Friction of calcium phosphate brackets to stainless steel wire

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Objective: Esthetic brackets which resemble the color of natural teeth have been widely used. But the frictional resistance of ceramic brackets, a typical esthetic bracket, is greater than that of metal brackets. The purpose of this study was to measure the frictional resistance of the new calcium phosphate brackets (CPB) which were recently developed and to evaluate its clinical usability by comparing the frictional differences of CPB with metal brackets and metal slot inserted ceramic brackets. **Methods:** Experimental groups were CPB (Hyaline II, Tomy, Tokyo, Japan), metal bracket (Kosaka, Tomy, Tokyo, Japan) and metal slot inserted ceramic bracket (Clarity, 3M Unitek, Monrovia, CA, USA). All of the brackets had 0.022-inch slot sizes. The brackets were tested with 0.019 x 0.025 inch stainless steel wire (3M Unitek, Monrovia, CA, USA). A biologic model was used to simulate the situation which would occur during orthodontic treatment with fixed appliances. Retraction force was applied at a speed of 5 mm/min for 30 seconds. The frictional resistance was measured on a universal testing machine (Instron 4467, Instron, Norwood, MA, USA). **Results:** CPB showed significantly higher friction than metal brackets ($p < 0.05$) and lower friction than metal slot inserted ceramic brackets ($p < 0.01$). **Conclusions:** CPB can be considered to be a useful orthodontic esthetic bracket with respect to frictional resistance, as its friction is remarkably lower than that of metal slot inserted ceramic brackets. **(Korean J Orthod 2007;37(5):376-85)**

Key words: Frictional resistance, Calcium phosphate bracket, Simulated biological model

INTRODUCTION

One of the main purposes of orthodontic treatment using fixed appliances is esthetic improvement. Conventional metal brackets are generally used, but many patients want to receive orthodontic treatment using invisible appliances. This tendency is becoming more apparent with the increase of adult orthodontic cases. Second-generation brackets were developed using plastic, ceramic, lingual and metal slot inserted ceramic brackets. However, these brackets have some downsides. Plastic brackets have many disadvantages such as discoloration, distortion, falling off, and the possibility of effluence of environmental hormones such as dioxins which have recently raised problems.[1] Ceramic brackets show such disadvantages as abrasion of opposing teeth, archwire damage, fractures because of its brittleness, and high frictional resistance between the bracket and the archwire.[2,3] Lingual brackets are aesthetically appealing but need very delicate control and have clinical limitations.[4] The metal slot inserted ceramic bracket is an improved product over ceramic brackets but still have several of the ceramic brackets'

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Table 1. Orthodontic materials used in this study

Materials	Specification (M - D width)	Stock No.	Manufacturer
Orthodontic bracket	Calcium phosphate bracket (3.55 mm)	159 - 02	HyalineII, Tomy, Tokyo, Japan
	Metal bracket (3.15 mm)	936 - 02	Kosaka, Tomy, Tokyo, Japan
	Ceramic bracket with metal slot (3.57 mm)	6400 - 127	Clarity, 3M Unitek, Monrovia, CA, USA
Orthodontic wire	0.019 x 0.025 inch stainless steel wire	251 - 925	3M Unitek, Monrovia, CA, USA
Ligation	Elastomeric module (0.120 inch)	640 - 0078	Ormco, Glendora, CA, USA

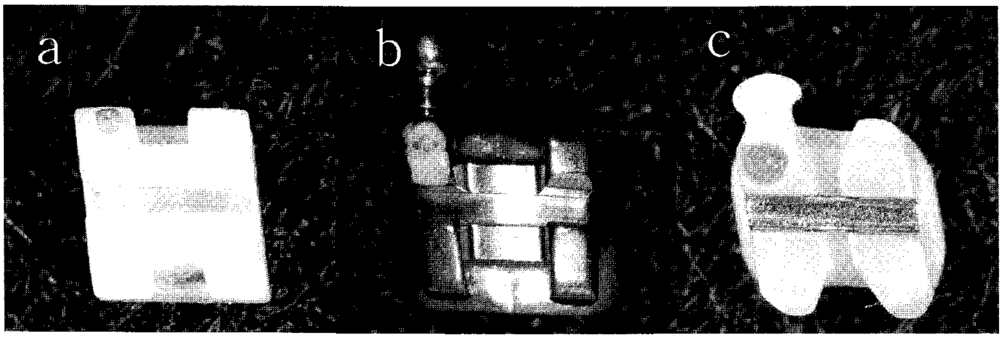

Fig 1. Testing brackets. **a,** Calcium phosphate bracket; **b,** metal bracket; **c,** ceramic bracket with metal slot.

disadvantages and show comparatively higher frictional resistance between the bracket and the archwire than conventional stainless steel metal brackets.[2]

Friction is the resistance to motion when one object moves tangentially against another. For one object to slide against another the applied force must overcome the frictional resistance; higher frictional resistance requires greater orthodontic force.[5] Many variables can affect the frictional resistance between the bracket and the archwire. Factors affecting frictional force between the bracket and the archwire are material, surface roughness, hardness, wire stiffness, geometry, fluid media, and surface chemistry.[6] Orthodontists and manufacturers have tried to reduce frictional resistance by improving and controlling these factors.

For these reasons, the need of a third-generation bracket, a more esthetic, functional and biological bracket has been raised. The calcium phosphate bracket (CPB) was recently developed. CPB (Hyaline II, Tomy, Tokyo, Japan) is made of a new material which is composed of phosphate and calcium, which are the main components of natural teeth. Reliable studies on frictional resistance of CPB to an archwire are rare.

The purpose of this study is to measure the frictional resistance of the CPB and evaluate its clinical usability by comparing the frictional differences of CPB with those of metal bracket and metal slot inserted ceramic brackets.

MATERIAL AND METHODS

Material

Three kinds of brackets were used in this study (Fig 1 and Table 1). CPB (Hyaline II, Tomy, Tokyo, Japan) with a 0.022-inch slot size was used for the experimental group. Metal brackets (Kosaka, Tomy, Tokyo, Japan) and metal slot inserted ceramic brackets (Clarity, 3M Unitek, Monrovia, CA, USA) with the same slot size were used for the control groups. All of

Table 2. Elastic modulus (kg/mm^2) of the periodontium and materials used in this study

	Elastic modulus	Elastic modulus	Manufacturer
Periodontium	Periodontal ligament	6.8×10^{-2}	·
	Cancellous bone	70.41	·
Materials	Polyether impression material	7×10^{-2}	ESPE, Seefeld, Germany
	Blue inlay wax	76.04	Shofu, Osaka, Japan

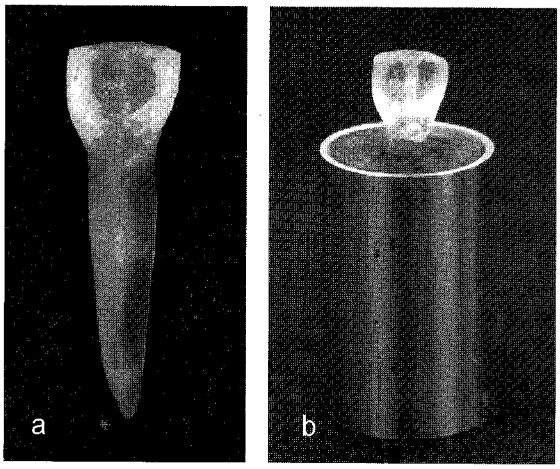

Fig 2. Fabrication of simulated biological model. **a,** Resin duplication of upper canine; **b,** fabrication of biological model was completed by implantation of tooth-PDL replica in alveolar bone substitute composed by inlay wax.

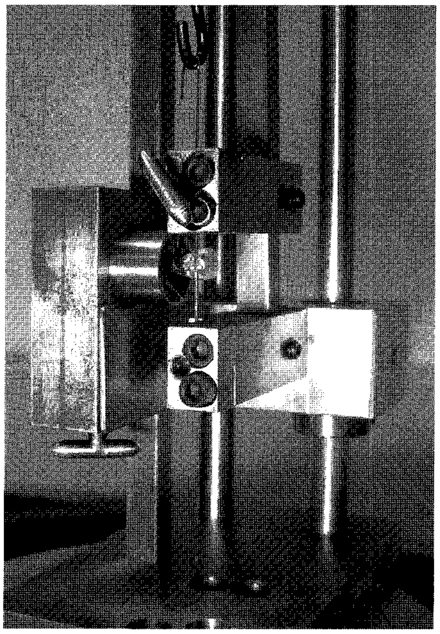

Fig 3. The testing device in this study. The distance of the posts to insert the archwire was fixed in 20.0 mm to imitate the distance between distal side of the bracket of the lateral incisor and mesial side of the bracket of the second premolar.

them were upper canine brackets. The mesiodistal width of all three types of brackets are also shown in Table 1. Elastomeric modules (Ormco, Glendora, CA, USA) were used to give a constant ligation force.[7]

Methods

Set-up of bracket and archwire

A simulated biological model was manufactured. Natural upper canine was selected and corrected to meet the report of Ash[8] in the shape of the upper canine. Incisal and labial sides of the teeth were trimmed to facilitate the bonding of testing brackets in a standardized position. Corrected tooth was duplicated with resin. The duplicated resin tooth was covered with polyether impression material (Impregum F, ESPE, Seefeld, Germany) which has a similar elastic modulus to periodontal ligament in a real thickness of 0.25 ± 0.1.[8] The prepared tooth was implanted in a stainless steel cylinder filled with a blue inlay wax (Shofu, Kyoto, Japan) which has a similar elastic modulus to alveolar bone (Fig 2 and Table 2).

The measuring device used in this study was improved from the testing device of Pizzoni et al.[9] (Fig 3). The device was comprised largely of two parts. One fixed the archwire and the other fixed the simulated

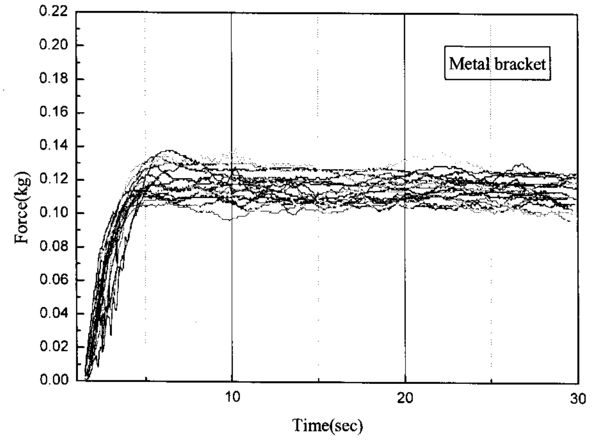

Fig 4. Frictional force level versus time in metal brackets. The frictional forces between brackets and archwires increased gradually and reached constant level of plateau.

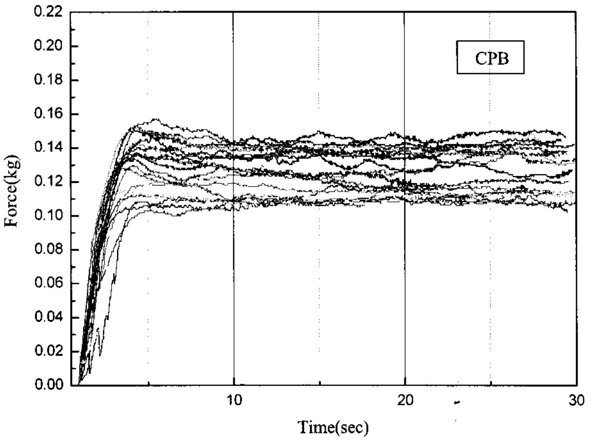

Fig 5. Frictional force level versus time in calcium phosphate brackets. The constant levels of the frictional forces showed mild oscillating motion likewise in metal brackets.

biological model. The first part was comprised of two aluminum posts with two ball bearings made to run on two vertical parallel rods. The distance of the posts for insertion of the archwire was controllable and fixed at 20.0 mm. This was to imitate the distance between the distal side of the bracket of the lateral incisor and the mesial side of the bracket of the second premolar in case of extraction of the first premolar. The posts had holes that were the same size as 0.022 x 0.028 inch slot tubes. The second part comprised of an aluminum carriage opposing the aluminum posts. It had a circular hole to fix the simulated biological model. The mesial side of the bracket bonded to the prepared duplicated tooth had a fixed distance of 6.0 mm from the post which was considered to be the bracket of the lateral incisor.

The simulated biological model had a fixed position. The bracket to be tested was bonded with a light cured resin (Transbond XT, 3M Unitek, Monrovia, CA, USA) through a 0.022 x 0.028 inch stainless steel wire and a passive bonding procedure. A 0.019 x 0.025 inch stainless steel archwire was inserted through the holes in the aluminum posts and bonded bracket. Elastomeric modules were used to ligate the bracket just before each test.

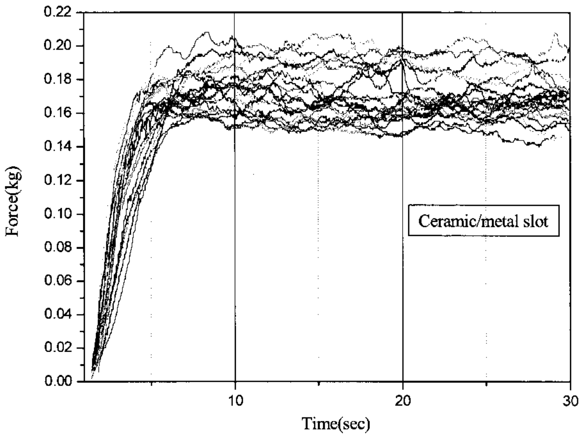

Fig 6. Frictional force level versus time in metal slot inserted ceramic brackets. The constant levels of the frictional forces showed severe oscillating motion.

Measurement of frictional force

The frictional force was measured using a universal testing machine (Instron4467, Instron, Norwood, MA, USA) attached to a load cell (Push & pull gauge, RX-2 AIKOH, Osaka, Japan). Data was transmitted to computer program (Origin, Northampton, MA, USA) and recorded. The test was run at a speed of 5 mm/min for 30 seconds and three times on each bracket. 10 brackets from each group were tested. The tested archwire was changed after testing of each bracket three

Table 3. The mean and standard deviation (gm) of frictional force of each bracket

Metal bracket	Calcium phosphate bracket	Ceramic bracket with metal slot	Sig
Mean ± SD	Mean ± SD	Mean ± SD	
115.4 ± 6.6	123.4 ± 13.0	171.8 ± 14.2	
√	√		*
	√	√	†
√		√	†

Significant difference between cheked, $^*p < 0.05$, $^†p < 0.01$ between checked cells.

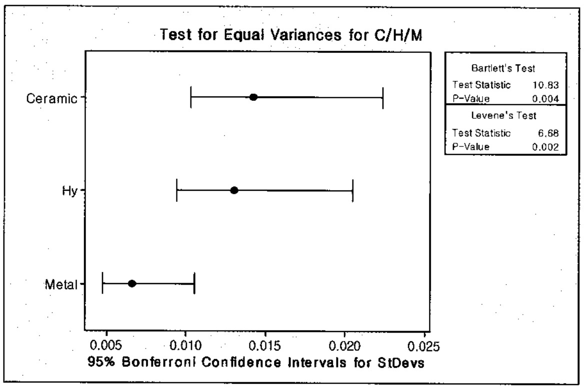

Fig 7. Test for equal variance for metal slot inserted ceramic bracket, CPB, and metal bracket. The testing values could not be said to show equal variance ($p < 0.05$).

times. Static and kinetic frictional forces were not classified, based on the assertion made by Drescher et al.[10] that static and kinetic friction are generated simultaneously. The test was made at room temperature and in a dry state.

Constant frictional force was usually recorded after 5 seconds, the mean and standard deviation were calculated from 10 to 25 seconds in each group. 2-sample *t*-test was used to compare the means of the tested groups at a significance level of 0.05.

Additional experiments

To examine the surface texture and structural differences of each bracket, random samples of three types of brackets and enamel of extracted natural tooth were submitted to scanning electronic micrography (S-2300, Hitachi, Tokyo, Japan).

RESULTS

Raw data showing the changing frictional force level depending on time are plotted in Figs 4 - 6. The frictional forces between brackets and archwires increased gradually and reached a plateau. The constant levels of the frictional force were not flat but show oscillating motion. The mean values and standard deviations are shown in Table 3.

For statistical analyses, 2 sample *t*-tests were used to compare the differences of the frictional force of the tested brackets. ANOVA was not used because test values did not satisfy ANOVA assumptions of independency, normality and equal variance. In Bartlett's test for equal variance, tested groups did not show equal variance because the *p* value was lower than 0.05 (Fig 7), despite all tested groups showing normal distribution because their respective *p* values were higher than 0.05 in the normality test.

Frictional resistance increased in order of metal bracket, CPB and metal slot inserted ceramic bracket. The frictional force level of the metal slot inserted ceramic bracket was significantly higher than that of the metal bracket and CPB ($p < 0.01$) (Table 3). The frictional force level of CPB was significantly higher than that of the metal bracket ($p < 0.05$) (Table 3).

Roughness increased in the following order; metal bracket, CPB and metal slot inserted ceramic bracket, as seen in Fig 8. CPB has a fine microstructure similar to enamel where columnar calcium phosphate crystals get intertwined (Fig 9).

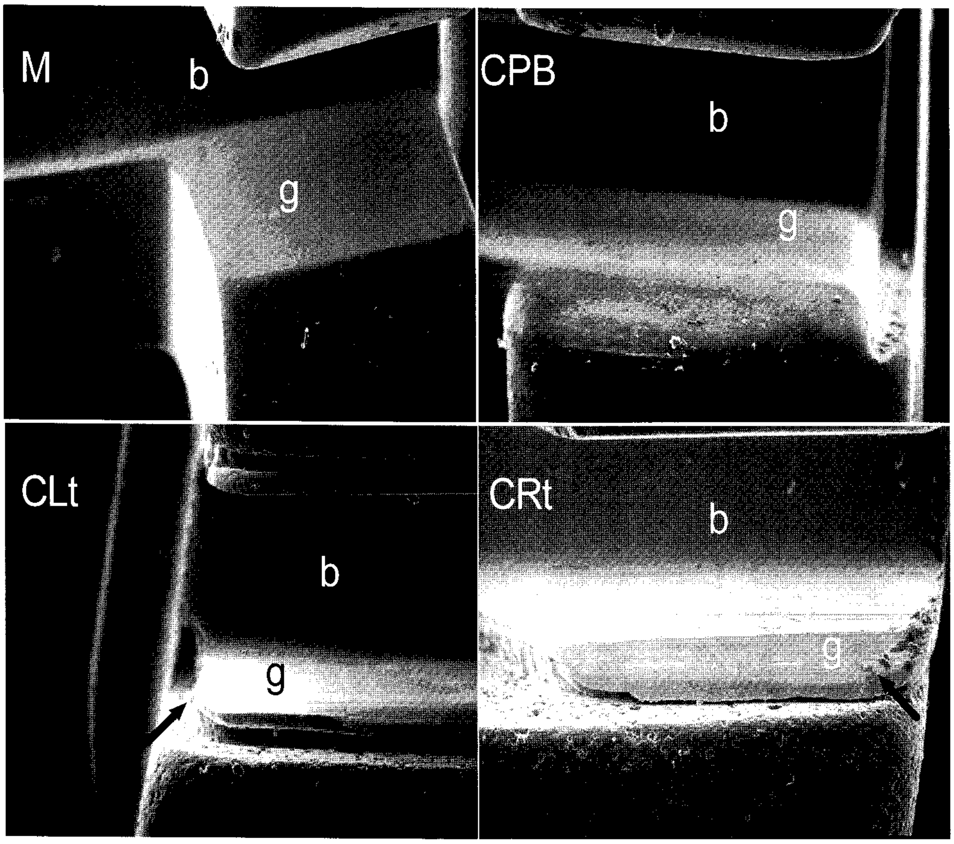

Fig 8. Scanning electron micrographs (× 60): **M,** metal bracket; **CPB,** calcium phosphate bracket; **CLt,** left side of a metal slot inserted ceramic bracket; **CRt,** right side of a metal slot inserted ceramic bracket; *b,* base side of a slot; *g,* gingival side of a slot. Marks of arrow indicate different shape of edge of metal slot on one bracket.

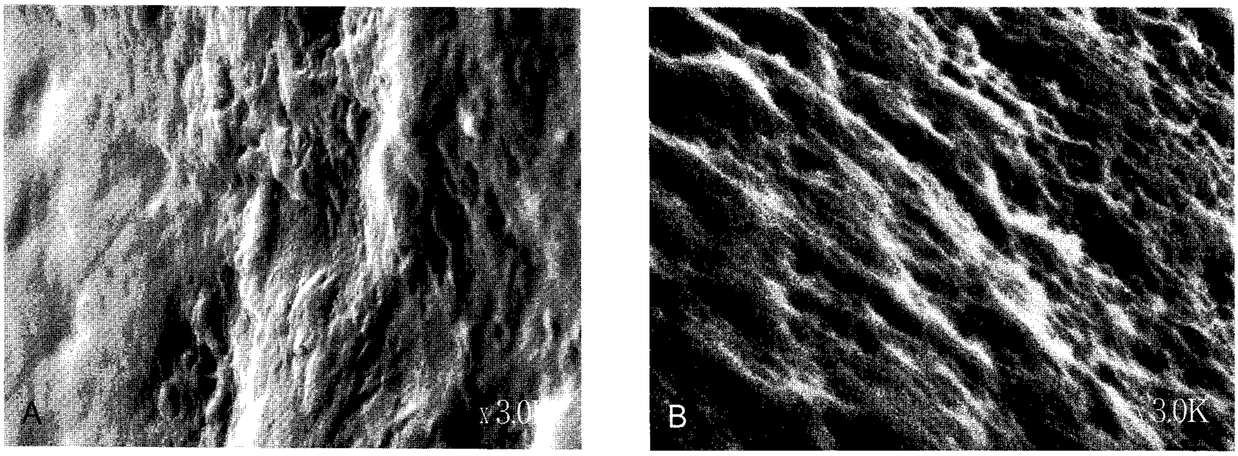

Fig 9. Scanning electron micrographs (× 3000): **A,** natural enamel; **B,** CPB.

DISCUSSION

During the sliding mechanics, the frictional resistance factor is an important counterforce to orthodontic tooth movement. The proper magnitude of force during orthodontic treatment will result in an optimal tissue response and rapid tooth movement. Therefore, an understanding of the forces required to overcome friction is important so that the appropriate magnitude of force can be used to produce an optimal biological tooth movement.[11] To understand optimal orthodontic forces, several effecting variables must be studied.

Over any other variables, the experimental method is the most important effecting factor. There have been many reports on frictional resistance between brackets and archwires using variable methods. Frictional resistance levels have shown a wide range of distribution depending on measuring methods. These methods can be classified into four main groups.

The first method allows archwires to slide through the contact flat, limiting the investigation to the influence of the material only.[12,13]

In the second method, archwires are allowed to slide through brackets parallel to the bracket slot, allowing research into the influence of the material, bracket design, wire dimension, impact of saliva and different types of ligation.[14-23]

The third method allows the archwires to slide through the bracket with different second and third order angulation.[3,24-27]

Most experimental studies on orthodontic frictional resistance have used models where archwires were pulled through the slot of brackets bonded to simulated teeth that were mounted in a fixed medium. However, such models did not permit the initial tipping of the teeth until contact was established between the archwire and the bracket corners and did not require ligation to prevent rotation. Differences in results among such studies may therefore reflect differences in the method error due to inaccurate mounting of the models in the testing machine, and differences in the normal force through differences in ligation tightness, rather than differences in frictional coefficients.

Recently, designs were developed to simulate the impact of the biological resistance to tooth movement.[11,28,29] These can simulate tipping and uprighting movements of natural teeth when orthodontic wire is pulled and slid in a bracket slot. In this study, such an improved biological model was used. In Figs 4-6, constant levels of the frictional force showed a cyclic oscillating motion. It seemed that the reason for this phenomenon is that the used testing model simulated tipping and uprighting movement of a natural tooth.

When selecting a new orthodontic material, it is important that it should be submitted to testing to help understand the physical properties, allowing for comparison with known materials. In this study, a new material, CPB (Hyaline II) and two known brackets were tested with 0.019 x 0.025 inch stainless steel archwires in frictional resistance.

The second effecting factor is the archwire; its dimension, shape and size, composition, surface texture, elastic properties, and abrasive wear resistance.[10,11,14,25] It was excluded by simplification to one type of 0.019 x 0.025 inch stainless steel archwire which is commonly used in sliding mechanics.

The third effecting factor is ligation[30,31]; the force and ligation type. Ligation between bracket and archwire could influence the frictional resistance level. An interaction between ligation with elastomeric modules and the bracket may contribute to the explanation of the different results on the friction of brackets according to their dimensions. On the other hand, the frictional force used through stainless steel ligature varies also according to how the experiment is carried out by different authors. It was assumed that the relationship between elastomeric modules or stainless steel ligature and frictional force could not be defined. We suggest further research is required to understand the effects of ligation. In this study, only the relative force was evaluated.

The fourth effecting factor is the dimension of the bracket.[2,25] Although some authors state that frictional force does not depend on the contact area between the bracket and the archwire,[32] others believe that this interferes with the frictional force.[10,25,32] Larger brackets could offer more contact area between the surfaces, creating more attrition components and increasing frictional force. On the other hand, narrower brackets could lead to a larger dental inclination, the angulation between the bracket and the archwire would be increased, offering attrition between the surfaces. Thus the relationship between the dimension of a bracket and frictional force could not be defined.

The fifth effecting factor is surface texture and manufacturing qualities of the bracket.[18,33-37] Three kinds of brackets and enamel of natural tooth were submitted to scanning electron micrography to evaluate the surface morphology. The stainless steel metal bracket showed the smoothest surface texture and had the lowest and statistically most significant frictional force value, maybe because the characteristic of the metal allows better polishing and smoother surfaces (Fig 8). The difference of frictional force values between the metal slot inserted ceramic brackets and the stainless steel metal brackets can be due to the difficulty in adjusting the metal slot to the ceramic body and their different expansion coefficients.[2,3] The metal slot inserted ceramic brackets combine the esthetic advantages of ceramic and functional advantages of metal brackets. However, not only is there a gap between the ceramic and metal slot, but also different shaped edges were observed in one bracket when this bracket was submitted to scanning electron micrography (Fig 8, *CLt, CRt*). Because of this uneven structural defaults, it is assumed that the plateau level of the frictional force of the metal slot inserted ceramic bracket showed severe fluctuating motion and higher frictional levels as compared with those of metal brackets and CPB. CPB had a rougher surface texture than metal brackets. But, it showed a comparatively smooth and even surface texture and rounded edges and had fine micro structures similar to enamel where columnar calcium phosphate crystals get interwined (Figs 8, *CPB* and 9). For these reasons, even though CPB showed higher frictional force levels than metal brackets, it showed a mild oscillating motion similar to metal brackets, and lower frictional levels as compared with those of metal slot inserted ceramic brackets (Figs 4-6).

In vitro studies do not correspond to what really happens during tooth movement. Therefore readers must be careful when evaluating the results from this study. The recorded values should be used to compare the relative frictional resistance of the different kinds of brackets.

CONCLUSIONS

The frictional resistance of CPB (HyalineII, Tomy, Tokyo, Japan), metal brackets (Kosaka, Tomy, Tokyo, Japan) and metal slot inserted ceramic brackets (Clarity, 3M Unitek, Monrovia, CA, USA) were tested with 0.019 x 0.025 inch stainless steel archwires under simulated clinical conditions.

Frictional resistance was increased in the following order; metal bracket, CPB, and metal slot inserted ceramic bracket. CPB is considered to be a useful orthodontic esthetic bracket with respect to frictional resistance because its friction is remarkably lower than that of metal slot inserted ceramic brackets.

Additional studies regarding hardness, bonding and debonding strength of CPB, are necessary to adjust CPB for clinical use.

- 국문초록 -

인산칼슘재 브라켓과 강선사이의 마찰저항에 관한 연구

주효진·박영국

고정성 장치를 이용한 교정 치료는 심미적 개선이 주목적 중 하나이나, 금속재 브라켓은 치료기간 동안 비심미적으로 보이는 단점이 있다. 이러한 이유로 치아색과 유사한 심미적 브라켓이 선호되었으나 호선과의 마찰저항이 금속재 브라켓보다 큰 것으로 알려져 있다. 본 연구는 최근 개발된 심미적 브라켓의 일종인 인산칼슘재 브라켓의 마찰저항을 측정하고 기존 금속재 브라켓과 금속슬롯 삽입형 도재 브라켓과의 마찰저항의 차이를 구명(究明)해 보고자 하였다. 실험군으로서 인산칼슘 재질의 Hyaline II (Tomy, Tokyo, Japan) 브라켓을, 대조군으로서 metal slot이 삽입된 도자기 재질인 Clarity (3M Unitek, Monrovia, CA, USA) 브라켓과 스테인레스 스틸 금속재 브라켓인 Kosaka (Tomy, Tokyo, Japan) 브라켓을 사용하고, 0.019 × 0.025 인치 스테인레스 스틸 강선 (3M Unitek, Monrovia, CA, USA)을 이용하며 결찰재는 합성고무링 (Ormco, Glendora, CA, USA)을 사용하였다. 치아의 생리학적 환경을 재현하기 위해 모의 생물학적 모형을 고안하였으며 이에 강선을 삽입하여 load cell (Push & pull gauge, RX-2 AIKOH, Osaka, Japan)로 분당 5

mm로 견인하며 만능시험기(Instron4467, Instron, Norwood, MA, USA)로 마찰저항을 측정하였다. 실험결과, 실험군인 인산칼슘 재질 브라켓의 마찰저항은 대조군인 금속슬롯 삽입형 도재 브라켓 보다 작고 ($p < 0.01$) 금속재 브라켓의 마찰저항보다 크게 나타나 ($p < 0.05$), 인산칼슘재 브라켓은 심미적 측면에서 금속재 브라켓을, 효율적 측면에서 금속슬롯 삽입형 도재 브라켓을 대체하여 사용 가능함을 시사하였다.

주요 단어: 마찰저항, 인산칼슘재 브라켓, 모의 생물학적 모형

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