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The effect of bracket width on frictional force between bracket and arch wire during sliding tooth movement

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Frictional force between the orthodontic bracket and arch wire during sliding tooth movement is related to many factors, such as the size, shape and material of both the bracket and wire, ligation method and the angle formed between the bracket and wire. There have been clear conclusions drawn in regard to most of these factors, but as to the effect of bracket width on frictional force there are only conflicting studies.

This study was designed to investigate the effect of bracket width on the amount of frictional forces generated during clinically simulated tooth movement. Three different widths of brackets (0.018x0.025"standard), narrow (2.40mm), medium (3.00mm) and wide (4.25mm) were used in tandem with 0.016x0.022" stainless steel wire. Three bracket-arch wire combinations were drawn on for 4 minutes on a testing apparatus with a head speed of 0.5mm/min and tested 7 times each. To reproduce biological conditions, dentoalveolar models were designed with indirect technique using a material with similar elastic properties as periodontal ligament (PDL). In addition, to minimize the effect of ligation force, elastomer was used with added resin, which was attached to the bracket to make up for the discrepancies of bracket width.

The results were as follows:

1. Maximum frictional force for each bracket-arch wire combination was:
   Narrow (2.40mm) : 68.09 ±4.69 gmf
   Medium (3.00mm) : 72.75 ±4.98 gmf
   Wide (4.25mm) : 72.59 ±4.54 gmf
2. Frictional force was increased with more displacement of wire through the bracket slot.
3. The ANOVA post-hoc test showed that the bracket width had no significant effect on frictional force when tested under clinically simulated conditions ($P>0.05$).

Key words : Bracket width, Frictional force

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Canine retraction and space closure during orthodontic treatment with sliding mechanics involve a displacement of wire through the bracket slots. In the sliding movement of a tooth, frictional force is generated at the contact area between the bracket and the arch wire interface. During such a procedure, tooth movement occurs only when applied forces overcome friction at the bracket-wire interface. Therefore, high levels of bracket-wire friction may result in binding of the bracket followed by little or no tooth movement. Several variables have been found to affect the levels of friction between bracket and wire. These variables are either mechanical variables such as bracket material[1-9], slot size[2,10], bracket width[1,13,14] and angulation[13-16], wire shape[2,10], wire size and wire material[1-9] as well as ligature material and force of ligation[17-19], or biologic variables such as saliva [25], plaque and corrosion during treatment. Among these, the effect of mesiodistal bracket width on the frictional force has not been fully investigated. Athough there were a few reports in the literature, including Frank and Nikoli(1980)[1] and Tidy(1989)[12] , there was conflict within their experimental results.

Therefore, the purpose of this study was to obtain data on frictional force during the retraction movement of canines under simulated clinical conditions, and in particular, to investigate the resultant effect of bracket width. Additional aims were to analyze how frictional force changes as the wire displaces through the bracket slots, and to discover the most appropriate bracket width for canine retraction.

MATERIALS AND METHODS

1. Materials

Bracket-Arch Wire Combinations (Figure1, 2)

Three types of maxillary canine twin brackets with the same slot size were tested (RMO, 0.018 x 0.025 " standard SS), and narrow (2.40mm), medium (3.00mm) and wide (4.25mm) mesiodistal widths of brackets were used. To minimize the effect of ligation force, elastomer was used because steel ligature leads to frictional forces

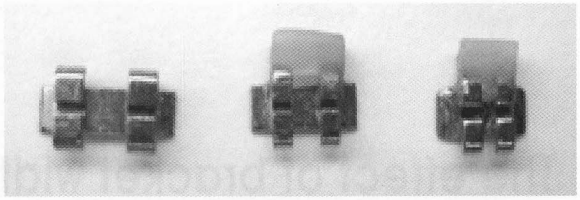


Fig. 1. Three types of standard bracket. Resin was added to medium and narrow bracket.

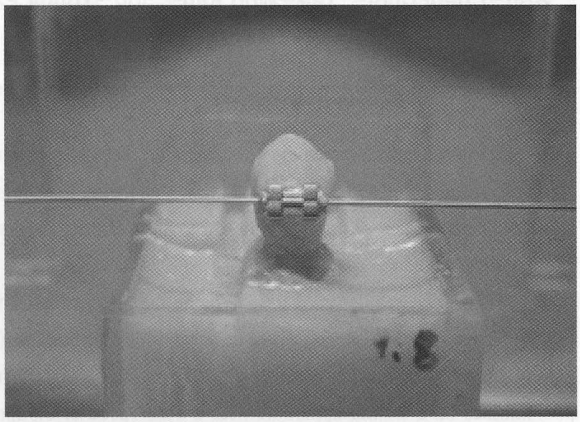
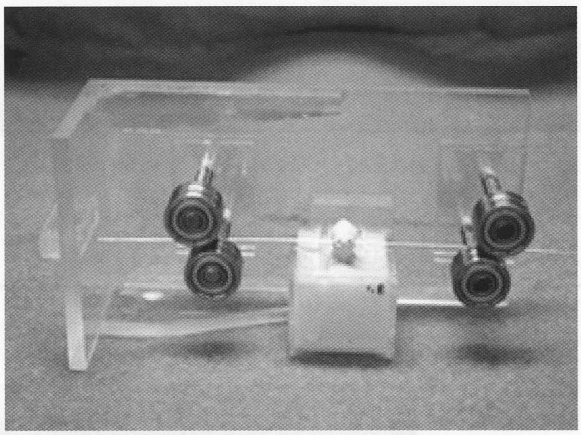


Fig. 2. The wire ligated to bracket with elastomer. Ivorine tooth was inserted into resin block.

that are technician-sensitive. The friction caused by the elastomeric ligature, however, should increase in step with the increasing width of brackets, so bonding resin was attached to the bracket to make up for the discrepancies of width. For the experiment, 0.016x0.022 " stainless steel wire (RMO) was used.

Dentoalveloar model (Figure 2)

An indirect technique was used to reproduce a model of identical width to material with similar elastic properties as periodontal ligament (PDL), and located between the root of an Ivorine maxillary canine (Chokwang Dental, Seoul, Korea) and an acrylic socket. Initially, lead foil of 0.66mm thickness (8 layers taken from occlusal radiograph film) was tightly adapted to the entire canine root surface. This thickness was determined based on the average PDL space in human teeth, which is known to be approximately 0.2mm. Teeth tend to have a functional wider space however, particularly in



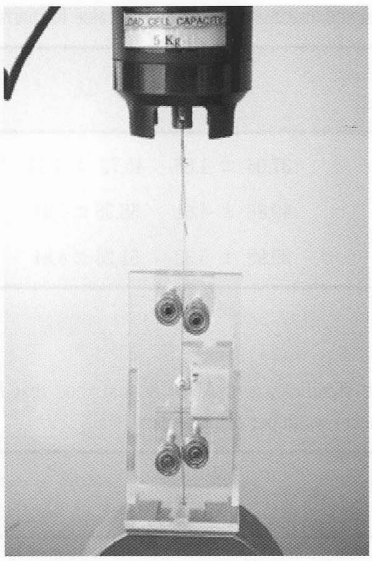


Fig. 3. Frictionless ball bearing piece to permit sliding of the wire(left). The tooth-bearing test device was mounted on Instron and connected with its load cell(right).

the cervical and apical portions. During periods of orthodontic tooth movement, the distance between the root surface and the alveolar socket may double or triple. After lubrication with petroleum jelly, the foil-covered root was inserted into wet acrylic (SNAP, Parkell) poured into the box of the test device and excess acrylic was trimmed upon curing. The foil-covered root was separated from the acrylic socket. After removal of the foil from the canine root and injection of a light body polyvynilsiloxane impression material (Examix, NDS, GC AMERICA Inc., USA) into the acrylic socket, excess material was trimmed on setting. Its elastic modulus was 0.31 MPa.

Test Apparatus (Figure 3)

A device was designed to permit sliding of the straight arch wire. A frictionless ball bearing piece allowed for passive adjustment of the wire rotation to the bracket slot before force was applied. The base of the device allowed attachment to a universal testing machine, Instron (Model 4466, Instron Corp., USA).

2. Methods

Test Procedure (Figure 3)

The bracket to be tested was bonded to the midbuccal surface of each tooth with bonding resin (Ortho-one, Bisco, USA). A 200mm straight wire was prepared and assigned to each of the three different types of brackets. The wire to be tested was fitted into the bracket slot and ligated passively to the tie wing with an elastomer. Each tooth was mounted to the tooth-bearing test device and then the Instron machine. A connection between the arch wire and load cell (5kg) was made with nylon string. The tests were run at a head speed of 0.5mm/minute for 4 minutes, producing 2mm of arch wire movement. The data was recorded on an XY recorder by computer monitor. The X axis recorded wire movement in mm/time of the experiment in seconds, while the Y axis recorded the frictional force in grams.

A total of six test sessions were conducted. Before each new session, all light body silicone material was removed from each acrylic socket. Bracket bonding, wire ligation and mounting in the Instron machine were executed as previously described.

Data Analysis

From each session, frictional force at six displacement points (0.3, 0.6, 0.9, 1.2, 1.5, 1.8 mm) and maximum frictional forces were calculated. To find any significant difference among the frictional forces of the three bracket-wire combinations, one way ANOVA (Analysis of variance) and post-hoc testing were carried out.

Table 1. Mean and maximal frictional force value for narrow, medium and wide brackets (in grams)

Displacement(mm) Bracket width	0.3	0.6	0.9	1.2	1.5	1.8	maximum
narrow	37.06 ± 1.86	45.72 ± 1.53	52.55 ± 5.04	58.44 ± 2.80	62.89 ± 3.21	65.81 ± 3.26	72.78
medium	49.86 ± 4.61	56.75 ± 7.61	61.83 ± 6.05	65.29 ± 5.78	67.96 ± 5.28	69.62 ± 5.16	77.73
wide	39.98 ± 5.33	51.25 ± 8.84	57.12 ± 6.01	60.83 ± 4.94	65.79 ± 6.88	68.51 ± 4.76	77.1

Table 2. The significance of ANOVA post-hoc test for three bracket width per displacement

Displacement (mm)	Bracket width	narrow	medium
0.3	medium	*	
	wide	ns	*
0.6	medium	*	
	wide	ns	ns
0.9	medium	*	
	wide	ns	ns
1.2	medium	ns	
	wide	ns	ns
1.5	medium	ns	
	wide	ns	ns
1.8	medium	ns	
	wide	ns	ns
Maximal value	medium	ns	
	wide	ns	ns

* : significant ($p<0.05$). ns : not significant

RESULTS

Results for the frictional force with time or displacement of wire are shown in Table 1. It showed that friction between the bracket and arch wire increased propor-tionally with displacement or time. The maximal frictional forces between different bracket widths were 72.78, 77.73 and 77.13 grams respectively (Table 1). The dependence of frictional force on bracket width is illus-trated in Figure 4. Analysis of variance for these results and post-hoc testing showed that the effect of bracket width on the maximal frictional force was not significant at the level of 0.5% (Table 2).

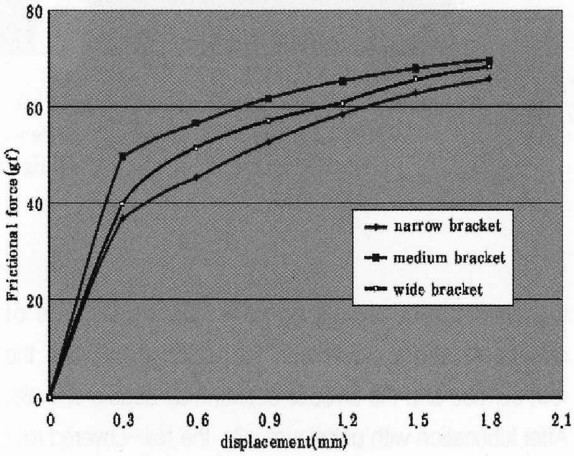


Fig. 4. The frictional force for each bracket width

DISCUSSION

Wire displacement and frictional force

Our explanation for increased friction with wire displacement (Fig 4) may be the increased angle formed between the wire and bracket slot, and finally the binding of the wire to bracket during the course of the experiment. This speculation may be supported by previous studies measuring friction with an increased angle[1,21]. They have suggested that with an increase in the angle between bracket and arch wire, the frictional force during sliding movement also increased.

The effect of bracket width

Our results showed that bracket width had no effect on friction, which was found by the ANOVA post-hoc test (Table 2). This agreed with the previous study[21].

However, this finding may not be easily compared with those of other studies, because the previous studies used models that did not simulate the natural tipping and rotation movement of teeth with PDL environment. Most experimental studies on orthodontic friction have used a model wherein arch wires were pulled through slots of brackets bonded to simulated teeth that were mounted in fixed mediums[1,4,9,19-24]. For example, in the study of Frank and Nikolai, fixed angles between the wire and bracket slot were given in a stepwise fashion, such as 0, 3, 6 and 10 degrees, to simulate the initial tipping of canine teeth immediately before sliding movement1. For different bracket widths, however, a comparison of frictional forces under the same angle and the same retracting force should be a significant error in testing conditions, since the different bracket width generates a different amount of binding angle and frictional force as well. That is, a larger retracting force was needed for a wider bracket under the same angle.

On the other hand, in the second study, Tidy did not need to give fixed angulations because he used the weights to represent a single equivalent retracting force, and the initial tipping was allowed naturally according to the retracting force[12]. He positioned retracting force application at the center of resistance. Since orthodontic forces are typically clinically applied at a distance from the center of resistance, using the weights at that point generated an undesirable tipping of the teeth. In his study, more tipping was established within the narrow bracket rather than the wider one, because the former was easier to tip at retraction. The tipping would generate a frictional force when the arch wire was drawn through the bracket slot, and therefore, this experiment made the error of placing uneven retracting force on the teeth. In addition, the two studies mentioned above did not allow for the rotation of teeth during sliding movement; rather, they only simulated the two-dimensional tipping of canine teeth[1,12,25].

Our dentoalveolar model was designed to simulate the PDL action during orthodontic tooth movement. Accordingly, the experimental conditions could simulate the contact established among arch wire, bracket slot and ligature upon the application of orthodontic force for sliding tooth movement in every clinical case. If the arch wire does not deform, the teeth will maintain slightly tipped and rotated positions and slide parallel along the archwire. The two previous studies that found the effect of bracket width on frictional force used models that do not allow these natural tipping and rotation to occur in our clinic[1,12].

One explanation for the non-significant effect of bracket width may be the same mechanism generating frictional force, which is the binding of wire material to the material of the bracket slot. There might be two point-contacts between the edges of the bracket slot and arch wire at the maximal friction point. At the initial stage of sliding movement, there were some differences in frictional force among the narrow, medium and wide brackets (Figure 4). We assume that this might result from variations in angle between bracket slot and the direction of wire movement at the initial stage. We don't know precisely why at the initial stage of sliding movement the largest frictional forces were measured for medium brackets. As the wire continued to displace, the frictional force value became increasingly similar. The reason for this phenomenon may be because the PDL-like light body polyvynilsiloxane impression material adjusted the angle between wire and bracket, buffered the different frictional forces for three brackets, and resulted in similar force values.

Therefore our results suggest that in clinics the wide brackets, rather than narrow ones, may be a better choice to control the rotation and tipping of teeth at retraction.

Ligation method

We should note the methodological error in ligation method because of differences in frictional force caused by different pressure from the ligature ties. Several studies have documented that an increase in normal force from tight ligation will cause an increase in the measurement of frictional force[2,9,19]. To reduce the potential for such bias, all ligation was carried out with

elastic modules; but at the same time friction should also increase with the increasing width of brackets. Therefore, bonding resin was attached in a rectangular shape on one side of the smaller bracket edge (Fig 1), so that we could make the total length around tie wing the same across all three brackets, while still not generating any different effects on bracket-wire interfaces.

Light body impression material and saliva effect

It should be noted that the material we used to simulate the PDL might have different physical properties from the actual tissue[26]. According to research, many different amounts of elastic modulus of PDL have been reported[27]. It was impossible to find an exact material representing the elastic modulus of real PDL. Thus, from among the materials with a somewhat lower elastic modulus we selected the light body of silicone impression material, which was easy to handle.

The material did allow tipping until contact was established between the bracket and arch wire. The results of this study may lead to speculation that actual PDL are of minor significance in the development of different frictional forces, but rather it may serve to buffer the varying frictional forces.

Another criticism may be that no efforts were made to simulate saliva effect. However, lubrication appears to play only a minor role. Tests done under dry conditions gave the same results as tests in water, whereas the use of artificial saliva only produced reductions in frictional force of 17% or less[2,5,6]

CONCLUSION

This study of frictional force between bracket and arch wire during canine retraction movement under dentoalveolar model presented some conclusions as follows:

1. Maximum frictional force for each bracket-arch wire combination was:
   Narrow (2.40mm) : 68.09±4.69 gmf
   Medium (3.00mm) : 72.75±4.98 gmf
   Wide (4.25mm) : 72.59±4.54 gmf
2. Frictional force was increased with the greater displacement of wire through the bracket slot.
3. ANOVA post-hoc tests showed that the bracket width had no significant effect on the frictional force when tested under clinically simulated conditions. ($P>0.05$).

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국문초록

치아의 활주 이동시 브라켓 폭이 브라켓과 호선 사이의 마찰력에 미치는 효과

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치아의 활주 이동시 교정용 브라켓과 호선 사이의 마찰력은 많은 요인들, 예를 들면 브라켓과 호선의 크기, 형태 그리고 재료, 결찰방법 그리고 브라켓-호선간 각도 등과 관련이 있다. 이런 요인들 대부분에 관하여 명확한 결론이 내려져 있지만 브라켓 폭이 마찰력에 미치는 효과에 관해서는 논란이 있다.

이번 연구는 임상에서와 비슷한 모의 치아 이동시 브라켓 폭이 발생되는 마찰력의 양에 미치는 효과를 조사하기 위해 고안되었다. 폭이 다른 세가지 브라켓 (0.018x0.025 standard) 즉 좁은 것 (2.40mm),중간 것 (3.00mm), 그리고 넓은 것 (4.25mm) 등을 0.016x0.022 스테인레스 스틸 호선과 함께 사용하였다. 세가지 브라켓-호선 조합들은 분속 0.5mm로 4

분동안 장치에서 움직이도록 하였고 각각 7회씩 반복 측정하였다. 생물학적인 상태를 재현하기위해 치아 치조 모형은 치근막과 유사한 탄성을 갖는 재료를 이용하는 간접법으로 제작되었다. 게다가 결찰력의 효과를 최소화하기 위하여 브라켓에 레진을 덧붙여서 고무로 결찰함으로써 브라켓 폭의 차이를 보상해주었다.

결과는 다음과 같다:

1. 각 브라켓-호선 조합의 최대 마찰력은;
   좁은것(2.40mm):68.0 ± 94.69 gmf
   중간것(3.00mm):72.7 ± 54.98 gmf
   넓은것(4.25mm):72.5 ± 94.54 gmf
2. 호선이 브라켓 슬롯을 지나서 나아갈수록 마찰력은 증가하였다.
3. ANOVA 사후검정 결과 임상과 비슷한 모의 실험에서 브라켓 폭은 마찰력에 아무런 영향을 미치지 않았다($p>0.05$).

주요 단어 : 브라켓 폭, 마찰력