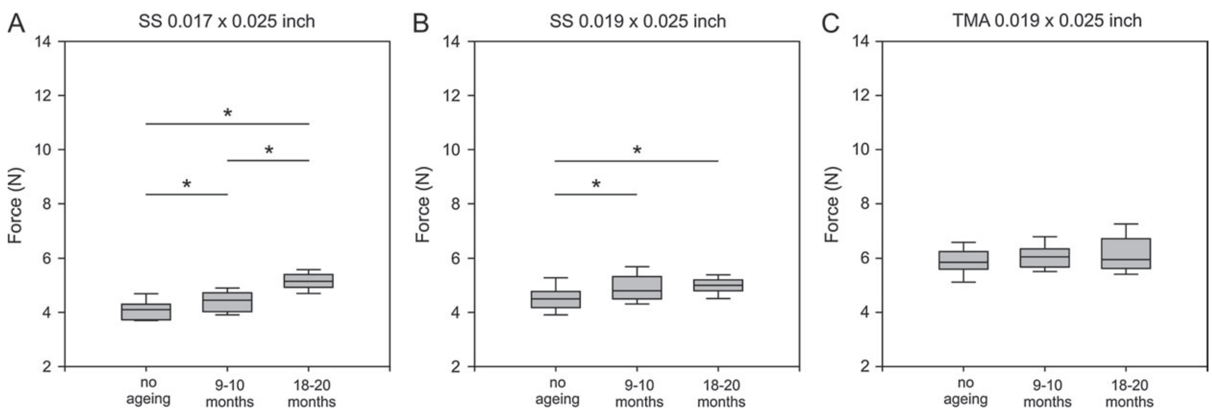

Figure 3 Box-plots showing the maximum frictional forces of the Opal bracket system before and after 9–10 and 18–20 months of ageing. Different wire dimensions and qualities were examined: (A) Stainless steel (SS) 0.017 × 0.025 inch, (B) SS 0.019 × 0.025 inch, and (C) TMA 0.019 × 0.025 inch. The significance of testing in pairs is shown: *$P \leq 0.05$ ($n = 20$ for each configuration).

that period, the decrease in pressure proved to be minimal and the elastics exerted almost constant pressure. Tying with SS ligatures was found to vary both inter- and intraindividually. Since Schumacher *et al.* (1990) reported a considerable variation of pressure between 2 and 8 N with 0.011 inch SS ligatures, elastic ligatures were used in the present study in order to minimize variations and to standardize ligation.

Tipping is a constant phenomenon during sliding tooth movements. For this reason, teeth will tip until contact is established between the archwire and the diagonally opposite corners of the bracket wings. In order to simulate this clinical condition, rotation of the bracket and wire was permitted according to the previously described model for measuring friction.

No study thus far appears to have investigated the frictional behaviour of the new aesthetic self-ligating brackets in comparison with conventionally ligated brackets. However, metal self-ligating brackets have been tested in a considerable number of studies. Similar to the present experimental set-up, these tests allowed a free or predetermined tipping of the bracket relative to the wire during movement (second-order angulation; Bednar *et al.*, 1991; Sims *et al.*, 1994; Read-Ward *et al.*, 1997; Pizzoni *et al.*, 1998; Thorstenson and Kusy, 2001).

Compared with these types of studies, the present results support previous investigations by Sims *et al.* (1994), Read-Ward *et al.* (1997), Pizzoni *et al.* (1998), and Thorstenson and Kusy (2001), who also found self-ligating brackets to produce significantly less friction than conventional brackets. Schumacher *et al.* (1999) also reported reduced friction with Damon SL self-ligating brackets in comparison with conventionally designed brackets, despite the fact that this decrease was associated with negative side-effects in terms of levelling losses after completion of retraction.

However, despite similar testing conditions, the results found by Bednar *et al.* (1991) were not confirmed. During their investigation of the frictional properties of the Speed self-ligating bracket compared with a conventional bracket, those authors reported increased friction for the self-ligating Speed bracket. One reason for this finding may be the fact that the effect of humidity and temperature in the oral cavity was not simulated. More important, however, is the fact that the different results are likely to be caused by the particular design of the Speed bracket. With this bracket, the wire is actively engaged by the spring clip and pressed into the slot so that a certain amount of pressure proportional to the size of the wire is exerted. In contrast, the locking cap in aesthetic self-ligating brackets just passively converts the bracket slot into a tube, and hence, no pressure is exerted on the wire.

In the present investigation, torque effects (third-order angulation) were not simulated. Even though torque effects increase friction in clinical situations, only a few studies simulating this effect are found in literature (Drescher *et al.*, 1991; Bourauel *et al.*, 1992).

Generally, friction appears to intensify with the increase of archwire diameter (Angolkar *et al.*, 1990), a finding supported by the results of the present research. For all bracket types, the 0.019 × 0.025 inch SS wire produced higher friction than the 0.017 × 0.025 inch SS wire.

Five of the six bracket types used in the test regimen produced higher frictional forces in combination with the 0.019 × 0.025-inch TMA wire than with the SS wire of the same dimension. This difference was significant ($P \leq 0.05$) and independent of bracket material and ligation type. Only the Allure bracket showed significantly adverse results, in agreement with the study of Saunders and Kusy (1994), who found that this bracket, in a wet state, induced less friction with TMA wires than with SS wires. These high frictional forces are caused by the surface properties of the TMA wires. TMA has more porosities and a noticeably rougher surface than SS. These findings are in agreement with those of Angolkar *et al.* (1990) and Drescher *et al.* (1989), who also observed higher frictional forces with TMA wires compared with SS wires.

Ageing was only carried out for the Opal brackets because they showed the most appropriate frictional qualities. With all types of archwires, aged Opal brackets exhibited greater frictional forces than new Opal brackets. This increase was significant for Opal brackets aged for 9–10 and 18–20 months with respect to SS wires. The negative influence of ageing on frictional behaviour may be due to abrasion of bracket material caused by alternate warm and cold cycles in the chewing simulator. This wear and tear resulted in increased surface roughness and probably in an accumulation of debris in the slot, which, in turn, increased friction. The results are in accordance with those of Riley *et al.* (1979), who found that friction of polycarbonate brackets gradually increased in distilled water due to corrosion, and the results of the study by Keith *et al.* (1993) on ceramic brackets.

Conclusion

This *in vitro* study measured the frictional properties of different aesthetic brackets. The results demonstrate a difference in the friction produced by self-ligating aesthetic brackets and elastomeric tied aesthetic brackets.

1. Both self-ligating aesthetic brackets had significantly lower friction than conventionally ligated aesthetic brackets with 0.017 × 0.025 and 0.019 × 0.025 inch SS wires. For the Opal bracket, significantly lower friction was found compared with conventionally ligated brackets regarding the 0.019 × 0.025-inch TMA wire.
2. The Opal bracket produced the lowest level of friction for all bracket/archwire combinations. The difference was significant ($P \leq 0.05$). The Opal bracket resulted in even lower frictional forces than the Oyster bracket. This

difference was significant with the 0.017 × 0.025 inch SS wire and 0.019 × 0.025 inch TMA wire but insignificant with the 0.019 × 0.025 inch SS wire.

3. Ageing of Opal brackets increased friction for all wire dimensions and qualities. This difference was significant for the 0.017 × 0.025 and 0.019 × 0.025 inch SS wires aged for 9–10 and 18–20 months. After ageing, Opal brackets showed lower frictional forces than most of the aesthetic brackets. Only the self-ligating new Oyster bracket showed similar results in some cases.

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