Original Article

Surface roughness of three types of modern plastic bracket slot floors and frictional resistance

Sung-Hwan Choi[a]; Da-Young Kang[b]; Chung–Ju Hwang[c]

ABSTRACT

Objective: To quantitatively analyze the surface roughness of the slot floors of three types of modern plastic brackets and to measure static frictional force during sliding mechanics in vitro.

Materials and Methods: Control groups comprised stainless steel brackets and monocrystalline ceramic brackets. Test groups comprised three types of 0.022-in slot, Roth prescription, plastic, maxillary right central incisor brackets. Test groups included glass fiber-reinforced polycarbonate, filler-reinforced polycarbonate, and hybrid polymer with inserted metal slot brackets. The static frictional resistance caused by sliding movements with an archwire (stainless steel) in vitro was quantitatively analyzed. Both scanning electron microscope and three-dimensional optical surface profiling were used.

Results: Scanning electron microscope and three-dimensional optical surface profiler revealed that all as-received brackets had irregular slot floor surfaces, and both irregularity and roughness increased after the archwire sliding test. The ceramic brackets in the control group showed significantly lower surface roughness values and higher frictional values during the archwire sliding test compared with the other brackets. The glass or filler-reinforced plastic brackets exhibited significantly higher static frictional values than the metallic slot type brackets ($P < .001$). The hybrid polymer with inserted metal slot brackets showed relatively lower surface roughness and frictional values compared with the stainless steel control bracket.

Conclusion: Glass or filler-reinforced plastic brackets showed higher frictional resistance than metallic slot–type brackets. A plastic bracket with inserted metal slot may be the best choice among plastic brackets for low frictional resistance and to avoid damage from sliding movements of the archwire. (*Angle Orthod.* 2014;84:177–183.)

KEY WORDS: Plastic brackets; Surface roughness; Three-dimensional optical surface profiler; Static frictional resistance

INTRODUCTION

In recent years, because of increasing esthetic demands of orthodontic patients, various esthetic brackets made of plastic or ceramic materials have become popular. Such brackets are currently being developed, and many have become available on the market.[1,2] However, when it became evident that ceramic brackets damaged the enamel during debonding, plastic brackets began to increase in popularity.[3]

The original plastic brackets were made of unfilled polycarbonate and caused some problems related to reduced hardness, less wear resistance, intraoral plasticization, oral fluid absorption leading to an undesirable odor,[4] and irregular surfaces of the bracket slot floor. These disadvantages influenced the magnitude of friction between the bracket and archwire.[5] The bracket slot floors were originally designed to be smooth macroscopically. However, irregularities in the slot floor surface increased the pressure exerted by the wire onto a few small peaks (asperities), and this led to abrasion during tooth sliding movements. Thus, ideally, the raw materials for manufacturing plastic

[a] Postgraduate student, Department of Orthodontics, College of Dentistry, Yonsei University, Seoul, Korea.
[b] Fellow, Department of Dentistry, Yongin Severance Hospital, Kyunggido, Korea.
[c] Professor, Department of Orthodontics, Institute of Craniofacial Deformity Center, College of Dentistry, Yonsei University, Seoul, Korea.
Corresponding author: Chung–Ju Hwang, DDS, PhD, Department of Orthodontics, Institute of Craniofacial Deformity Center, College of Dentistry, Yonsei University, 134 Shinchon-dong, Seodaemun-gu, Seoul 120-752, Korea
(e-mail: hwang@yuhs.ac)

Accepted: May 2013. Submitted: March 2013.
Published Online: June 14, 2013

Table 1. Identification of Brackets Used in This Study

Name of Bracket	Manufacturer	Composition	Slot Type	Torque/ Tip
MicroArch	Tomy, Tokyo, Japan	Stainless steel	Metallic	+12/ +5
Inspire ICE	Ormco, Glendora, Calif	Monocrystalline alumina	Ceramic	+12/ +5
Image	Gestenco International, Gothenburg, Sweden	Glass-reinforced polycarbonate	Plastic	+12/ +5
Silkon M	American Orthodontics, Sheboygan, Wis	Filler-reinforced polycarbonate	Plastic	+15/ +5
Esther MB	Tomy, Tokyo, Japan	Polycarbonate with polyethylene terephthalate	Metallic	+12/ +5

brackets, apart from providing reduced surface roughness, should possess adequate stiffness and hardness to resist the morphologic deformation associated with frictional forces during tooth sliding movements. Efforts have been undertaken to improve the mechanical properties of plastic brackets by manufacturing new polymers reinforced with glass fibers or fillers and by incorporating metal slots into the bracket.[4,6]

The vast majority of in vitro studies that have investigated frictional resistance show that friction increases with increased roughness of the wire and bracket surfaces.[7–9] However, these studies focused mainly on the mechanical properties of archwires and the frictional behavior of as-received metal or ceramic brackets.

Three-dimensional (3D) optical profilers are used to measure height variations on surfaces using the wavelength of light. Optical profilers are noninvasive, and provide 3D information regarding surface morphology and mechanical properties; quantification of surface roughness can be useful for quantitative analysis.[10,11]

The aim of this study was to quantitatively analyze and compare the surface characteristics and roughness of the slot floors of three types of modern plastic brackets: glass fiber-reinforced polycarbonate, filler-reinforced polycarbonate, and hybrid polymer. The roughness was related to the static frictional force against the sliding movement of an archwire (stainless steel) when measured in vitro. We used scanning electron microscope (SEM) and 3D optical surface profiling.

MATERIALS AND METHODS

Brackets and Wires

We included two control groups: one used a stainless steel bracket (MicroArch, Tomy, Tokyo, Japan) and the other a monocrystalline ceramic bracket (Inspire Ice, Ormco, Glendora, Calif). We analyzed three test groups of different types of 0.022-in slot, Roth prescription, plastic, maxillary right central incisor brackets; it was easy to experiment because the maxillary central incisor bracket is larger than other brackets. The test bracket materials included glass fiber-reinforced polycarbonate (Image, Gestenco International, Gothenburg, Sweden), filler-reinforced polycarbonate (Silkon M, American Orthodontics, Sheboygan, Wis), and hybrid polymer composed of polycarbonate and polyethylene terephthalate with an inserted metal slot (Esther MB, Tomy). A total of eight brackets were tested in each group (Table 1). For all tests, the archwire was made of stainless steel (Ormco) with dimensions of 0.019×0.025 in. A total of 40 archwire segments of each wire were used.

SEM Analysis

To characterize the surface morphology of the brackets before and after sliding the archwires, the brackets were processed for SEM analysis. Brackets were coated with platinum with anion sputter (IB-3, Eiko Engineering, Ibataki, Japan) at 6 mA for 6 minutes. The slot floor surface between upper and lower wings was then examined and photographed with a Hitachi S3000N SEM (Hitachi, Tokyo, Japan) at a 20 kV acceleration voltage and $\times$1000 magnification.

3D Optical Profiler Analysis

Each of the brackets was prepared by cutting the wings using a fine diamond disk. The bracket slot floor roughness was analyzed with a 3D optical surface profiler (NewView 6300, Zygo Corp, Middlefield, Conn). The profiler was based on noncontact scanning and white light interferometry. This method allowed a quantitative analysis of the change in surface roughness and morphology of the slot floors of the plastic brackets after in vitro archwire sliding movements. The profiler was operated in the vertical shift interference mode with a 300-μm scan length at $\times$20 magnification (360×270 μm sampling area). The 3D interferograms of the specimens were recorded, and two surface-roughness parameters were investigated: the average roughness (Ra) and the root mean square (RMS). Ra represented the average of the z-axis height values and could be considered the most common parameter. RMS represented the root mean square value of the z-axis height; this calculation had the advantage of mathematical convenience.

Archwire Sliding Test

The archwire sliding test was performed with a universal testing machine (Universal Testing Machine, Instron R 3366, Instron Corp, Norwood, Mass) at 30°C in the dry state (Figure 1). A total of 40 bracket-wire combinations were carried out at 0° angulation. The

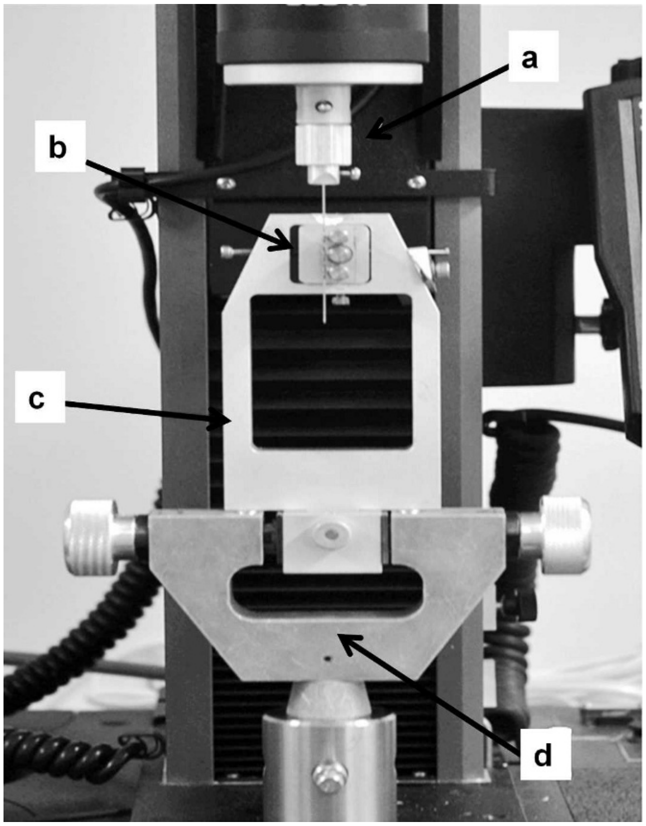

Figure 1. Testing machine, bracket-wire assembly, and static friction force measuring equipment. (a) Rotation fixture; (b) Aluminum block; (c) Anterior-posterior adjustable block; (d) Anterior-posterior adjusting handle.

archwire was attached to the bracket with an elastic ligature (Ormco); the same person placed all the elastomeric rings immediately before each test to avoid ligature force decay. Before testing, the bracket and archwire were cleaned with 95% alcohol. An experimental model was prepared by bonding brackets to an aluminum plate (20 × 30 × 20 mm) with resin paste (Transbond XT, 3M Unitek, Monrovia, Calif). A line was scribed on the midline of each bar parallel to the long axis to act as a guide for reproducing the bonding position.

The upper end of the wire was connected to the tension-loading cell of a universal testing machine, and the lower end was fixed to a 150-g weight. A rotating fixture, which was connected to the upper end of the wire, was used to facilitate insertion of the wire into the bracket slot without producing any torque. For the sliding test, the archwire was drawn through the bracket with the 500 KgN load cell, at a crosshead speed of 7 mm/min^{-1} over a 10-mm stretch of archwire. A computer program was set to highlight the maximum friction force during the initial movement. The peak values observed in force-distance graphs represented static friction force.

Statistical Analysis

The bracket slot floor surface roughness values are expressed as means and standard deviations or 95% confidence intervals. Statistical analyses were performed with the SPSS 15.0 program (SPSS Inc., Chicago, Ill). Normality of the data was calculated using the Kolmogorov-Smirnov test. A two-tailed Student's *t*-test was used to compare surface roughness values before and after archwire sliding. One-way analysis of variance (ANOVA) was used to compare the mean values between multiple groups. Duncan's multiple range tests were used for post hoc comparisons. The level of statistical significance was set at $\alpha = .05$.

RESULTS

SEM Analysis

SEM showed that all brackets had irregular slot floor surfaces before the archwire sliding test. After the archwire sliding test, bracket slots were scanned at 1000 times the original magnification. After the archwire sliding test, the slot floor surfaces showed numerous scratches, pockmarks, and facets caused by the sliding movements of the archwire (Figure 2).

3D Optical Profiler Analysis

Figure 3 shows the changes in surface roughness parameters and morphology of bracket slot floors before and after the in vitro sliding archwire tests. The 3D topographic images show the characteristic surface features. The surface roughness values (μm) of the as-received brackets were as follows (Table 2): Image (Ra, 1.14; RMS, 1.45), Silkon M (Ra, 0.32; RMS, 0.38), MicroArch (Ra, 0.28; RMS, 0.35), Esther MB (Ra, 0.26; RMS, 0.33), and Inspire ICE (Ra, 0.17; RMS, 0.24). An ANOVA test indicated significant differences among the various groups ($P < .001$), and four brackets showed significant increases in surface roughness parameters after the archwire sliding test: the MicroArch (Ra, 0.49; RMS, 0.62; $P < .01$), Inspire ICE (Ra, 0.37; RMS, 0.45; $P < .01$), Image (Ra, 1.36; RMS, 1.71; $P < .05$), and Silkon M (Ra, 0.51; RMS, 0.65; $P < .01$).

Archwire Sliding Test With Static Friction Force Measurements

The frictional measurements showed a significant bracket effect ($P < .001$; ANOVA). The Inspire ICE (monocrystalline ceramic) bracket had the highest frictional force value, followed by (in decreasing order) the Image, Silkon M, MicroArch, and Esther MB (Table 3). Interestingly, the Inspire ICE bracket was the smoothest but showed the highest frictional values.

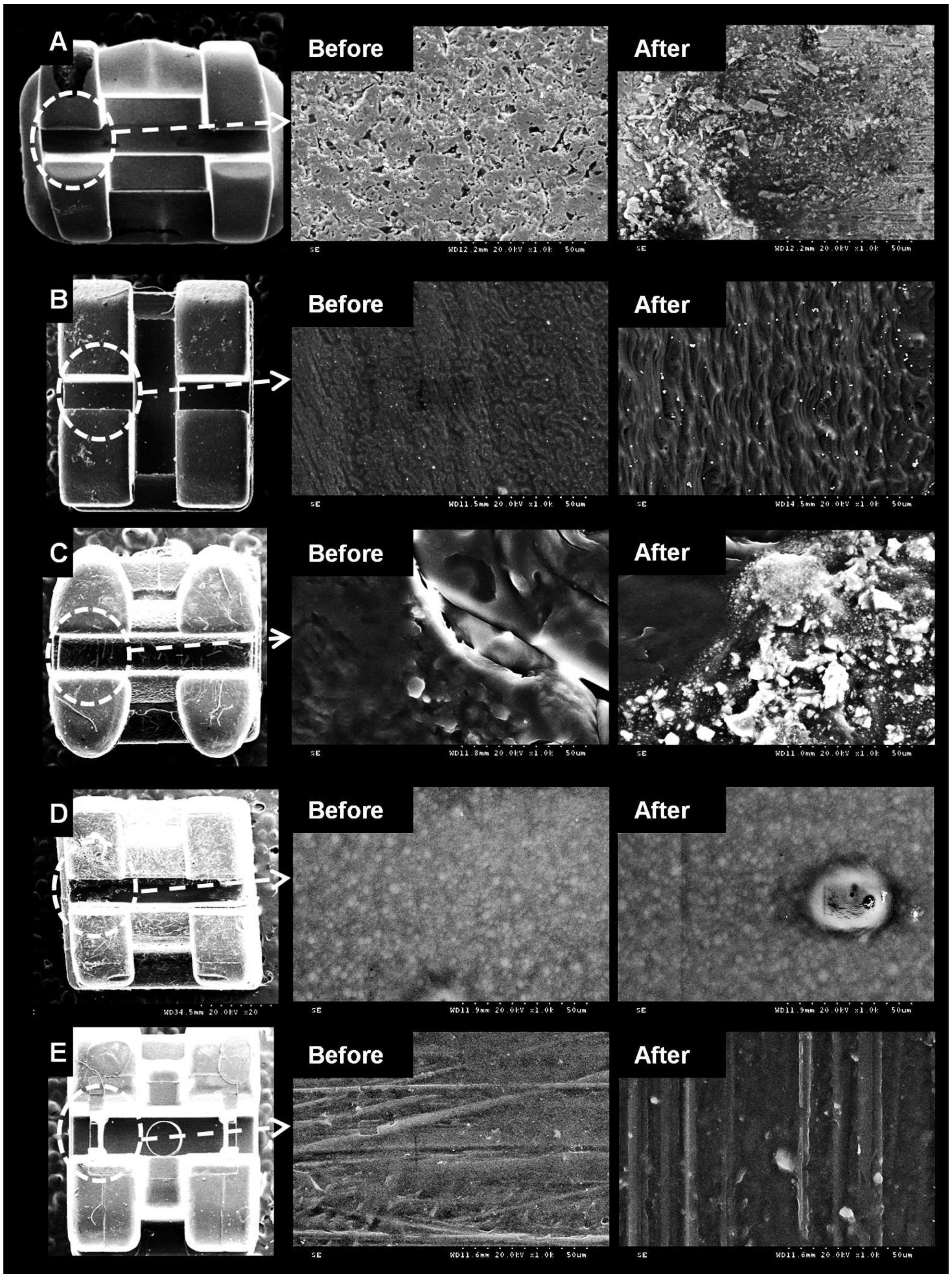

Figure 2. Scanning electron photomicrographs of each bracket slot floor (original magnification ×1000). (A) MicroArch; (B) Inspire ICE; (C) Image; (D) Silkon M; (E) Esther MB.

The Image and Silkon M brackets exhibited significantly higher static frictional values than the Esther MB and MicroArch brackets.

DISCUSSION

Polycarbonate brackets were first manufactured in the 1970s but exhibited many problems. These problems included tie wing fractures, slot distortion due to lack of strength and stiffness, increased slot roughness, and bracket staining.[4,12]

Recently, polycarbonate brackets have been reinforced with ceramic fillers and/or metal slots to compensate for the lack of strength and rigidity. Currently, both polycarbonate fiber-reinforced and filler-reinforced brackets are available.

In previous studies, edgewise metal brackets produced more friction than unfilled plastic brackets when tied with elastomeric ligatures.[13,14] This was because the unfilled plastic bracket did not have the hardness and wear resistance of metal brackets. Our results

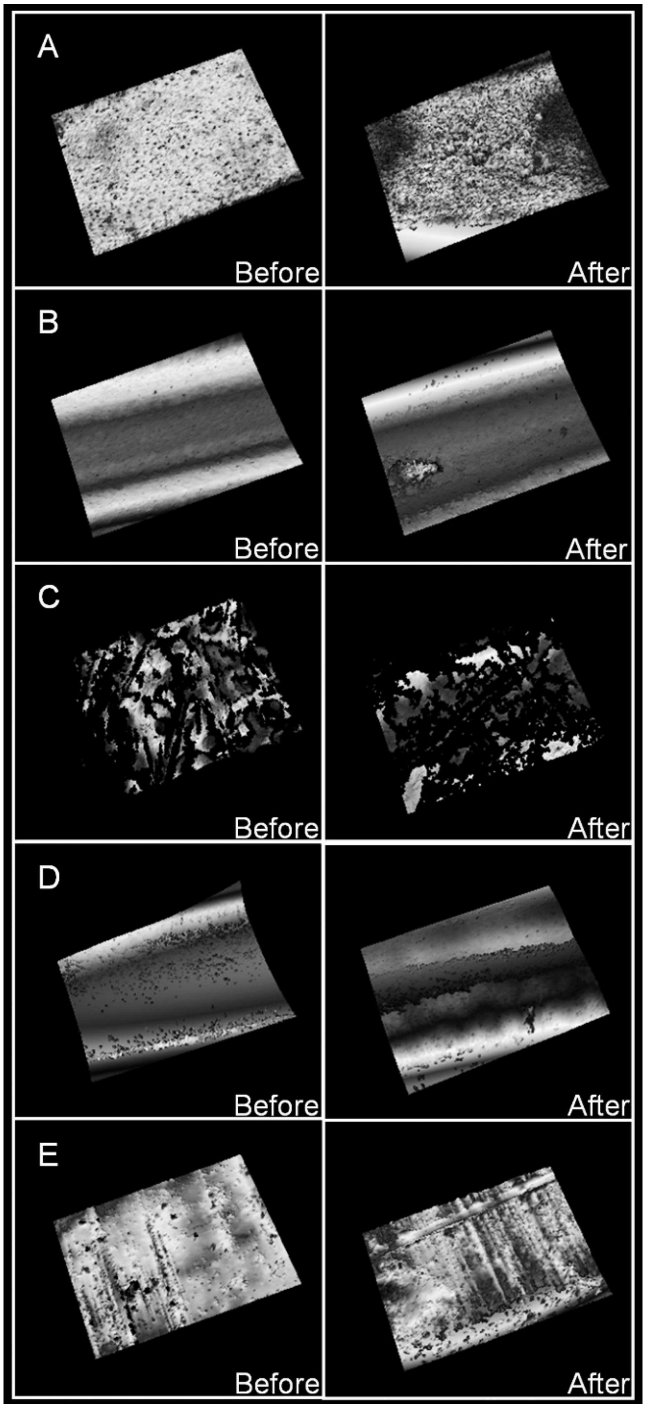

Figure 3. 3D interferograms of each bracket slot floor (×20 magnification). (A) MicroArch; (B) Inspire ICE; (C) Image; (D) Silkon M; (E) Esther MB.

showed that fiber- or filler-reinforced plastic brackets (Image and Silkon M) had significantly higher static frictional values than stainless steel brackets (MicroArch) or metal slot inserted plastic brackets (Esther MB). The 3D optical surface profiler revealed that Image brackets had significantly higher roughness values than other brackets, both before and after archwire slide testing. The Image bracket is made of polycarbonate reinforced with glass fiber. Fiber-reinforced composites consist of a polymer matrix embedded with reinforcing fibers. It has been shown that mechanical properties are improved through reinforcement with Ca-Al-silicate glass fibers oriented parallel to the slot length; this product withstands the force pattern more effectively than other reinforcement fibers, such as polyethylene.[12,15] However, the glass fibers increase the surface roughness compared to other fibers with lower surface energy.[16] In a static frictional force measurement, the Image bracket showed higher frictional values compared with other plastic brackets and metal brackets, despite the improved mechanical properties of hardness and wear resistance with glass fiber reinforcement.

Similarly, the Silkon M bracket (polycarbonate reinforced with SiO_2 filler) showed improved fracture toughness and fracture strength compared with unfilled plastic brackets.[6] We found that the slot surface roughness of the Silkon M bracket was lower than that of the Image bracket, but the static frictional force values were not significantly different.

In the as-received condition, the Inspire ICE (monocrystalline ceramic) bracket in the control group showed significantly lower surface roughness values and higher frictional values during the archwire sliding test than the other brackets. Lee et al.[17] reported that monocrystalline ceramic brackets were significantly smoother than polycrystalline alumina brackets. Matasa et al.[18] showed that ceramic brackets were harder than stainless steel brackets, correlating with higher frictional resistance. Although the Inspire ICE bracket surface was smoother than those of the other brackets, previous studies[19–21] suggested that high frictional values could be produced by sharp, hard edges created at the intersection of the floor and walls of the slot with the external surface of the bracket. Additionally, the chemical characteristics of alumina on a ceramic surface can cause the metal wire to adhere to the alumina surface.[19,22]

Both before and after archwire slide testing, the Esther MB bracket (metal slot inserted into composite polycarbonate and polyethylene terephthalate) showed relatively lower surface roughness and frictional values than the MicroArch bracket (stainless steel) in the control group. Esther MB bracket slots also showed lower surface roughness values and frictional resistance than fiber- reinforced and filler-reinforced plastic brackets. The Esther MB bracket slots were made of austenite stainless steel, which is commonly used in orthodontic appliances, to effectively transfer torque onto the teeth. After the archwire sliding test, the surface roughness values of the Esther MB bracket slots showed relatively small changes

Table 2. Surface Roughness Values Measured by 3D Optical Profiler (μm) Expressed as Roughness Average (Ra) and Root Mean Square (RMS)[a]

		Before Archwire Sliding						After Archwire Sliding					
		Ra			RMS			Ra			RMS		
			95% CI[b]			95% CI			95% CI			95% CI	
Bracket	n	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
MicroArch	8	0.28[B]	0.23	0.33	0.35[B]	0.34	0.36	0.49[B**]	0.42	0.55	0.62[B**]	0.53	0.71
Inspire ICE	8	0.17[A]	0.13	0.21	0.24[A]	0.19	0.28	0.37[A**]	0.28	0.45	0.45[A**]	0.34	0.56
Image	8	1.14[C]	0.97	1.32	1.45[C]	1.24	1.72	1.36[C*]	1	1.72	1.71[C*]	1.24	2.18
Silkon M	8	0.32[B]	0.3	0.35	0.38[B]	0.31	0.44	0.51[B**]	0.36	0.67	0.65[B**]	0.51	0.79
Esther MB	8	0.26[B]	0.12	0.39	0.33[B]	0.17	0.49	0.3[A]	0.2	0.39	0.38[A]	0.26	0.49

[a] The same uppercase letters indicate no statistically significant difference between the groups ($P > .05$). Increasing group mean values were expressed in ascending alphabetical order.
[b] CI indicates confidence interval; Min, minimum; Max, maximum.
* $P < .05$, ** $P < .01$ (before vs after archwire sliding test).

compared with the other brackets. In fact, simply having low slot floor surface roughness does not indicate the enhancement of efficiency of orthodontic treatment because the surface roughness is just one of many factors associated with frictional resistance. However, it is obvious that the metallic slot type brackets, such as the Esther MB, have improved mechanical and structural stability among plastic brackets.

All the brackets, regardless of material composition, showed increased slot floor surface roughness after the archwire sliding test compared with the as-received condition. These increases in surface roughness values were significant for the MicroArch, Inspire ICE, Image, and Silkon M brackets.

The focus of this in vitro study was the friction and scratching caused by the sliding movement of the archwire through the bracket slots. However, the clinical performance of brackets also depends on diverse synergistic effects, including corrosion from saliva, mouth-washing solutions, and galvanic corrosion between two materials. These effects of the oral environment cannot be simulated in an in vitro investigation,[23] and a possible limitation of the present study the small sample size in each group. In vivo studies with a large sample size in each group will be needed to examine the intraoral exposure effects on static frictional force and surface characteristic changes of modern plastic brackets.

Table 3. Static Frictional Force in Grams for the 0.022-Inch Bracket[a]

		Frictional Resistance (g)	
Bracket	n	Mean	SD
MicroArch	8	214.9[A]	13.7
Inspire ICE	8	405.2[C]	47.0
Image	8	311.3[B]	17.0
Silkon M	8	279.7[B]	20.8
Esther MB	8	193.1[A]	26.1

[a] The same uppercase letters indicate no statistically significant difference between the groups ($P > .05$). Increasing group mean values were expressed in ascending alphabetical order.

CONCLUSIONS

- All as-received modern plastic brackets had irregular slot floor surfaces, and both irregularity and roughness increased after the archwire sliding test.
- Glass or filler-reinforced plastic brackets showed higher frictional resistance than the metallic slot–type brackets
- A metal slot inserted into a plastic bracket may be the best choice among plastic brackets for low frictional resistance and to avoid damage from the sliding movements of the archwire.

REFERENCES

1. Rosvall MD, Fields HW, Ziuchkovski J, Rosenstiel SF, Johnston WM. Attractiveness, acceptability, and value of orthodontic appliances. *Am J Orthod Dentofacial Orthop*. 2009;135:276 e1–e12.
2. Eliades T, Brantley WA. The inappropriateness of conventional orthodontic bond strength assessment protocols. *Eur J Orthod*. 2000;22:13–23.
3. Eliades T, Viazis AD, Lekka M. Failure mode analysis of ceramic brackets bonded to enamel. *Am J Orthod Dentofacial Orthop*. 1993;104:21–26.
4. Zinelis S, Eliades T, Eliades G, Makou M, Silikas N. Comparative assessment of the roughness, hardness, and wear resistance of aesthetic bracket materials. *Dent Mater*. 2005;21:890–894.
5. Alkire RG, Bagby MD, Gladwin MA, Kim H. Torsional creep of polycarbonate orthodontic brackets. *Dent Mater*. 1997;13:2–6.
6. Faltermeier A, Rosentritt M, Faltermeier R, Mussig D. Influence of fibre and filler reinforcement of plastic brackets: an in vitro study. *Eur J Orthod*. 2007;29:304–309.
7. Kusy RP, Whitley JQ. Coefficients of friction for arch wires in stainless steel and polycrystalline alumina bracket slots. I.

The dry state. *Am J Orthod Dentofacial Orthop*. 1990;98: 300–312.
8. Kusy RP, Whitley JQ, de Araujo Gurgel J. Comparisons of surface roughnesses and sliding resistances of 6 titanium-based or TMA-type archwires. *Am J Orthod Dentofacial Orthop*. 2004;126:589–603.
9. Angolkar PV, Kapila S, Duncanson MG Jr, Nanda RS. Evaluation of friction between ceramic brackets and orthodontic wires of four alloys. *Am J Orthod Dentofacial Orthop*. 1990;98:499–506.
10. Coelho PG, Marin C, Granato R, Giro G, Suzuki M, Bonfante EA. Biomechanical and histologic evaluation of non-washed resorbable blasting media and alumina-blasted/acid-etched surfaces. *Clin Oral Implants Res*. 2012;23: 132–135.
11. Cehreli ZC, Lakshmipathy M, Yazici R. Effect of different splint removal techniques on the surface roughness of human enamel: a three-dimensional optical profilometry analysis. *Dent Traumatol*. 2008;24:177–182.
12. Ali O, Makou M, Papadopoulos T, Eliades G. Laboratory evaluation of modern plastic brackets. *Eur J Orthod*. 2012; 34:595–602.
13. Bazakidou E, Nanda RS, Duncanson MG Jr, Sinha P. Evaluation of frictional resistance in esthetic brackets. *Am J Orthod Dentofacial Orthop*. 1997;112:138–144.
14. Articolo LC, Kusy RP. Influence of angulation on the resistance to sliding in fixed appliances. *Am J Orthod Dentofacial Orthop*. 1999;115:39–51.
15. Kolbeck C, Rosentritt M, Behr M, Lang R, Handel G. In vitro study of fracture strength and marginal adaptation of polyethylene-fibre-reinforced-composite versus glass-fibre-reinforced-composite fixed partial dentures. *J Oral Rehabil*. 2002;29:668–674.
16. Lassila LV, Garoushi S, Tanner J, Vallittu PK, Soderling E. Adherence of *Streptococcus mutans* to fiber-reinforced filling composite and conventional restorative materials. *Open Dent J*. 2009;3:227–232.
17. Lee GJ, Park KH, Park YG, Park HK. A quantitative AFM analysis of nano-scale surface roughness in various orthodontic brackets. *Micron*. 2010;41:775–782.
18. Matasa CG. Biomaterials in orthodontics. In: *Orthodontics: Current Principles and Techniques.* 3rd Eds: Graber TM, Vanarsdall R. St Louis, Mo: Mosby; 2000:331–332.
19. Saunders CR, Kusy RP. Surface topography and frictional characteristics of ceramic brackets. *Am J Orthod Dentofacial Orthop*. 1994;106:76–87.
20. Khambay B, Millett D, McHugh S. Archwire seating forces produced by different ligation methods and their effect on frictional resistance. *Eur J Orthod*. 2005;27:302–308.
21. Kusy RP, Whitley JQ, Prewitt MJ. Comparison of the frictional coefficients for selected archwire-bracket slot combinations in the dry and wet states. *Angle Orthod*. 1991;61:293–302.
22. Doshi UH, Bhad-Patil WA. Static frictional force and surface roughness of various bracket and wire combinations. *Am J Orthod Dentofacial Orthop*. 2011;139:74–79.
23. Choi S, Park KH, Cheong Y, Kim HK, Park YG, Park HK. Changes in ultrastructure and properties of bracket slots after orthodontic treatment with bicuspid extraction. *Scanning*. 2011;33:25–32.