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Dimension Tolerance of Ceramic Bracket

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DIMENSION TOLERANCE OF CERAMIC BRACKET

by

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DEDICATION

To my wife, Tchang, for her love,inspiration, support and understanding through my education and through whole this tough challenge and task.

To my parents, my brother and my sisters.

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VITA

Yuan-Chun Tseng was born on February 22, 1957, the second of four children to Sho-In L. and Lin-Hwan Tseng in Hsin-Chu, Taiwan.

His elementary education and secondary education were obtained in the public schools in Hsin-Chu. He continued his high school at the first public high school Hsin-Chu, Taiwan, where he graduated in 1976.

In September, 1977, he entered the dental school, Kaowshoung Medical College, for a six year program in dentistry and he graduated in 1982.

In December, 1982, he started practicing General Dentistry as a private practitioner for almost four years.

In July, 1986, he entered Loyola University School of Dentistry for a two year post-graduate course in Orthodontics, leading a certificate of specialty and a Masters of Science in Oral Biology.

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Chapter I

Introduction

Rectangular wire, round wire, auxiliary appliances and extra-oral headgear have been used by orthodontists for many years to achieve facial esthetics, functional harmony, and denture function and stability for patients. It is usually necessary to modify wires in order to move teeth precisely during orthodontic treatment. One of the modifications is to add "torque" in the orthodontic rectangular wire.

Torque is a force able to produce pure rotational movement around a long axis of the wire. The applied force is a couple (Nikoli,1985). A couple is defined as a pair of forces having equal magnitude but opposite directions. While the net force for a couple is equal to zero, the couple provides a rotational movement equal to the product of the force magnitude and the perpendicular distance between the lines of action of the two force vectors (Jarabak,1960) (Fig 1).

In orthodontics, torque is used to angulate and control facio-lingual root movement with respect to tooth crowns (Nikoli,1985). By applying adequate torquing force, the root will be moved more than the

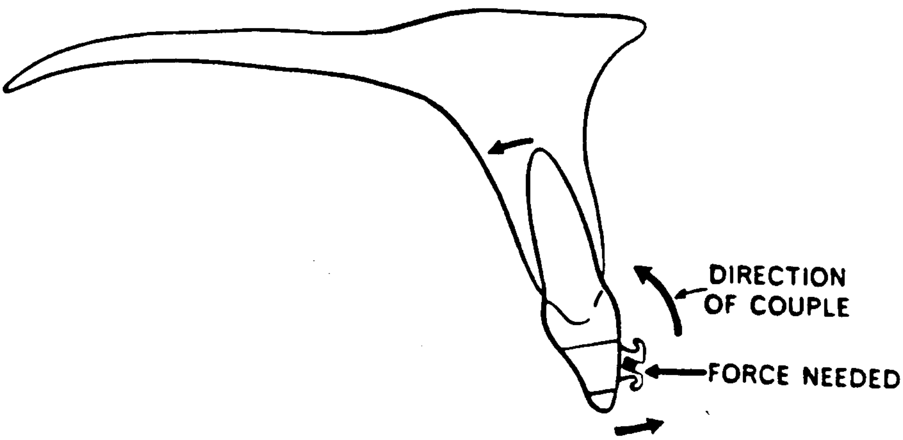


Figure 1. The effect of torquing force on tooth movement (Jarabak)

crown due to the center of rotation being moved from the apical root third to the contact points between rectangular wire and slot.

In the typical edgewise appliance, there are many indications for the use of torquing forces. For example, in the retraction of anterior teeth, it is necessary to balance the tipping moment on the anterior segment with an opposite torquing moment on the posterior segment of the arch wire. This is necessary to produce the proper "couple" to effect bodily retraction of the incisors instead of simple tipping.

It is also necessary to adjust torquing for individual posterior teeth in the course of properly positioning malposed teeth. There are many similar examples of need to precisely control torquing forces in the application of orthodontic mechanics.

Graber (1960) stated in treatment of many class II, division 2 cases, the maxillary central incisors are merely tipped forward and aligned with the lateral incisors. Then the problem is treated as a class II, Division 1 malocclusion. He found the result is acceptable but unstable. He also described torquing maxillary central incisors lingually first seemed to produce greater stability of the result.

For many years since Angle (1927) first mentioned the edgewise appliance, the rectangular wire with conventional bracket slot has been used to produce proper torquing force by orthodontists. However, recently the straight-wire appliance (SWA) due to its versality has been widely accepted. The SWA was designed to build ideal torquing angulation into the bracket slots to compensate for the different buccal slopes of each individual tooth contour, rather than repeating the tedious task of bending the wire to accommodate each individual tooth.

Binding is very important to control the torquing force to affect the desired result. It depends on the precise fit between the wire and bracket slot. The binding relationship between rectangular wire and slot has been evaluated by some authors. They showed different results from their studies but stressed the importance of torque.

The purpose of this research is to investigate the " tolerance " between the rectangular wire and the new generation of ceramic and sapphire brackets. Stainless steel slots from one manufacturer are used as a control group to compare the shape of slot among ceramic, sapphire, and stainless steel brackets.

Chapter II

Review of Literature

Definition of Torque:

Thurow (1972) defined torque as :

> a force causing twist in a structure; the resulting twist of the mechanical part is called torsion. In orthodontic terminology, it is defined as bucco-lingual root tipping in which movement of the crown is minimized and movement of the root apex is maximized. This is usually accomplished orthodontically through the application of force by means of mechanical torsion in the arch wire.

Nikolai (1985) defined torque as :

> an internal force system, carried longitudinally through a shaft or wire, and its resultant at any location is a couple in the plane of the right cross-section. In the field of orthodontics, torque is often associated with the angulation of long axes of teeth and pertains to the positioning of root apices with respect to the crown.

Angle (1929) introduced the mechanics of the pin and tube appliance. He stated it was the first practical technique for the proper control and distribution of force to move the roots of teeth. The force delivered by this device was very close to the requirements of the physiology of the tissue involved in tooth movement. By the manner of "vise-like grip" between the wire and slot, the force was transmitted from the wire to the roots of teeth.

The clinician could control the movement of the root either labially or lingually by placing bends in the ribbon arch in the arch wire either inward or outward prior to bracket engagement, so the desired directional force to the root could be achieved by the engagement of the wire.

Angle used a curvilinear sheath on terminal molars to control the direction of the force for moving the roots of the anterior teeth either buccally or lingually, in conjunction with or independent of crown movement.

Holdaway (1952) described a system which used angulated brackets to eliminate the need for second-order bends, including artistic bends for the incisors. In 1955, he stated one of the objectives of orthodontic treatment was keeping the upper incisors in a good labial and axial inclination. It would be helpful for reducing the angle of Sella-Nasion-Point A (SNA) by employing anterior lingual root torque.

Rauch (1959) in his article "Torque and Its Application to Orthodontics" stated torque is the force enabling an orthodontist to control the axial inclinations of teeth and to place them in the harmonizing positions that were so desirable for a nicely finished result. An operator could control the movements of roots of teeth by applying adequate torque. It was the force that helped orthodontists to get a desirable change of point A and B which, in turn, would make the results of treatment more desirable.

He stressed if orthodontists wanted to reduce the difference between the angles Sella-Nasion-Point A (SNA) and Sella-Nasion-Point B (SNB), he must use the proper application of torque force.

By incorporating the proper degree of torque in the arch wire, he showed an operator could keep the apex of a root in its same relative position while the crown was moved lingually. To create this action, the buccal segments lay just gingival to the buccal tube when the wire was engaged in the incisal segment. For example, if an operator wanted to move the tooth bodily in a lingual direction, he could add labial crown torque into the incisal segment of the arch wire and place the incisal segment into the slots. The arch wire should lie 6 to 8 mm gingival to the buccal tube. He also demonstrated if the wire were parallel to the bracket slot after incorporated with torque, there would not be any torque force exerting on the teeth (Figure 2). If the incisors were in extremely labial inclination, the crown would go lingually even the wire was torqued labially (Figure 3).

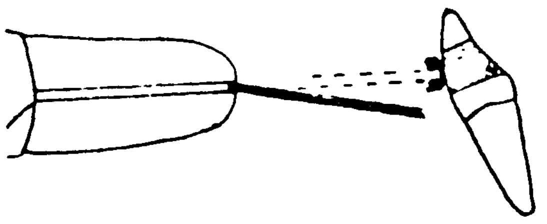


Fig. 2.- Labial torque of the wire but no torque force exerted on the tooth since wire is parallel to the bracket box.

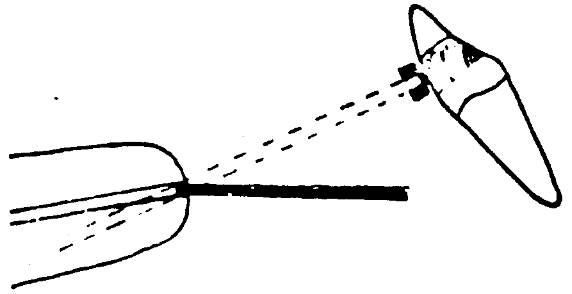


Fig. 3.- Labial torque of the wire but lingual torque force is created when the wire engages the bracket of extremely labial inclination of this incisor.

Jarabak(1960) noted there should be a small amount of "play" between the rectangular arch wire and the slot to prevent the deterious effect of full-size arch wire. This "play" could allow the clinician to apply the physiologic forces to move a tooth free from injury. In 1963, he described torque, based on analytical mechanics, was a combination of a force and a couple. He tested both an 0.016 inch x 0.016 inch wire and an 0.025 inch x 0.028 inch wire and found that there was a linear relationship between clearance and degrees of torque lost due to the rotation of wires. He found that the clearance between a wire and slot or tube was for each 0.001 inch wire-to-tube or wire-to-slot clearance, there was a torque loss of twisted wire in the slot or tube from 3 to 5 degrees. So the less the wire-to-tube clearance is, the more effective the torquing force will be.

Thompson (1961) in his article "Function and Growth" stated if maxillary incisors were found to be more uprightly and lingually positioned, either by nature or by treatment, it would give rise to abnormal function, such as clicking and crepitus of the joints, facial pain, irregular mandibular movement, jiggling excessive mobility of the incisors, and abnormal pattern of incisal attrition.

Andrews (1972) introduced "The Six Keys to Normal occlusion". The third key is crown inclination. The crown inclination refers to the labio-lingual or bucco-lingual inclination of the long axis of the crown. He noted upper and lower anterior crown inclination allowed properly distal positioning of the contact points among the teeth.

When the upper anterior crowns were improperly inclined, all upper contact points were forward of their normal position. This might also create undesirable spaces somewhere between anterior and posterior teeth. These spaces were often incorrectly blamed on tooth size discrepancy.

Biodgett and Andreasen (1968) said in extraction cases where closing loops were used to retract incisors, the crown of these teeth were tipped lingually to such an extent that the teeth appear "rabbitted". Such mechanics invariably caused excessive vertical overclosure of anterior teeth. In such a case lingual root torque was usually required to achieve satisfactory labiolingual inclination, and to prevent relapse in the overbite and overjet relationships.

Thurow (1972) noted "torque" was the force that caused twist. Torsion was the actual twisting that took place in the material as a result of the torque. In other words, torque was a force from a twisted wire that would have an effect on a tooth. Torsion was a twisting phenomenon.

He described an 0.001 inch vertical freedom of the wire in the slot would give from 2 degrees to 4 degrees of freedom in tipping in the direction of torque with common wire widths. A difference of 0.002 inch would bring this freedom to well over 5 degrees. So the thickness of any rectangular wire used for torque control should be kept within 0.002 inch of the width of the slot.

He also stressed an important consideration in undersized wires for torque action. Full-sized arch wire should never be used to torque an individual tooth to prevent unnecessary back-and-forth action on the adjacent tooth. The basic rule in this adjustment was that the arch wire should be sufficiently undersized to permit free reverse movement equal to any active torque action being applied to an adjacent tooth. He found freedom of 0.001 or 0.002 inch would provide this margin with careful adjustment.

Schrody (1974) evaluated buccal segment reaction to edgewise torque in the laboratory. He found the reaction of buccal segments to anterior lingual root torque was a complex system including a combination of countertorque, bucco-lingual linear, and occluso-gingival linear force. The countertorque force ranged from a mean value of 320 gm/mm to 4500 gm/mm and was the major reactive force component. From his experimental model, he showed there was an intrusive force on the buccal segment teeth when anterior lingual root torque was activated.

He noted slight buccal expansion of a torquing wire in the buccal segment would reduce the crossbite tendency from activating this torque. Progressive torque should be used wherever possible for more equitable reactive force distribution.

He stated by understanding the active and reactive forces, types, direction, and magnitudes related to torque, an orthodontist could control the movement of teeth in three planes of space.

Dellinger (1978) evaluated the concept of the straight-wire appliance. He used twenty-five non-extraction and twenty-five extraction cases after orthodontic treatment. He analyzed these fifty wax setups of malocclusion with the aid of an optical comparator to determine the validity of the straight-wire appliance concept. He used a horizontal occlusal line established by connecting left and right midcrown molar points and the clinical crown average of the left and right central incisors according to methods used by proponents of the straight-wire appliance. He found the ranges of torque measurement were great and total inconsistence. From his table, for example, the mandibular right central incisor showed a range of 18.75 degrees of torque, or from a positive 10.25 degrees to a negative 8.5 degrees (Table I). He stated present day straight-wire theory had little scientific basis. He considered only manufacturer's wire tolerance and used a formula to calculate "play" or deviation angle related to wire and slot dimension. The effective torque angle could be gotten by substrating deviation angle from torque angle (Figure 4).

The formula is :

$$\phi = \text{arc sin}\left[\frac{bc - \sqrt{a^2 + b^2 - c^2}}{a^2 + b^2}\right]$$

$$Q = \sigma - \phi$$

where ϕ = Deviation Angle
σ = Torque Angle
Q = Effective Torque Angle
a, b = Wire Dimension
c = Slot Dimension

He showed there was 11.02 degrees of deviation angle for an 0.018 inch x 0.025 inch wire size in an 0.022 inch slot. If an orthodontist used 30 degrees in pretorqued slots for a tooth, he must add additional 18.98 degrees in the wire to get the effective torque (Table II). He also compared the deviation angle between nominal wire size and the smallest allowable wire size and found the "maximum tolerance of deviation angle" for each wire-slot combination (Table III).

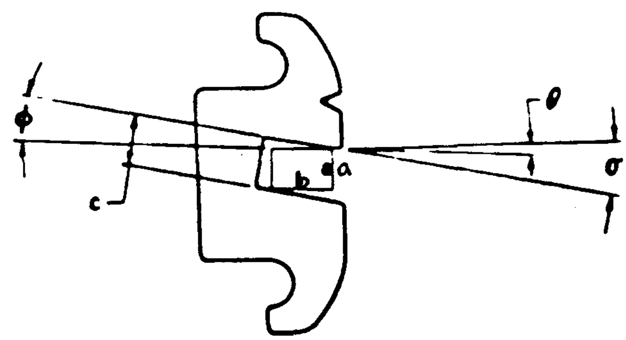
He stated differences in bracket position, various tooth morphology, and manufacturer's wire size all could give rise to torquing error.

Schwaninger (1978) described the "play" that existed for different sizes of arch wires in an 0.022 inch x 0.028

Table I

Statistical Analysis of Maxillary and Mandibular Arch Samples from Dellinger's study: Buccal/Labial Torque of Surface Adaptation Plane---------- Summary of 50 Cases

Tooth	Max. (x°)	Min. (y°)	Range (z°)	Average x (w°)	S.D.z
upper					
2	43.50	4.00	39.50	26.00	9.39
3	28.75	4.50	24.25	16.64	6.57
4	22.75	-.50	23.25	10.62	5.52
5	24.00	-4.50	28.50	6.53	5.89
6	18.00	-5.50	23.50	8.62	5.09
7	9.00	-10.25	19.25	.58	4.85
8	8.25	-10.75	19.00	-2.44	5.01
9	9.00	-10.75	19.75	-2.14	4.67
10	9.75	-12.50	22.25	-0.66	5.46
11	17.50	-.75	18.25	8.17	4.94
12	11.50	-5.75	17.25	5.01	4.99
13	19.75	-2.50	22.25	9.42	4.87
14	28.00	.75	27.25	15.66	7.05
15	36.75	11.75	25.00	23.19	6.69
lower					
18	48.00	20.75	27.25	31.16	6.60
19	48.25	13.00	35.25	30.35	7.74
20	37.50	6.50	31.00	22.82	6.26
21	33.75	10.75	23.00	19.27	6.44
22	25.25	2.75	22.50	12.33	4.29
23	18.50	4.50	23.00	2.91	4.76
24	10.00	-8.00	18.00	0.70	4.29
25	10.25	-8.50	18.75	1.07	4.35
26	16.50	-9.50	26.00	2.70	5.25
27	31.75	5.00	26.75	13.06	4.72
28	35.00	9.00	26.00	17.92	4.87
29	33.00	14.25	18.75	22.14	4.08
30	44.50	16.25	28.25	28.83	6.17
31	44.25	20.25	24.00	29.76	7.17



WHERE:

- ϕ = DEVIATION ANGLE
- σ = TORQUE ANGLE
- θ = EFFECTIVE TORQUE ANGLE
- a & b = WIRE DIMENSIONS
- c = SLOT DIMENSIONS

$$\phi = \text{ARC SIN}\left[\frac{bc - a\sqrt{a^2 + b^2 - c^2}}{a^2 + b^2}\right]$$

① $\theta = \sigma - \phi$

Fig. 4.- Dellinger's Equation to Calculate Deviation Angle.

Table II

Dellinger's Table of Effective Torque--0.022 Slot[8]

Wire Size (in.)	Deviation Angle (degrees)	Effective Tor ue Angle (degrees)								
		Bracket Tor ue Angle (degrees)								
		1	3	7	10	11	17	22	25	30
0.016 x 0.022	18.85	0	0	0	0	0	0	3.15	6.15	11.15
0.016 x 0.026	15.18	0	0	0	0	0	0	6.82	9.82	14.82
0.017 x 0.017	22.74	0	0	0	0	0	0	0	2.26	7.26
0.017 x 0.022	15.46	0	0	0	0	0	1.54	6.54	9.54	14.54
0.017 x 0.025	13.17	0	0	0	0	0	3.83	8.83	11.83	16.83
0.018 x 0.018	17.11	0	0	0	0	0	0	4.89	7.89	12.89
0.018 x 0.022	12.86	0	0	0	0	0	4.14	9.14	12.14	17.14
0.018 x 0.025	11.02	0	0	0	0	0	5.98	10.98	13.98	18.98
0.019 x 0.025	7.88	0	0	0	2.11	3.11	9.11	14.11	17.11	22.11
0.021 x 0.021	3.52	0	0	3.48	6.48	7.48	13.48	18.48	21.48	26.48
0.021 x 0.025	2.93	0	0.07	4.07	7.07	8.07	14.07	19.07	22.07	27.07
0.0215x 0.025	1.74	0	1.26	5.26	8.26	9.26	15.26	20.26	23.26	28.26
0.0215x 0.028	1.55	0	1.45	5.45	8.45	9.45	15.45	20.45	23.45	28.45
0.022 X 0.022	0.66	0.35	2.35	6.35	9.35	10.35	16.35	21.35	24.35	29.35

Table III
Deviation Angle for Nominal and Worst Tolerance Conditions[8]

Nominal Wire Size (in.)	Smallest Allowable Wire Size (in.)	Nominal Deviation Angle		Maximum Tolerance Deviation Angle	
		0.018	0.022	0.018	0.022
0.016 x 0.016	0.01575 x 0.01575	9.82	-----	12.89	-----
0.016 x 0.022	0.01575 x 0.021	6.68	18.85	8.56	22.13
0.016 x 0.026	0.01575 x 0.025	5.58	15.18		
0.017 x 0.017	0.01675 x 0.01675	5.12	22.74	7.13	26.78
0.017 x 0.022	0.01675 x 0.021	3.88	15.46		
0.017 x 0.025	0.01675 x 0.024	3.39	13.17	6.08	15.33
0.018 x 0.018	0.0176 x 0.0176	2.13	17.11	3.70	19.68
0.018 x 0.022	0.0176 x 0.021	1.71	12.86		
0.018 x 0.025	0.0176 x 0.024	1.50	11.02	2.67	12.86
0.019 x 0.025	0.01875 x 0.024	----	7.88	----	9.63
0.021 x 0.021	0.02075 x 0.02075	----	3.52	----	5.06
0.021 x 0.025	0.02075 x 0.024	----	2.93	----	4.32
0.0215x 0.025	0.02125 x 0.024	----	1.74	----	3.06
0.0215x 0.028	0.02125 x 0.027	----	1.55	----	2.70
0.022 x 0.022	0.02175 x 0.02175	----	0.66	----	2.01

inch slot. He noted if exact dimensions were observed, there would be 2 degrees of "play" for an 0.021 inch x 0.025 inch wire in an 0.022 inch x 0.028 inch slot, 7 degrees for an 0.019 inch x 0.025 inch wire, and 12 degrees for an 0.017 inch x 0.025 inch wire in the same slot (Figure 5). By using a typodont with only central incisors banded, he described there would be 5 degrees rotation for an 0.021 inch x 0.025 inch arch wire in the 0.022 inch x 0.028 inch slot, and 15 degrees for an 0.019 inch x 0.025 inch wire, and 25 degrees for an 0.017 inch x 0.025 inch wire in the same slot. He stated this deviation angle was due to manufacturers tending to make the slots slightly larger and the arch wire dimensions slightly smaller than indicated. He also noted there were some factors influencing torque requirements (1) initial position of the incisors, (2) type of mechanics, and (3) size of arch wire.

As for the initial position of the incisors, he stated he liked to "overtorque" the arch wire to achieve a proper axial inclination of anterior teeth at the end of treatment for facial esthetics, function, and stability. It was true for both the conventional and the straight arch wire appliance.

As for the type of mechanics, for example, in extraction cases, he noted that third-order bends were needed even in the "straight" arch wire to retract four

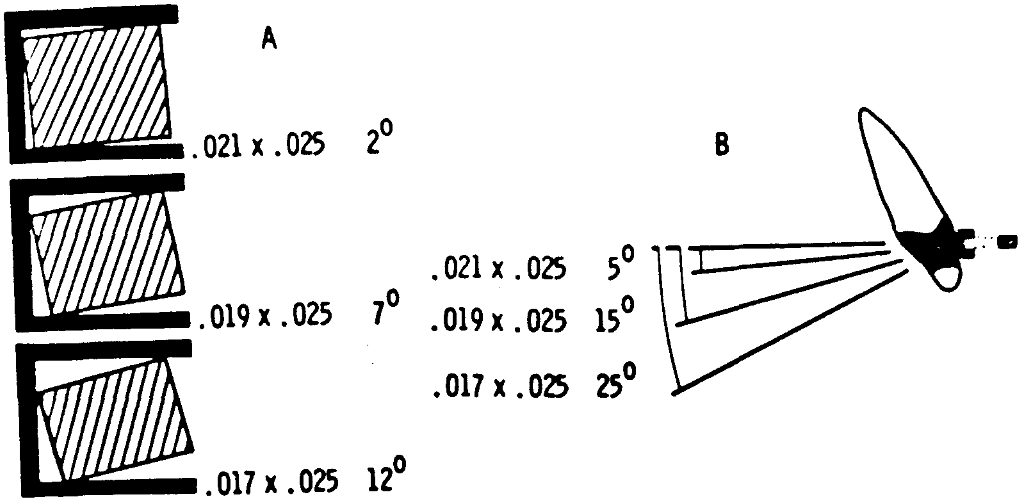


Fig. 5.- The different "play" between the exact and actual wire dimensions was demonstrated by Schwaninger.

incisors, and made treatment more efficient.

As for factor (3), he stated that there did exist the "play" between arch wire and slot. It would be even larger if arch wires with round edges were used. To get a better end result due to the variations in tooth morphology and bracket position, he suggested additional bends be placed in the "straight" arch wire.

Furthermore, he stressed the straight-wire system did not make orthodontic treatment easier. The clinician must have the training, the biomechanics knowledge, the in-depth diagnosis, and the prognosis of an individual problem that made his treatment successful.

Creekmore (1979) presented tables of effective root torque for various bracket torque angles and different wire size used in the 0.018 inch and 0.022 inch slots. In contrast to Dellinger, he considered only manufacturer's tolerance related to the slot size of bracket. According to his tables, the tolerance range for 0.018 inch slot was from 0.0182 inch to 0.0187 inch. The tolerance range for 0.022 inch slot was from 0.022 inch to 0.0225 inch. There would not be any effect on the teeth if the degrees of pretorqued 0.022 inch x 0.028 inch brackets combined with an 0.018 inch x 0.025 inch wire in the slot were less than 11 degrees. For example, if 7 degrees of torque were incorporated to the

Table IV
Effective Torque----0.018 Slot
Range .0182--.0187
Nominal 0.01845

Wire Size (in.)	Play (degrees)	Effective Torque (degrees) for Various Bracket Torque Angles: 1	3	7	10	11	17	22	25	30
0.016 x 0.016	16.7	0	0	0	0	0	0.3	5.3	8.3	13.3
0.016 x 0.022	9.3	0	0	0	0.7	1.7	7.7	12.7	15.7	20.7
0.016 x 0.026	7.3	0	0	0	2.7	3.7	9.7	14.7	17.7	22.7
0.017 x 0.017	8.2	0	0	0	1.8	2.8	8.8	13.8	16.8	21.8
0.017 x 0.022	5.4	0	0	1.6	4.6	5.6	11.6	16.6	19.6	24.6
0.017 x 0.025	4.5	0	0	2.5	5.5	6.5	12.5	17.5	20.5	25.5
0.018 x 0.018*	3.2	0	0	3.8	6.8	7.8	13.8	18.8	21.8	26.8
0.018 x 0.022*	2.4	0	0.6	4.6	7.6	8.6	14.6	19.6	22.6	27.6
0.018 x 0.025*	2.0	0	1.0	5.0	8.0	9.0	15.0	20.0	23.0	28.0

-* 0.018 Dim is actually 0.0178

Table V
Effective Torque----0.022 Slot
Range .0220--.0225
Nominal 0.02225

Wire Size (in.)	Play (degrees)	Effective Torque (degrees) for Various Bracket Torque ANgles 1	3	7	10	11	17	22	25	30
0.016 x 0.022	27.4	0	0	0	0	0	0	0	0	2.6
0.016 x 0.026	20.0	0	0	0	0	0	0	2.0	5.0	10.0
0.017 x 0.017	Rotation	0	0	0	0	0	0	0	0	0
0.017 x 0.022	22.3	0	0	0	0	0	0	0	2.7	7.7
0.017 x 0.025	17.7	0	0	0	0	0	0	4.3	7.3	12.3
0.018 x 0.018*	31.8	0	0	0	0	0	0	0	0	0
0.018 x 0.022*	18.4	0	0	0	0	0	0	3.6	6.6	11.6
0.018 x 0.025*	14.8	0	0	0	0	0	2.2	7.2	10.2	15.2
0.019 x 0.025	10.5	0	0	0	0	0.5	6.5	11.5	14.5	19.5
0.021 x 0.021	5.0	0	0	2.0	5.0	6.0	12.0	17.0	20.0	25.0
0.021 x 0.025	3.9	0	0	3.1	6.1	7.1	13.1	18.1	21.1	26.1
0.0215x 0.025	2.3	0	0.7	4.7	7.7	8.7	14.7	19.7	22.7	27.7
0.0215x 0.028	2.0	0	1.0	5.0	8.0	9.0	15.0	20.0	23.0	28.0
0.022 x 0.022	1.0	0	2.0	6.0	9.0	10.0	16.0	21.0	24.0	29.0

* 0.018 Dim is actually 0.0178.

central incisors, 3 degrees to the lateral incisors, -7 degrees to the cuspids and bicuspids and a -10 degrees to the molars, the teeth would not be affected by an 0.018 inch x 0.025 inch wire in an 0.022 inch x 0.028 inch slot due to the presence of 14.8 degrees of deviation angle (Table V). On the other hand, in a combination of an 0.022 inch x 0.028 inch slot and an 0.018 inch x 0.025 inch wire, if 30 degrees pretorqued brackets were used, it must be compensated by 15.2 degrees in the wire to control teeth movement due to the "play" between wire and bracket.

He noted the pretorqued appliance was an efficient device because of simplifying arch wire construction, but it did not necessarily make the treatment better. So even finishing with a full-size wire in the slot, some adjustments had to be made to compensate for the "play" between the wire and slot to get the teeth on proper position.

Raphael (1981) measured the rotation of rectangular wires in conventional buccal tubes. He used four dimensions of rectangular wires and tested two conventional buccal tubes. He found that the degree of rotation was far greater than expected on the basis of theoretical calculations from Dellinger's equation. For example, in the 0.018 inch x 0.025 inch mandrel formed tubes from Ormco Company, there were about 13 degrees of difference between the theoretical rotation and experimental measurement for an 0.016 inch x 0.016 inch wire. In the 0.022 inch x 0.028 inch mandrel formed tubes from Rocky Mountain Company, there were about 14 degrees of difference between the theoretical rotation and his finding for an 0.018 inch x 0.022 inch wire.

Ricketts and associates (1979) described some concepts in edgewise orthodontics. They stated there should be proper control of torque, both anteriorly and posteriorly, for intrusion, advancement or retraction of incisors, in the beginning of the treatment. One of the objectives of Bioprogressive Therapy was to establish and maintain torque during the treatment. They recommended "cortical anchorage" be incorporated into torque design to keep the molar roots against the buccal cortical plate of the alveolar bone to prevent them from being moved mesially during retraction of cuspids and incisors. They used the cortical anchorage to resist the extrusive component of class 2 elastics and to retard vertical eruption and alveolar growth in vertically growing faces.

Lang (1981) used pretorqued buccal tubes to evaluate the amount of rotation of various-sized rectangular arch wires in buccal tubes. He found there were variations between the actual lumen size and the manufacturer's stated lumen dimension, even over the manufacturer's described tolerance.

These variations could change treatment response, depending on the appliance used. He concluded there were varying degrees of rotation of rectangular wire in a pretorqued rectangular tube, and it depended on the size of the wire used and the manufacturer of the appliance supplied. His results also showed the values from both theoretical calculation and experimental measurements were not consistent. He noted additional torsion might need to be added in the wire to compensate for torque lost through "play" between wire and slot in order to deliver the desired force to teeth.

Rodriguez (1981) studied the cross sectional geometry and dimensions of orthodontic rectangular wire. He concluded (1) there was variation in the shape of the corners of the orthodontic rectangular wire which could affect the efficacy of the appliance to produce torquing moments on the teeth, (2) the amount of rotation the rectangular wires would experience at binding was dependent on the size and shape of their cross section, and (3) rectangular wires with smaller diagonals than theoretical would rotate a greater amount than those of longer diagonals of the same size.

Hixson (1982) used stainless steel direct-bond orthodontic brackets from three companies to evaluate the changes in slot tolerance after brackets were recycled twice and measured the values of slot tolerance after each recycling. He used a torque-meter assembly to actually measure the values of deviation angle for some of various rectangular wire used in 0.018 inch and 0.022 inch slot.

He showed the deviation angle varied from 11.7 degrees of rotation for an 0.016 inch x 0.022 inch arch wire to 3.9 degrees of rotation for an 0.018 inch x 0.025 inch arch wire in 0.018 inch slot. In 0.022 inch slot, the deviation angle ranged from 32.1 degrees of rotation for an 0.016 inch x 0.022 inch arch wire to 8.4 degrees of rotation for an 0.0215 inch x 0.025 inch arch wire. For example, the average of tolerance between an 0.018 x 0.025 inch wire size and 0.022 inch slot is 18.6 degrees. His measured values were greater than those of Creekmore's and Dellinger's. He attributed the difference between actual torquing measurements and calculated values to the beveled edges of rectangular arch wires.

Sebanc (1984) investigated the variability of effective root torque as a function of edge bevel on orthodontic arch wires. He used 0.018 inch and 0.022 inch slots from two companies and examined three different size arch wires for each slot size. He found the average edge bevel contribution to the measured deviation angle varied from 0.2 degrees to 12.9 degrees for the different wire-bracket combinations, and the average percentage contribution varied from 3 to 63% due to the edge bevel of the tested wires. He stated the beta titanium wires had the highest deviation angles and edge bevel contributions, followed by stainless steel wires and nickel-cobalt wires. He concluded the greater the edge bevel was, the greater the deviation angle would be. He suggested for achieving the desired clinical results, an orthodontist had to constantly increase the amount of torque. For example, from his experiment, he showed an operator should increase an additional 17.4 degrees of torque for an 0.018 inch x 0.025 inch stainless steel wire in the 0.022 inch slot for achieving effective root control.

Nikolai (1985) stated the resultant of a torsional force system was a couple and the amount of torsional activation achieved on complete appliance engagement was actually less than permanent-twisted angle. He described the third-order clearance as the principal portion of the difference between wires and bracket slots. He used the actual cross-sectional dimensions of the arch wire and the occluso-gingival bracket-slot width to compute this clearance.

For example, the clearance for an 0.019 inch x 0.026 inch wire in an 0.022 inch slot is 6.9 degrees

(Figure 6). He presented a table of the third-order clearances for four combinations of wires and slot sizes (Table VI). There were 7.7 degrees of clearance for an 0.016 inch x 0.016 inch wire in an 0.018 inch slot; 2.3 degrees of clearance for an 0.0175 inch x 0.025 inch wire in an 0.018 inch slot; 6.9 degrees of clearance for an 0.019 inch x 0.026 inch wire in an 0.022 inch slot, and 2.2 degrees of clearance for an 0.021 inch x 0.027 inch arch wire in an 0.022 inch slot. He also noted true third-order clearances depended on the actual wire and slot dimensions and, in effect, upon a stiffness of the bracket slot.

Vardimon and associates (1986) used fifty-four ideal occlusion subjects (thirty-four orthodontically treated and twenty untreated cases) for evaluating SWA theories by a statistical method. The result from this study showed the desired torque of the teeth was in close agreement with Andrews' mean built in torquing values for slots except those for the upper incisors. No agreement was found with Ricketts' torque data. They stated the maximal arch wire in an 0.018 inch slot not producing iatrogenic deleterious effect was 0.016 inch x 0.022 inch arch wires using Andrews' data and 0.016 inch x 0.016 inch arch wires with Ricketts'data. They described the relationship between the standard torque and deflection angle as follows:

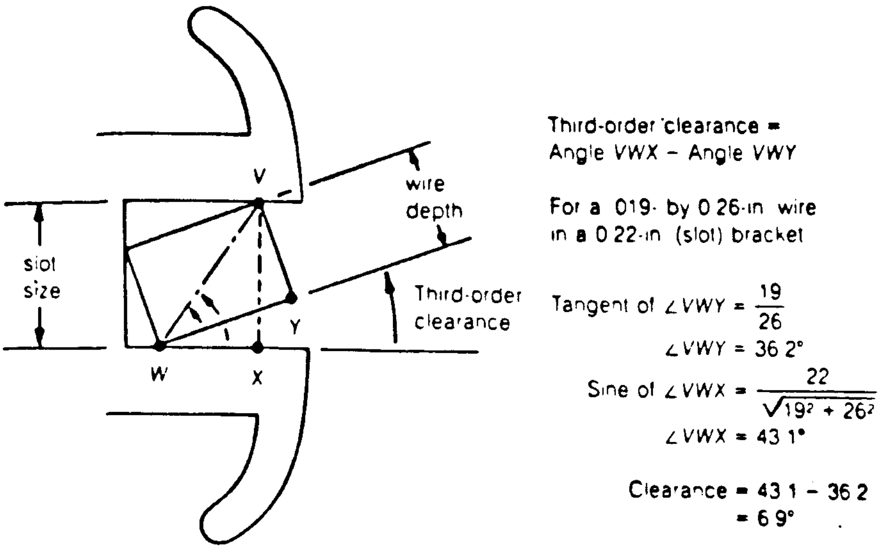


Figure 6. The formulas used by Nikolai to calculate the third-order clearance is demonstrated.

Table VI

Third-order clearances between rectangular arch wire and bracket slots from Nikolai's calculation

Wire size (inches)	Slot size (inches)	Clearance (degrees)
.016 x .016	.018	7.7
.017 x .025	.018	2.3
.019 x .026	.022	6.9
.021 x .027	.022	2.2

standard torque $\pm$ deflection angle = mean torque $\pm$ 1S.D.

The deflection angle was due to the amount of rotation established by an undersized wire in the given slot. They concluded because of inconsistency in torque data on diverse SWA attachments, an orthodontist could not neglect the biologic principles of torque for pursuit of perfection in treatment technique.

Hussels and Nanda (1987) evaluated the effect of maxillary incisor angulation and inclination on dental arch length. They used rectangular shape to represent the incisor tooth crown and calculated the change in arch length when teeth were tipped. They showed torque could cause little change in arch length. Vertical positioning of the brackets played an important role because torquing was a rotational movement around the center of the bracket slot. They stated by placing the bracket closer to the incisal edge, one could get the most effective torquing. On the other hand, torquing would be the least effective when brackets were placed closer to the cervical part of the crown. They suggested "peg" lateral incisors should be restored to their normal size before the final space closure and finishing stages so that the bracket could be at a proper height to prevent flaring and incorrect inclination of this tooth due to higher bracket placement.

Chapter III

Materials and Methods

Materials:

One upper arch of ceramic and sapphire brackets from each manufacturer (0.022 inch x 0.028 inch) were used in this study as experimental groups.

Standard stainless steel brackets (N=6) from Ormco were used as a control group. Ten stainless steel wires (0.018 inch x 0.025 inch) within an un-opened batch from Rocky Mountain* (Tru-Chrome) were used to evaluate the binding relationship between brackets and rectangular wires.

Two types of ceramic, two types of sapphire and one type of stainless steel brackets were used:

Brand	N	Type	Manufacturer
Gem	06	sapphire	Ormco**
Transcend	10	polycrystaline	Unitek***
Allure	10	polycrystaline	GAC****
Starphire	06	sapphire	A-Company*****
Tru-Chrome	06	Stainless Steel	Ormco**

*Rocky Mountain Corporation, P.O. Box 17085, Denver, Colorado 80217 (Order No. E-97, 08588)
**Ormco Corporation, 1332 South Lone Hill Ave., Glendora, California 91740 (Cat. No. N/A).
***Unitek Corporation, 2724 South Peck Road, Box Number 5018, Monrovia, California 91016-7118 (Cat. No. 2001- 701-----2001-706, 2001-715).
****GAC international, inc. 185 Oval Drive, Central Islip, N.Y. 11722 (LOT NO. CD3087).
*****A-Company, P.O. Box 81247, San Diego, California 92138 (Cat. No. N/A).

<u>Method I:</u>

The Unitron Metallographic microscope model N (Fig. 7) was used as a testing device. A rotating stage (Fig. 8-1) with two adjustable screws was adapted to the Unitron Metallographic microscope. To assist in firm placement of brackets to be tested in the center of the stage, an adjustable vise (Fig. 8-2) was attached to the rotating stage. A spring loaded pin vise (Fig. 8-3) was placed above the rotating stage to hold the rectangular wire which was rotated in the bracket slots.

Two adjustable screws were mounted to the spring loaded pin vise to ensure the wire being centered in the slot. This ensured that the wire was coaxial with the bracket slot. A Xenon lamp was used as the light source and its beam was reflected through the microscope lens to the rotating stage. Observation was accomplished on the microscope's tube at a magnification of 10X.

A graph paper was attached to a block which was placed in the vise of the rotating stage. Each preadjusted and preangulated bracket (experimental groups) and standard stainless steel bracket (control group) were placed on the graph paper and oriented, so each slot and the graph paper were parallel. The block-graph paper-bracket was placed in the vise of the rotating stage with the mesial side of the bracket facing up.

An 0.021 inch x 0.025 inch of wire size held in the pin vise of the microscope was inserted into each slot. The stage was rotated, so that the wire and slot were perfectly oriented using the 10X magnification. The reference wire was removed and replaced by an 0.018 inch x 0.025 inch of test wire size.

The test wire (30 mm in length) was lowered to pass through the slot and placed in a passive rotation position within the slot before rotating the stage. Values of wire-bracket rotating angles were recorded in degrees by rotating the stage-vise-bracket in both clockwise and counterclockwise directions. Five measurements were recorded in each direction. Ten values were obtained from each wire-slot combination.

The reason for designing the experiment to measurement clockwise and counterclockwise rotation of the wire from a neutral position is subtle. It is known from the previous experiments of Lang and Raphael that the rotation of the wire in the slot is affected by the variation in shape of the slot and corners of the wire. From Molina's study of wire cross-section, it is obvious that all four corners are rarely identical in shape. It is followed from the above that the rotating of wire in clockwise and counterclockwise direction from a neutral position would like be unequal. This is relevancy clinical because either labial or lingual root torque is selected, it is desired in a given situation. Merely rotating the wire clockwise and counterclockwise until binding, and dividing by two will not approach the clinical situation as accurately as the method actually used.

Method II:

A test-wire (15 mm in length) was held by the loaded pin vise. Each bracket with mesial side of the bracket facing up was attached to the test-wire and secured by an orthodontic elastic O-ring. The wire-slot combination was lowered to the adjustable vise. Light curing resin was added between the inner walls of the adjustable vise and two sides of the bracket length to make sure the bracket was placed firmly. The stage was rotated until the wire bound in the slot, as determined by resistance felt from the rotating stage.

Light-curing resin was added to the wire-slot combination to maintain the wire orientation in the slot. The wire-bracket combination was removed from the adjustable vise and the elastic O-ring and residual resin on the sides of the bracket were removed after the resin had set.

The long axes of the test-wire and slot were oriented, so that these two axes could be ground perpendicular to them by the Buehler Ecomet III (NO. 49-1602) (Fig. 12-1)

A piece of wire in the shape of an inverted "V" was attached to the test-wire in the slot to permit the bracket to be mounted in the metallographic molding compound. A Buehler stainless steel mold assembly (NO. 20-2120) (Fig. 9) was used to mount the bracket in Epomet molding compound (23 gm). The filled mold assembly was heated to 140-150 °C for 12 minutes while under a pressure of 4200 p.s.i. in a metallogical press (Fig. 10).

Mounted samples were rigidly held by a specimen holder (Fig. 11) and prepared metallographically in a Buehler automet (NO. 60-1900) (Fig.12-2). The specimens were polished on SiC paper (240-600 grit) under pressure of 20lbs for 30 minutes on each paper and final polished with alumina (5; 1; 0.3; and 0.05 u) from 30 minutes to 8 hours.

Dimensions of the wires and bracket slots were measured on a Gaertner travelling microscope (Fig. 13-1) to 0.0001 cm and converted to inches. The inner dimensions of slots were measured at two contact points, contact point 1 and 2, which indicated the wire binding in the slot. The outer edge of slot dimension was also measured at the point from which the bevel of the slot start (Table VII).

Rotation of the wire in the slot was measured on the above microscope fitted with a Gaertner protractor attachment (Fig. 13-2) to $\pm$ 5' of a degree. The angle between the vertical dimension of wire and the inner wall of slot connected to the wing was called A1. The angle between the vertical dimension of wire and the inner wall of slot connected to the base of slot was called A2. Statistical comparisons of the data were made using the student t-test at $p \leqslant 0.01$.

The cross-section dimensions od wires were also measured by a micrometer along each wire to 0.0001 inch.

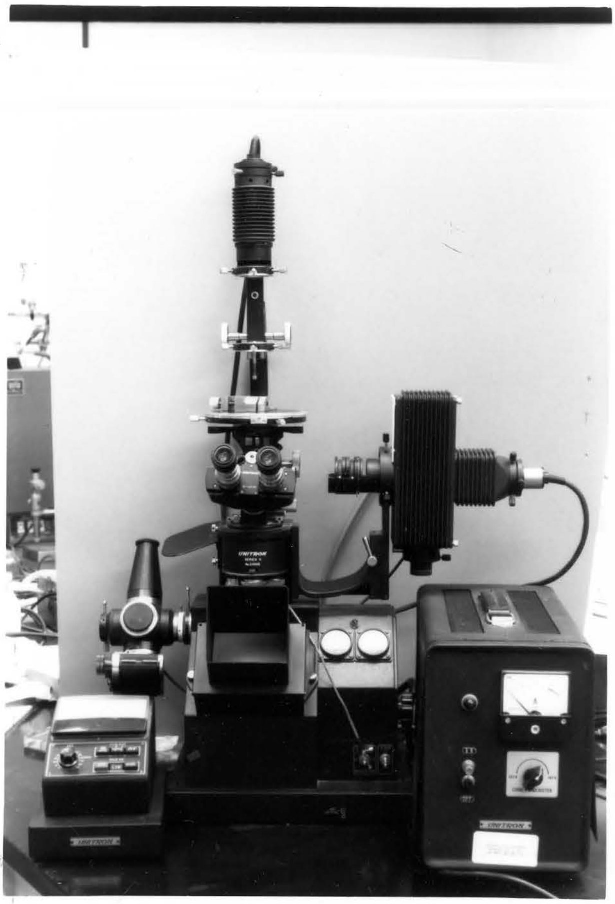


Figure 7. Unitron Metallographic Microscope.
(Model N)

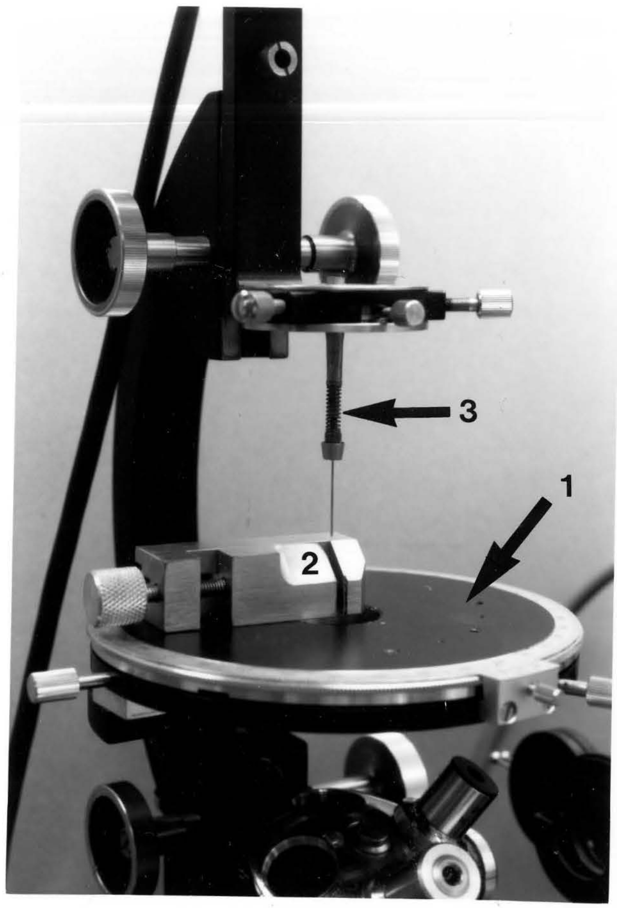


Figure 8. (1) Rotating stage
(2) Adjustable vise
(3) Spring loaded vice with a test-wire

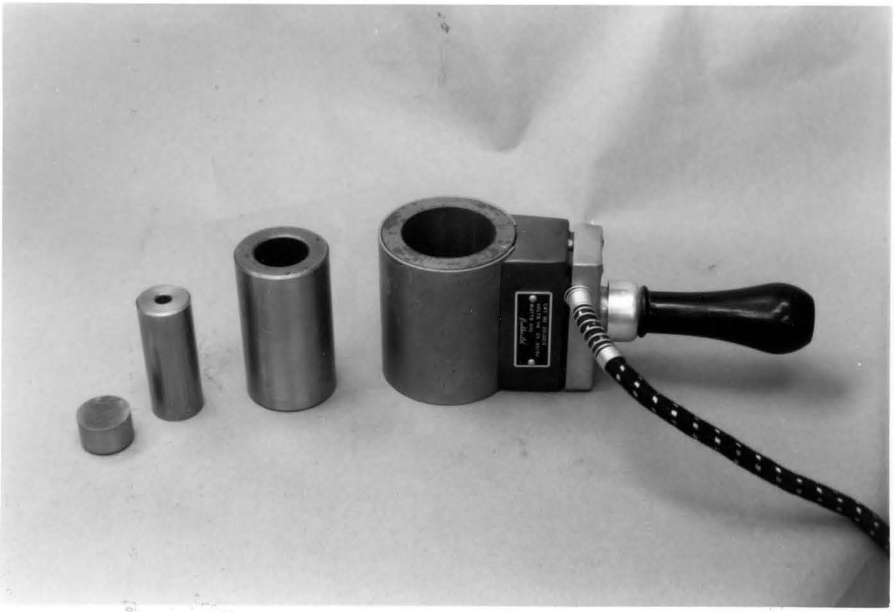


Figure 9. Buehler Stainless Steel Mold Assembly (NO. 20-2120)

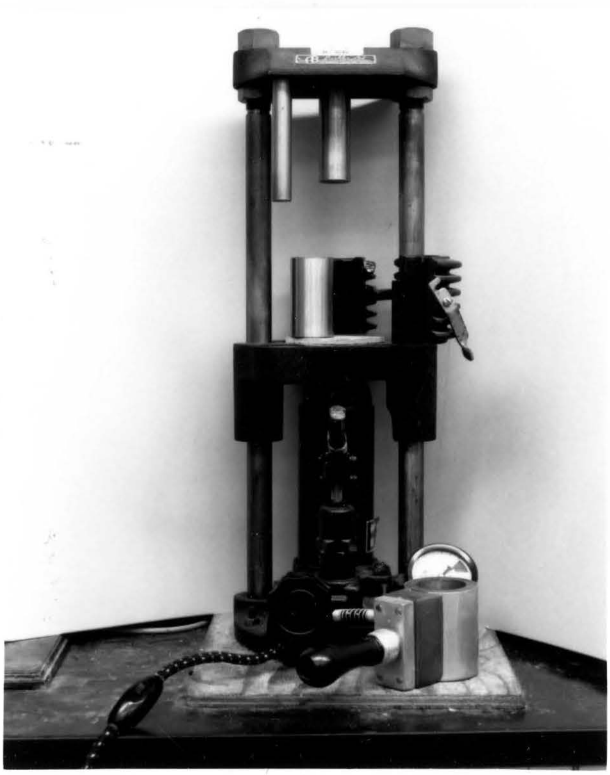


Figure 10. Metallogical press

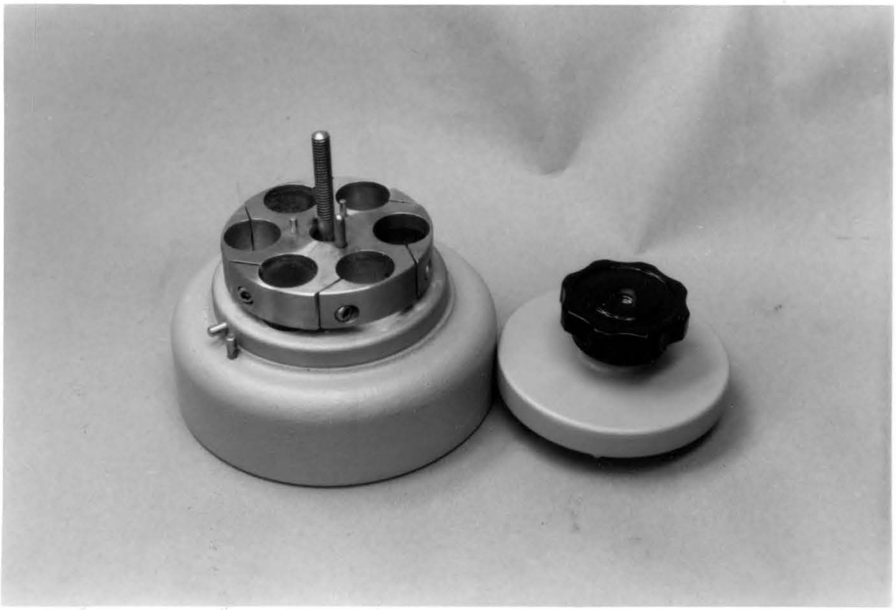


Figure 11. Specimen holder.

Figure 12. (1) 49-1602 Buehler Ecomet III
(2) Automet (60-1900)

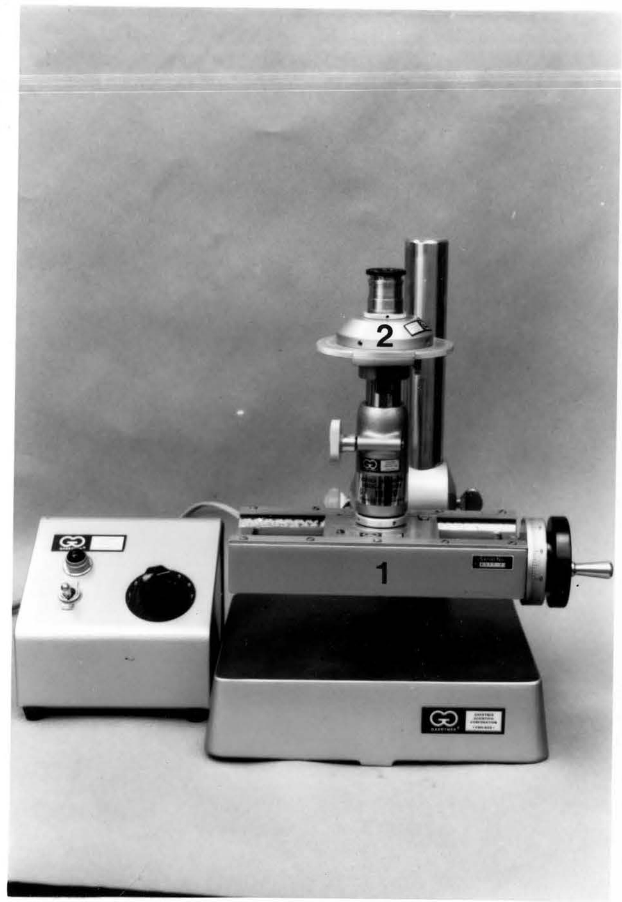


Figure 13. (1) Gaertner travelling microscope
(2) Protractor attachment

Chapter IV

Results

The following tables are the results of the methods which have been previously discussed in the Chapter III.

The mean values of width dimensions of the slots used in this study are shown in table VII.

Tables VIII and IX show the dimensions of the stainless steel wire obtained from the travelling microscope and micrometer, respectively.

Table X indicates the summary of degrees of rotation angle of rectangular wires in orthodontic brackets obtained with Unitron metallographic microscope.

Table XI displays the summary of degrees of rotation angle of rectangular wires in orthodontic brackets measured with the Protractor Eyepiece.

Table XII shows the comparison between method I and method II.

From table XIII to table XVII reveal the mean values of slot dimensions and rotation of wires in orthodontic brackets.

Tables XVIII to XXII indicate the contributions of wire morphology (bevel) to the extent of rotation of rectangular wires in orthodontic brackets and compare the theoretically calculated values of the rotation angles with those of the experimental measurements. The theoretical values were based on the following formula:

$$\phi = \text{ARC SIN}\left[\frac{bc - a\sqrt{a^2 + b^2 - c^2}}{a^2 + b^2}\right]$$

Where ϕ = rotation angle
a = vertical measured wire dimension
b = horizontal measured wire dimension
c = vertical measured lumen dimension

The calculations were incorporated by the mean value of each measured wire dimensions (Tables XVIII-XXII) and the average of the slot dimensions between CP1 and CP2.

Table XXIII shows the comparison among manufacturers by the mean values of rotation angle.

Table VII

Dimensions of Bracket Slot (0.022 slot)
x ± s.d. (inch),
(N)

	Contact Point 1	Contact Point 2	Top of slot
Ormco (Gem)	0.0224 ± 0.0003 (N=30)	0.0228 ± 0.0004 (N=30)	0.0236 ± 0.0010 (N=30)
A-Comp (Star)	0.0221 ± 0.0002 (N=30)	0.0226 ± 0.0002 (N=30)	0.0228 ± 0.0003 (N=30)
Unitek (Tran)	0.0224 ± 0.0002 (N=35)	0.0225 ± 0.0001 (N=35)	0.0226 ± 0.0001 (N=35)
GAC (All.)	0.0224 ± 0.0001 (N=35)	0.0225 ± 0.0001 (N=35)	0.0226 ± 0.0001 (N=35)
Ormco (T.C.)	0.0227 ± 0.0002 (N=30)	0.0228 ± 0.0001 (N=30)	0.0229 ± 0.0001 (N=30)

*Star=Starphire
Tran=Transcend
All.=Allure
T.C.=Tru-Chrome

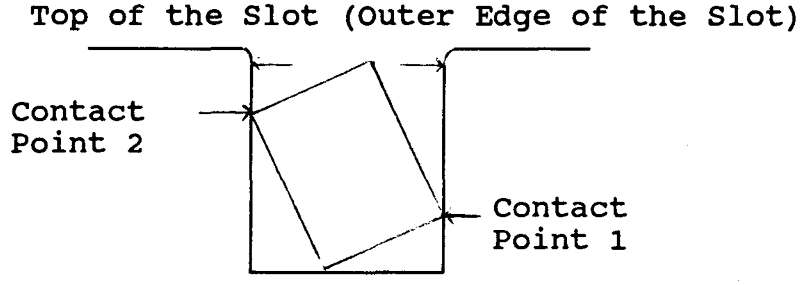


Table VIII

Dimensions of Stainless Steel Wire (0.018 x 0.025) used in This Study (Travelling Microscope) x ± s.d.

	width (inch)	length (inch)
x ± s.d.	0.0178 ± 0.0001	0.0248 ± 0.0001
N	160	160
range:	0.0176---0.0179	0.0245---0.0249

Table IX

Measured (Micrometer) wire dimensions
(0.018 x 0.025 inch) (inch)

Measurement	width	length
1	0.0180	0.0250
2	0.0180	0.0249
3	0.0180	0.0249
4	0.0179	0.0249
5	0.0178	0.0249
6	0.0179	0.0249
7	0.0180	0.0250
8	0.0180	0.0249
9	0.0178	0.0249
10	0.0180	0.0250
11	0.0180	0.0249
12	0.0180	0.0250
13	0.0180	0.0250
14	0.0180	0.0249
15	0.0180	0.0249
16	0.0179	0.0249
17	0.0180	0.0249
18	0.0180	0.0250
19	0.0180	0.0249
20	0.0179	0.0249
21	0.0177	0.0249
22	0.0180	0.0249
23	0.0180	0.0249
24	0.0179	0.0249
25	0.0179	0.0250
26	0.0179	0.0249
27	0.0177	0.0250
28	0.0177	0.0249
29	0.0177	0.0250
30	0.0180	0.0249
31	0.0181	0.0249
32	0.0180	0.0249
33	0.0179	0.0249
34	0.0179	0.0249
35	0.0179	0.0249
36	0.0177	0.0249
37	0.0178	0.0249
38	0.0176	0.0249
39	0.0177	0.0250
40	0.0178	0.0250

$x \pm s.d. = 0.0179 \pm 0.0001$ $\quad$ $x \pm s.d. = 0.0249 \pm 0.0001$

Table X (From method I)

Data Summary from Method I of Rotation of Rectangular Wire (0.018 x 0.025 inch) in Orthodontic Brackets (0.022 slot)
Degrees

	Clockwise	Counterclockwise	*Mean
Ormco (Gem)	19.57 ± 1.39	17.63 ± 0.77	18.60 ± 1.48
A-Comp (Star.)	19.19 ± 1.06	17.63 ± 1.51	18.31 ± 1.57
Unitek (Tran)	19.60 ± 1.06	17.46 ± 0.98	18.53 ± 1.48
GAC (All.)	18.54 ± 0.98	19.14 ± 1.41	18.84 ± 1.24
Ormco (T.C.)	19.28 ± 0.87	19.25 ± 0.79	19.27 ± 0.83

* Entries are the mean values of clockwise and counterclockwise measurements.

Table XI (From method II)

Data Summary from Method II of Rotation of Rectangular Wire (0.018 x 0.025 inch) in Orthodontic Brackets (0.022 slot)
Degrees
x ± s.d.
(N)

Brands	A1	A2	Mean	t-test
Ormco (Gem)	16.58 ± 1.92 (N=30)	15.20 ± 1.60 (N=30)	15.83 ± 1.79 (N=60)	3.02
A-Comp (Star.)	15.86 ± 0.70 (N=30)	14.60 ± 1.03 (N=30)	15.23 ± 1.08 (N=60)	5.54
Unitek (Tran.)	15.63 ± 0.46 (N=35)	15.28 ± 0.55 (N=35)	15.46 ± 0.53 (N=70)	2.89
GAC (Allure)	15.35 ± 0.55 (N=35)	15.00 ± 0.41 (N=35)	15.17 ± 0.51 (N=70)	3.05
Ormco (T.C.)	17.80 ± 0.45 (N=30)	17.30 ± 0.88 (N=30)	17.55 ± 0.74 (N=60)	2.77

Table XII

Comparison Between Method I and Method II

Method I	Method II
(1) attach a sample to a graph paper. (2) insert a wire to compensate angulation. (3) fix the sample to the block. (4) place the block within the vise.	(1) fix a test wire in the slot by light curing resin. (2) place the sample perpendicular to the horizontal surface. (3) tripod wire to stablize the sample
time : 30 minutes	45 minutes
	(4) preheat the sample die to 140°C (5) place the sample in the die (6) heat the sample die to 140°C - 150°C (7) cool down the sample die
time: 0 minute	30 minutes
	(8) initial grinding (9) final grinding
time: 0 minute	6 hours
(5) measurements	(10) measurements
time: 30 minutes	40 minutes
Total time: 1 hour	7 hours and 15 minutes

Table XIII

Mean Values of Slot Dimensions (0.022 slot) and Rotation of wires (0.018 x 0.025) in Orthodontic Brackets (Ormco-Gem)

N=6	CP1	CP2	TOS	A1	A2	*x
slot #		(inch)		(measured in degrees)		
3|	0.0223	0.0228	0.0235	**13.75	**13.25	**13.50
2|	0.0226	0.0233	0.0257	18.82	17.33	18.08
1|	0.0220	0.0225	0.0236	15.70	13.20	14.45
|1	0.0223	0.0223	0.0223	15.02	14.89	14.96
|2	0.0226	0.0232	0.0233	18.65	16.45	17.55
|3	0.0209	0.0229	0.0233	17.51	16.07	16.79

* Entries are the mean values of A1 and A2.

** The smaller values are due to a convex mass in the slot and the wire do not bind at the CP2. So, the measured values show smaller.

CP1=contact point 1
CP2=contact point 2
TOS=top of the slot (outedge of the slot)

Table XIV

Mean Values of Slot Dimensions (0.022 slot) and Rotation of wires (0.018 x 0.025) in Orthodontic Brackets (A-Comp)

N=6	CP1	CP2	TOS	A1	A2	*X
slot #	(inch)			(measured in degrees)		
3	0.0224	0.0226	0.0228	15.74	15.48	15.61
2	0.0220	0.0228	**0.0234	16.44	14.36	15.40
1	0.0220	0.0224	0.0225	15.01	14.21	14.61
1	0.0218	0.0223	0.0226	15.08	13.31	14.20
2	0.0222	0.0226	0.0228	15.99	13.91	14.95
3	0.0224	0.0225	0.0226	16.90	16.33	16.62

* Entries are the mean values of A1 and A2.

** This larger value is due to big bevel on both inner walls of slot above the wire.

Table XV

Mean Values of Slot Dimensions (0.022 slot) and Rotation of Wires (0.018 x 0.025) in Orthodontic Brackets (Unitek-Transcend)

N=7	CP1	CP2	TOS	A1	A2	*X
slot #		(inch)		(measured in degrees)		
5|	0.0223	0.0224	0.0225	15.23	14.88	15.10
4|	0.0222	0.0223	0.0225	15.48	14.90	15.19
1|	0.0228	0.0228	0.0228	16.67	16.53	16.60
|1	0.0224	0.0225	**0.0228	15.58	15.23	15.41
|3	0.0224	0.0224	0.0225	15.48	15.13	15.31
|4	0.0223	0.0225	0.0227	15.28	14.87	15.10
|5	0.0225	0.0225	0.0226	15.70	15.43	15.57

* Entries are the mean values of A1 and A2.

** There is a big bevel at top of slot, otherwise the inner walls of slot are very parallel to each other.

Table XVI

Mean Values of Slot Dimensions (0.022 slot) and Rotation of Wires (0.018 x 0.025) in Orthodontic Brackets (GAC-Allure)

N=7	CP1	CP2	TOS	A1	A2	*X
slot #	(inch)			(measured in degrees)		
5|	0.0223	0.0223	0.0224	14.51	14.34	14.43
4|	0.0224	0.0226	0.0227	15.96	15.25	15.61
3|	0.0223	0.0224	0.0225	15.34	15.00	15.17
2|	0.0224	0.0226	0.0228	15.74	15.23	15.49
|2	0.0224	0.0225	0.0227	16.01	15.67	15.84
|3	0.0223	0.0223	0.0224	14.99	14.83	14.91
|5	0.0223	0.0223	0.0224	14.89	14.67	14.78

* Entries are the mean values of A1 and A2.

Table XVII

Mean Values of Slot Dimensions (0.022 slot) and Rotation of Wires (0.018 x 0.025) in Orthodontic Brackets (Ormco-Stainless Steel)

N=6	CP1	CP2	TOS	A1	A2	*X
slot #	(inch)			(measured in degrees)		
3/0	**0.0236	0.0231	0.0231	18.62	18.91	18.77
3/1	0.0225	0.0232	0.0233	17.43	16.89	17.16
3/2	0.0230	0.0232	0.0233	18.00	17.42	17.71
1/K	0.0230	0.0230	***0.0233	17.63	17.39	17.51
4/2	0.0227	0.0229	0.0233	17.25	15.99	16.62
4/3	0.0229	0.0231	0.0232	17.75	17.26	17.51

* Entries are the mean values of A1 and A2.

** There is a concave surface near to the base of slot, so the value is larger.

*** The inner walls of slot are very parallel to each other except the surfaces near the top of slot. There is step out surfaces over there.

Table XVIII

Contributions of Wire Morphology (bevel) to Extent of Rotation of Rectangular wire in Orthodontic Brackets (Ormco-Gem)

Wire Size (0.018 x 0.025) (inch)	Slot Width (0.022)	Wire Rotation (degrees) Theoretical=9.82		Bevel Contribution to Rotation
Measured	*Measured	#Calculated	Actual	Percentage (%)
3| 0.0178 x 0.0248	0.0226	12.09	13.50	11.66
2| 0.0177 x 0.0247	0.0230	13.57	18.08	33.24
1| 0.0178 x 0.0248	0.0223	11.26	14.45	28.33
|1 0.0178 x 0.0247	0.0223	11.31	14.96	32.27
|2 0.0178 x 0.0247	0.0229	13.00	17.55	35.00
|3 0.0178 x 0.0249	0.0219	10.12	16.79	65.91

* Entries are the mean values between CP1 and CP2.

The calculated values are obtained by using measured dimensions of the bracket slot and wire size.

Table XIX

Contributions of Wire Morphology (bevel) to Extent of Rotation of Rectangular wire in Orthodontic Brackets (A-Company)

Wire Size (0.018 x 0.025) (inch)	Slot Width (0.022)	Wire Rotation (degrees) Theoretical=9.82		Bevel Contribution to Rotation
Measured	*Measured	Calculated	Actual	Percentage (%)
3| 0.0178 x 0.0247	0.0225	11.87	15.61	31.51
2| 0.0178 x 0.0247	0.0224	11.59	15 40	32.87
1| 0.0178 x 0.0247	0.0222	11.04	14.61	32.34
|1 0.0177 x 0.0248	0.0221	10.98	14.20	29.33
|2 0.0178 x 0.0248	0.0224	11.54	14.95	29.55
|3 0.0175 x 0.0248	0.0225	12.63	16.62	31.59
				**X = 31.20

* Entries are the mean values between CP1 and CP2.

** mean value of bevel contributions of wires.

Table XX

Contributions of Wire Morphology (bevel) to Extent of Rotation of Rectangular wire in Orthodontic Brackets (Unitek-Transcent)

Wire Size (0.018 x 0.025) (inch)	Slot Width (0.022)	Wire Rotation (degrees) Theoretical=9.82		Bevel Contribution to Rotation
Measured	*Measured	Calculated	Actual	Percentage (%)
5| 0.0178 x 0.0246	0.0224	11.65	15.10	29.61
4| 0.0177 x 0.0248	0.0223	11.53	15.19	31.74
1| 0.0178 x 0.0248	0.0228	12.65	16.60	31.23
|1 0.0178 x 0.0248	0.0225	11.81	15.41	30.48
|3 0.0178 x 0.0246	0.0224	11.65	15.31	31.42
|4 0.0178 x 0.0249	0.0224	11.48	15.10	31.53
|5 0.0178 x 0.0248	0.0225	11.81	15.57	31.84
				**X = 31.12

* Entries are the mean values between CP1 and CP2.

** mean value of bevel contributions of wires.

Table XXI

Contributions of Wire Morphology (bevel) to Extent of Rotation of Rectangular wire in Orthodontic Brackets (GAC-Allure)

Wire Size (0.018 x 0.025) (inch)	Slot Width (0.022)	Wire Rotation (degrees) Theoretical=9.82		Bevel Contribution to Rotation
Measured	*Measured	Calculated	Actual	Percentage (%)
5| 0.0179 x 0.0248	0.0223	10.99	14.53	32.21
4| 0.0178 x 0.0249	0.0225	11.76	15.61	32.74
3| 0.0178 x 0.0248	0.0224	11.54	15.17	31.46
2 0.0178 x 0.0247	0.0225	11.87	15.49	30.50
|2 0.0177 x 0.0246	0.0225	12.20	15.84	29.84
|3 0.0178 x 0.0247	0.0223	11.31	14.91	31.83
|5 0.0178 x 0.0247	0.0223	11.31	14.78	30.68
				**X = 31.32

* Entries are the mean values between CP1 and CP2.

** mean value of bevel contributions of wires.

Table XXII

Contributions of Wire Morphology (bevel) to Extent of Rotation of Rectangular wire in Orthodontic Brackets (Ormco-Stainless Steel)

Wire Size (0.018 x 0.025)	Slot Width (0.022) (inch)	Wire Rotation (degrees) Theoretical=9.82		Bevel Contribution to Rotation
Measured	*Measured	Calculated	Actual	Percentage (%)
3/0 0.0176 x 0.0248	0.0234	14.94	18.77	25.64
3/1 0.0177 x 0.0248	0.0229	13.21	17.16	29.90
3/2 0.0178 x 0.0248	0.0231	13.51	17.71	31.09
1/k 0.0178 x 0.0248	0.0230	13.22	17.51	32.45
4/2 0.0178 x 0.0248	0.0228	12.65	16.62	31.38
4/3 0.0177 x 0.0248	0.0230	13.50	17.51	29.93
				**X = 30.07

* Entries are the mean values between the CP1 and CP2.

** mean value of bevel contributions of wires.

Table XXIII

Comparison of Manufacturers by Mean Rotation Angle

	ORMCO (GEM)	A--Comp (Star.)	Unitek (Tran.)	GAC (Allure)
Ormco (Gem)	X	X	X	X
A-Comp. (Star.)	NSD 2.36	X	X	X
Unitek (Tran.)	NSD 1.83	NSD 1.57	X	X
GAC (All.)	SD 3.08	NSD 0.41	SD 3.30	X
Ormco (T.C.)	SD 6.36	SD 13.73	SD 18.69	SD 21.59

t-value = 2.62 (n=120); based on p=0.01.
= 2.61 (n=140); based on p=0.01.

SD = Significant difference at $P \leq 0.01$ level.
NSD = No significant difference.

Chapter V

Discussion

Slot Dimensions

The average dimensions of bracket slots from four companies used in this study are shown in table VII. The average measurements of slots of stainless steel brackets from Ormco shows the largest value (0.0227 inch) at the contact point 1 (CP1), followed by the slots from Unitek Transcend (0.0569 mm= 0.0224 inch), Ormco Gem (0.0568 mm = 0.0224 inch), GAC Allure (0.0567 mm = 0.0224 inch), and A-Company Starfire (0.0562 mm = 0.0221 inch). The mean values of measurements at contact point 2 (CP2) show that Ormco Gem and stainless steel slots have the largest value (0.0580 mm=0.0228 inch), followed sequentially by A-Company, Unitek, and GAC. These two contact points are the function of the rotated wire binding in the slot. If a nominal wire (0.018 inch x 0.025 inch) were inserted into the slot, both products from Ormco would allow the wire more rotation than the other brackets measured. Therefore it will provide less torquing force transferred from the wire to the teeth.

Most of the slots used in this study showed a tapered shape, narrower at the base and wider at the outer edge of slot especially Ormco Gem and A-Company Starfire. Ormco Gem produced a mean difference of 0.0012 inch between CP1 (contact point 1) and TOS (top of slot). A-Company Starfire produced a mean difference of 0.0007 inch between CP1 and TOS. However, the slot base of the stainless steel bracket of # 3/0 was the only exception. Its base was wider than its top. Looking carefully under microscope, there was a concave surface along one of the inner walls of the slot. This might be due to the machine vibration during the milling process.

Matasa (1988) described crystal sapphire bracket was manufactured by injecting crystalline alumina into metal molds made out of iridium or molibdenum, and subjecting it to temperatures of about 3100°F where sinterization occurred, by melting it through metal dies to intricate profiles, or by refining it from sintered or compacted alumina rods through processes called zone refining and EFG (Edge defined Film-fed Growth technique). Once the crystal rod of polycrystalline alumina was made, further machining with diamonds wheel (or slurries) leaded, step by step, to the desired shape of single bracket.

From table VII, all brackets show larger lumen dimensions than stated by manufactures. Lang (1981) using molar tubes for his study stated the slightly larger lumen dimensions of the tubes would facilitate placement of wire and decrease friction, but torquing control might be lost through increasing wire rotation. Using stainless steel brackets, Sebanc (1984) also came to the same conclusion, that is, slightly wider slot dimension would prevent any problems in inserting wire, especially larger wire which was necessary to engage between bracket and wire during torquing.

Another finding from this study was that the bases of the slots from Ormco Gem showed the most rounded bevels. Again, it might be due to manufacturer's tendency to make the corners of slots bases more rounded to avoid the concentration of stress. One of these individual brackets (#3) from Ormco Gem had a convex mass at the base of the slot. It affected the measurements of both rotation angle and slot dimensions at the contact point 1 and contact point 2. The other experimental groups also displayed rounded bevel at the corners of slot bases. On the other hand, the slots of Ormco stainless steel brackets showed square corners at the bases, but uneven surface within the inner walls of slots.

The Measurement of Wire

Table VIII indicates the mean measurements of widths and lengths of the wires obtained by using the travelling microscope. The average value of the wires is 0.0178 inch for width and 0.0248 inch for length from total 320 measurements, 160 for each horizontal and vertical dimension. From table VIII, it also can be seen that the range for width is from 0.0176 inch to 0.0179 inch, and for length is from 0.0245 inch to 0.0249 inch. By inspecting under the microscope more carefully, one could see the four corners of each wire were not identical. These stainless steel wires were from Rocky Mountain, and included 10 pieces within an un-opened batch. Most of the wires displayed the rounded bevel corners and were slightly constricted at the middle portion of the surface between the corners.

All of these shapes affected the binding areas of the wire within the slot and the actual horizontal and vertical dimensions of wires. Furthermore, it also had an effect on the amount of rotation angle between the wires and slots. For example, the wider and longer the wire is, the less the rotation of wire in the slot will be. But the measurements of deviation angle within tables XVIII- XXII do not show this consistent change. It was probably due to the different bevel contribution of each wire at the corners. Table VIII also shows that the actual dimensions of the wires used in this study are smaller than that represented by the manufacturer. Lang (1982) and Sebac (1984) had the same findings too. They concluded manufacturers intended to make wire smaller than specified. Lang stated it would facilitate the insertion of wire, decrease friction between the wire and slot, but lose proper torquing control. Sebanc noted it would avoid any problem of insertion of the wire into the slot, especially the larger wire sizes.

Table IX shows the dimensions of the wires used in this study measured by the micrometer. The average value measured by micrometer is larger than that obtained by the travelling microscope. It is due to the distance between two corners of the wires (either vertical or horizontal) being wider than that of middle portion of the wire. So the corners of each wire would be the first contact points between the wire and the inner walls of the micrometer. Furthermore, most of the wires did not show even smooth surfaces along the walls and corners. To prevent measurement error, the actual dimensions of wire were selected under the microscope as the average points along the walls of the wire. It is this reason that the measured results from the microscope show smaller values.

Sebanc (1984) .....stated square or rectangular wire is manufactured by passing round wire through a device called a "Turk's Head," which is a set of two rollers positioned 90 degrees to each other, and rolling to the desired dimensions. The edges of the wire remain rounded after this rolling process, resulting in the edge bevel....... .

He also concluded the greater the edge bevel on the arch wire was, the greater the deviation angle in the bracket would be.

The Measurement of Rotation Angle

Table X shows the measurements of the rotation angle obtained with the metallographic microscope. These measurements do not show consistent increase when the dimension of the slot increases. For example, the slot dimension of the upper left cuspid from Ormco Gem is smaller (see appendix B, Table XXIV; XXXIV,CP1=0.0209 inch, CP2=0.0229 inch, T.O.S=0.0233 inch) but shows a slightly larger rotation angle (19.3°) when compared with measurements of the upper right lateral incisor from the same manufacturer. The latter displays larger slot dimensions (CP1=0.0226 inch, CP2=0.0233 inch, T.O.S.=0.0257 inch) but a smaller rotation angle (19.1°). This phenomenon also exists in other brackets used in this study. The Ormco stainless steel slots show the largest mean value of rotation angle, followed by GAC, Ormco, Unitek, and A-Company. This sequence is not consistent with their slot dimensions.

There were additional factors which might affect the measured values from the Unitrol Metallographic microscope. These will be discussed later in this chapter.

The data displayed in table V are the values of rotation angle collected by method II (embedded) already discussed in chapter III. The angle between the vertical dimension of wire and the inner wall of slot connected to the wing was called A1. The angle between the vertical dimension of wire and the inner wall of slot connected to the base of slot was called A2. The slots of stainless steel brackets from Ormco show the largest values of both A1 and A2. This can be confirmed from table VII which indicates that the measurements of these slots have the largest values at the contact point 1 and the contact point 2. These two contact points are the function of the wire binding within the slot. If the dimension of the wire were fixed, the stainless steel brackets from Ormco would allow the wire more rotation than other brackets measured. Clinically, it implies less torquing efficiency when Ormco stainless steel brackets are used.

From table XI, another finding is that the average values of rotation angle of A1 are larger than those of A2. By using a geometric graph, it will be easy to understand this phenomenon. Theoretically, if the inner walls of slot were parallel, both A1 and A2 should have the same value. However, due to the tapered shape of the slot, they do have different measurements. Furthermore, the difference between A1 and A2 will be larger as the inner walls of slot are more tapered.

In the table XI, the last column shows the t-test to compare the mean value of rotation angle between A1 and A2 for each brand. The result shows that there is significant difference between A1 and A2 at a $p \leq 0.01$ significance level. A-Company shows the largest t-value ($t=5.54$), followed by Ormco Gem. From data, the t-test value for Ormco Gem should be larger than that of A-Company because of the Gem's more tapered shape of slot.

This phenomenon can be explained by observing the Ormco Gem slots under the microscope. The measurements of rotation angle of A1 and A2 were picked up by superimposing the intersection point of the cross lines of microscope on the intersection point between the wire and inner wall of the slot. As stated above, the slots from Ormco Gem displayed the most rounded corners around the bases. Most of the measurement errors were from measuring the A2 rotation angle. This value took the most straight line extending to the outer edge of the slot, rather than the angle between the wire and rounded curvature of the slot near the base. There would not be a definite line to be used to measure the rotation angle of A2 if the curved line relating to A2 measurement were selected. So the results of measured values of the A2 for Ormco Gem slots actually would have been larger. This decreased the difference between A1 and A2 measurements for Ormco Gem. This is the reason why Ormco Gem slots showed the most tapered shape but less difference between A1 and A2. The values of A2 for other slots except Ormco Gem did not have their problem in measurement. There were almost straight lines of inner walls of slots related to the measurement of A2 for the other brackets.

Comparison between Method I and Method II

The rotation degrees from these two methods are different. The average of difference for Ormco Gem is 2.77 degrees, 3.08 degrees for A-Company, 3.07 degrees for Unitek Transcend, 3.67 degrees for GAC - Allure and 1.72 degrees for Ormco Stainless Steel (Table X and Table XI). There were some factors which would affect the measurements from these two methods, such as (1) the length of wire used in this study, (2) the binding locus of wire within the slot, (3) the wire holder, and (4) the coaxiality between the wire and slot, and the experimental measurement technique.

As for factor (1), the longer the distance between the slot and wire holder was, the larger the measurement would be. This is due to more flexibility of wire when the increase of length. For the method (I), the length of wire was 30 mm. The length of wire used in the method (II) was 15 mm. So it was possible that the degrees of rotation would be larger when a wire was inserted into the slot and rotated in the method I, due to more flexibility of the wire.

As for factor (2), if the wire bound closer to the base of the slot, the measurements would be smaller. On the other hand, the measurements would be larger when the wire bound closer to the top of slot. As stated above, most of the slots displayed a tapered shape, narrower at the base and wider at the outer edge of slots. It could be due to higher contact points of wire within the slot in the method I and lower contact points of wire within the slot in the method II. The latter could be confirmed from the prepared samples under the microscope.

As for factor (3), movement of the wire-holder assembling play could affect the results of measurement especially for the method (I). Factor (4) would decrease the measurements if the long axis of wire insertion were not parallel to the long axis of the slot.

The last factor also could contribute the differences between these two methods. The measurements obtained from the method I was confirmed by visual observation and tactile sensation. This did exist some measurement errors.

The preparation of samples and measurements for these two methods are compared and shown in table XII. The measurements from the travelling microscope were smaller and more consistent than those from the Unitron Metallographic microscope, but much more time consuming.

The Relationship Between Slot Dimension and Rotation Angle

The mean values of slot dimensions (0.022 inch x 0.028 inch) and rotation degrees of wires (0.018 inch x 0.025 inch) in slots for each bracket are shown in tables XIII to XVII. The last column gives the mean values of rotation angle between A1 and A2. As stated above, there is a significant difference between A1 and A2 at $p \leq 0.01$. However, the difference is so small that it may be neglected from a clinical view point. For convenience of comparison of the rotation angles in the slots from four companies, the mean values from all measurements of A1 and A2 of each brand are used.

In table XIII, the slot of 3| should have a larger mean value of rotation angle due to its larger slot dimension. But there was a convex mass at the base of the slot, the wire did not bind at contact point 2.

This means that the wire did not fully rotate. So the measurements for both A1 and A2 were smaller. The measurements for contact point 1 might slightly decrease, and slightly increase for contact point 2.

In table XV, most of the slots of Unitek Transcend appeared to be more parallel to each other. The slot of 1 is the most parallel along the inner walls. The difference between A1 and A2 also is the smallest (0.14°).

From tables XV-XVI, the measurements of each slot at both CP1 and CP2 for Unitek Transcend and GAC Allure show less difference. This indicates that the inner walls of the slots are more parallel and the products are more under control.

In table XVII, the mean dimension of CP1 for the 3/0 slot shows the largest value. It is due to a large concave curvature along one of the inner walls around the base of the slot. The measurement of 1/k slot at the TOS also is larger. This is due to a stepped out surface along one of the inner walls.

Tables XVIII-XXII show the average measurement of actual each wire size and each slot width between contact point 1 and contact point 2, the theoretical calculation of rotation angle from Dellinger's Equation for nominal wire size (0.018 inch x 0.025 inch) and slot width (0.022 inch), the mean value of rotation angle between A1 and A2 of each bracket, and the bevel contribution from the corners of each wire.

When the mean value of measured rotation angle of each brand (Table XI) is compared with that of the theoretical value (9.82 degrees) from the Dellinger's Equation, one can see that there are 6.01 degrees difference between these two measurements for Ormco Gem slots, 5.41 degrees difference for A-Company slots, 5.64 degrees for Unitek products, 5.35 degrees difference for GAC - Allure slots, and 7.73 degrees for Ormco stainless steel slots. The theoretical rotation value is 9.82 degrees for a perfectly nominal wire size (0.018 inch x 0.025 inch) and slot (0.022 inch x 0.028 inch), but actually there are three factors that will affect the rotation angle, They are: (1) the actual slot width, (2) the actual wire dimension, and (3) the rounded bevel at the corners of the wire. All of these factors are related to the quality of the manufacturer's products.

The actual mean value of slot width for each bracket is shown in tables XIII-XVII. The actual wire dimension for each combination between wire and slot is summarized at the second column from left margin in tables XVIII-XXII.

Due to the factors (1) and (2) already known, the percentage of the bevel contribution from each tested wire can be obtained by substrating the calculated rotation angle from actual mean value of rotation angle, then divided by calculated rotation angle and multiplied by 100 %. The formula is summarized as following:

$$\frac{\text{Actual Mean of Rotation Angle} - \text{Calculated Rotation Angle}}{\text{Calculated Rotation Angle}} \times 100\ \%$$

= Percentage of Bevel Contribution from a tested wire

The calculated rotation angle is based on the actual dimension of the wire and slot and obtained by substituting measured values into Dellinger's equation.

In table XVIII, the wires in the Ormco Gem slots show a range from 11.66% to 65.91% of the bevel contribution. The wire in the 3┘ slot displays only 11% of bevel contribution. It is due to the wire not binding at contact point 2. Therefore the smaller actual rotation angle would affect the calculated value of bevel contribution from the wire. But it is not the problem of the wire, it is due to the imperfect slot.

The wire in the └3 slot shows a 65.91% bevel contribution. The reason is that there was a very rounded bevel around the slot base. As discussed above, the rotation angle of A2 for this slot was picked up by the angle between wire and the most straight line of the slot wall. The measured angle of A2 was larger than expected, the result of calculation would show a larger bevel contribution from the wire.

On the average, the bevel contribution of the wires in the Ormco Gem slots is inconsistent and larger than the other manufacturer's products. Again it is the rounded bevel around the slot base that affects the measurements of actual rotation angle.

In table XIX, the average bevel contribution of wires in A-Company slots is 31.2% with a range from 29.33% to 32.87%. The range of bevel contribution of wires in Unitek slots is from 29.61% to 31.84% with a mean value of 31.12% and is shown in table XX. Table XXI indicates that the average bevel contribution of wires in GAC slots is 31.32% with a range of 29.84% to 32.74%.

The average bevel contribution of wires in Ormco stainless steel slots is 30.07% with a range from 25.64% to 32.45% and is shown in table XXII. The wire in 3/0 slot shows a smaller bevel contribution percentage (25.64%). Again, it is because a concave surface along one of the inner walls of slot which affected the measurement of CP1. The mean value of CP1 is the largest as seen in table XVII (0.0236 inch). So the mean value of slot width from CP1 and CP2 is larger and the calculated rotation angle is larger, too. The result of the calculated bevel contribution of the wire is smaller. The error is due to the machine during the milling process.

As stated before, the corners of wires examined under the microscope showed different morphology. These could provide different percentages of bevel contribution. It can also be confirmed that the greater the rounded bevel at the corners of wire is, the greater the percent contribution to rotation angle will be. For example, the mean value of wire (0.0178 inch x 0.0246 inch) size and slot width (0.0224 inch) for the Unitek 5 slot showed 29.61% of bevel contribution and 15.1 degrees of measured rotation angle; on the other hand, the same wire size and slot for the Unitek 3 indicate 31.42% of bevel contribution and 15.31 degree of measured rotation angle.

The value of rotation angles obtained by method II in this study differed from that of Dellinger's and Creekmore's, but was closer to the published data of Creekmore's. Dellinger only considered the manufacturer's tolerance of wire dimension, while Creekmore concentrated on the tolerance of the slot. Both wire and slot tolerance were considered and related to bevel contribution of the wire to the rotation angle in this study.

In table XXIII, it indicates that the degrees of rotation angle of wires (from method II) used in this study do not show significant difference among Ormco Gem, A-Company Starfire, and Unitek Trancsand. However there existed many errors from measured Ormco Gem slots due to more rounded bevel at the corners of the slots. There is also no significant difference of rotation angle between GAC-Allure and A-Company Starfire based on this study.

Chapter VI

Conclusion

By using two methods to evaluate the rotation angle of a rectangular wire in a slot, the following conclusions are made.

There do exist differences between the actual wire dimensions and manufacturers' stated dimensions.

There do exist differences between actual slot dimensions and manufacturers' specifications.

The ceramic and sapphire slot bases showed a more rounded surface bevel than those of stainless steel brackets, especially the sapphire slots from Ormco.

By using the student's t-test, the degrees of the rotation angles show little difference among the ceramic and sapphire brackets from four companies. The stainless steel brackets showed the largest degrees of rotation compared to the experimental groups.

In general, the measured degrees of the rotation angle from the metallographic microscope and travelling microscope did show differences. The values from the former were an average of two degrees larger than those from the latter.

To prepare the samples used in this study, method II was much more time consuming than method I, but the results of method II were more consistence between rotation angle and expected rotation from actual wire and slot dimensions.

The bevel contribution from the wire did play an important role related to the rotation. As expected, the more rounded the corners of the wire are, the more the rotation of wire within the slot will be.

There does exist a difference between theoretical rotation angle and actually measured rotation angle. The actual wire dimensions, slot dimensions and the amount of bevel at the corners of the wires contributed to this difference.

Chapter VII

Summary

The purpose of this study was to evaluate the rotation angles of orthodontic rectangular wires in the new generation of ceramic and sapphire brackets and compare the measured values and morphology of these slots with those of stainless steel slots.

Ceramic, Sapphire, and stainless steel brackets from Unitek, GAC, A-Company, and Ormco companies were used.

Each 0.022 inch x 0.028 inch slot from each company was tested by an 0.018 inch x 0.025 inch stainless steel rectangular orthodontic wire from Rocky mountain.

Measurements were obtained by using the Unitron Metallographic and the travelling microscope. On the Unitron Metallographic microscope, the coaxiality among the wire and slot was maintained by a holding vise, rotation stage, and spring wire holder.

Both axes of each bracket slot and test-wire were oriented, so these two axes were ground perpendicular to them by the Buehler Ecomet III.

Measurements of wire sizes, slot dimensions and rotation degrees were made.

The measurements of rotation degrees were compared with those of the theoretically calculated values based on the actual measured wire sizes and slot dimensions. The difference was attributed to the rounded bevels at the corners of the wire.

Student's t-test was used to compare the wire's angles of rotation in slots of different manufacturers.

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APPENDIX A

FIGURES 14 THROUGH 21

REPRESENTATIVE PHOTOGRAPHS OF RECTANGULAR WIRES ROTATING IN THE CERAMIC, SAPPHIRE, AND STAINLESS STEEL BRACKETS TESTED IN THIS STUDY FROM METHOD I.
(All photographs at 10X)

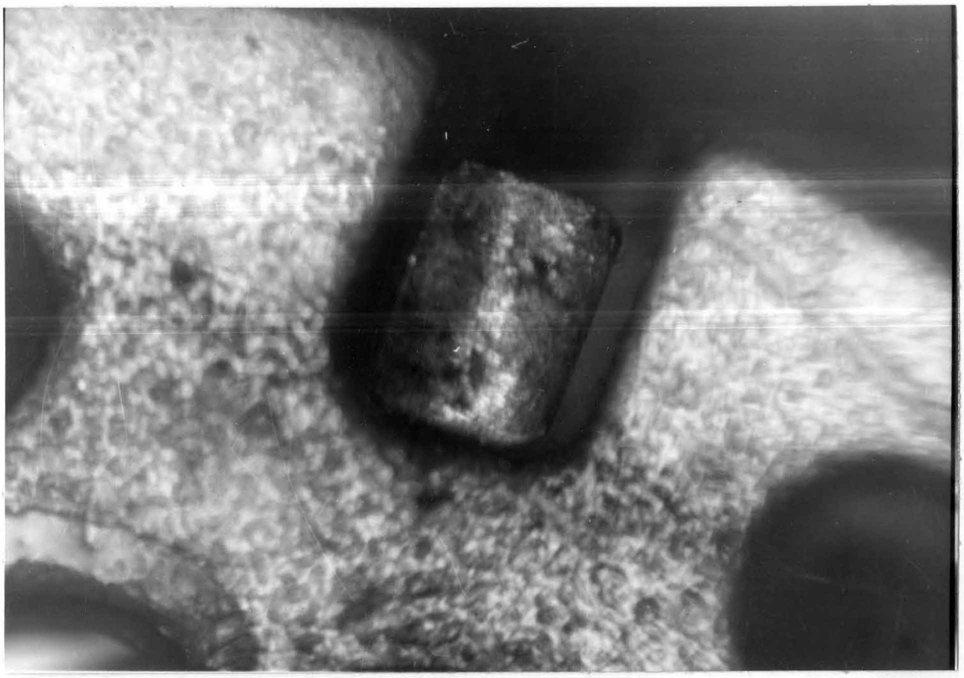

Fig. 14. .018 inch x .025 inch wire in Ormco. .022 inch x .028 inch sapphire bracket. (passive)

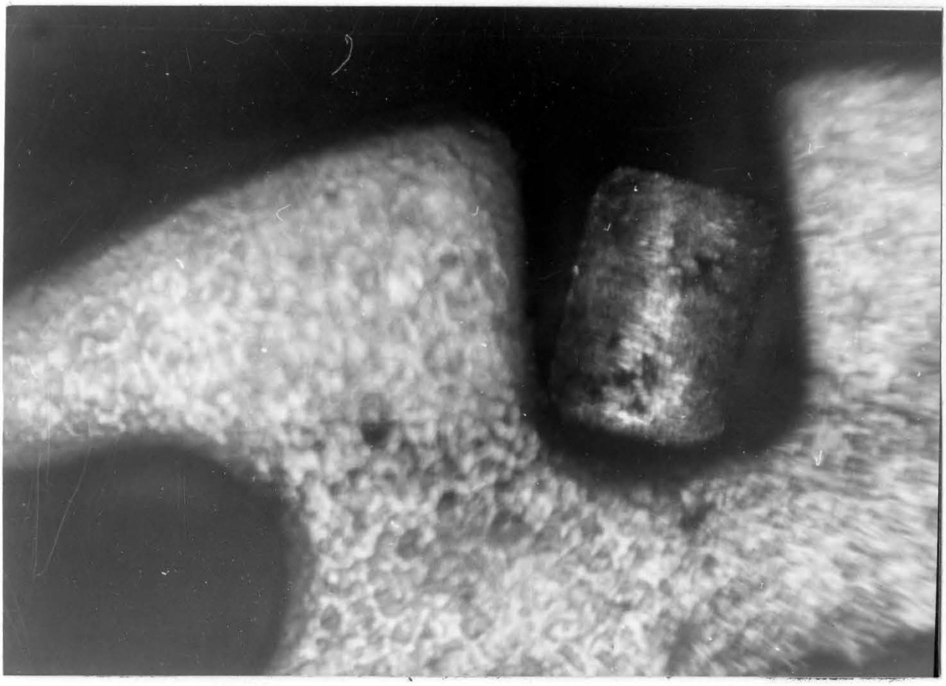

Fig. 15. .018 inch x .025 inch wire in Ormco. .022 inch x .028 inch sapphire bracket. (binding)

Fig. 16. .018 inch x .025 inch wire in Unitek.
.022 inch x .028 inch Transcend bracket.
(passive)

Fig. 17. .018 inch x .025 inch wire in Unitek.
.022 inch x .028 inch Transcend bracket.
(binding)

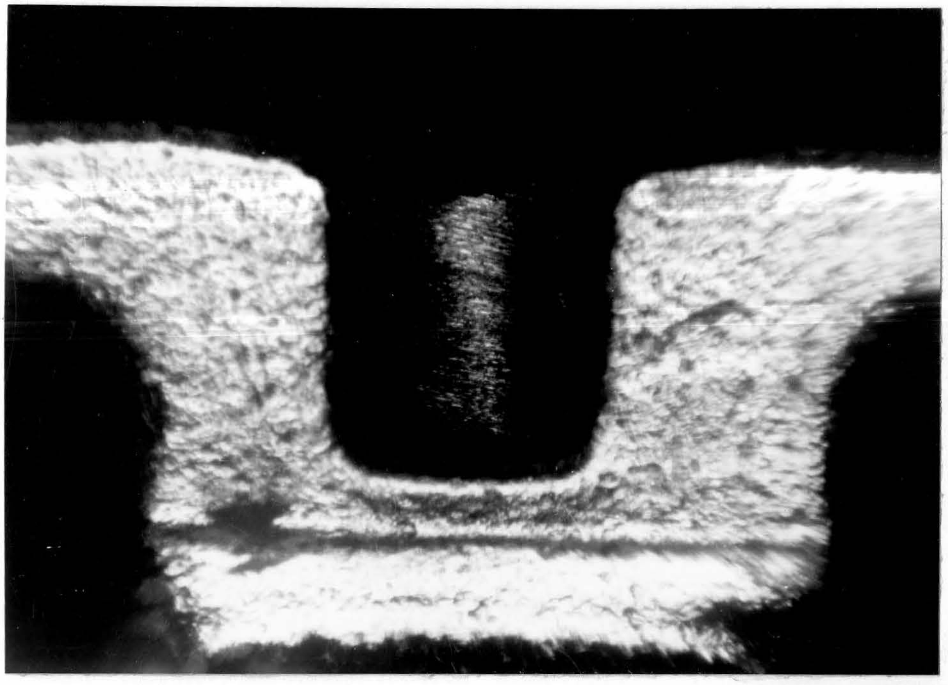

Fig. 18. .018 inch x .025 inch wire in GAC.
.022 inch x .028 inch Allure bracket.
(passive)

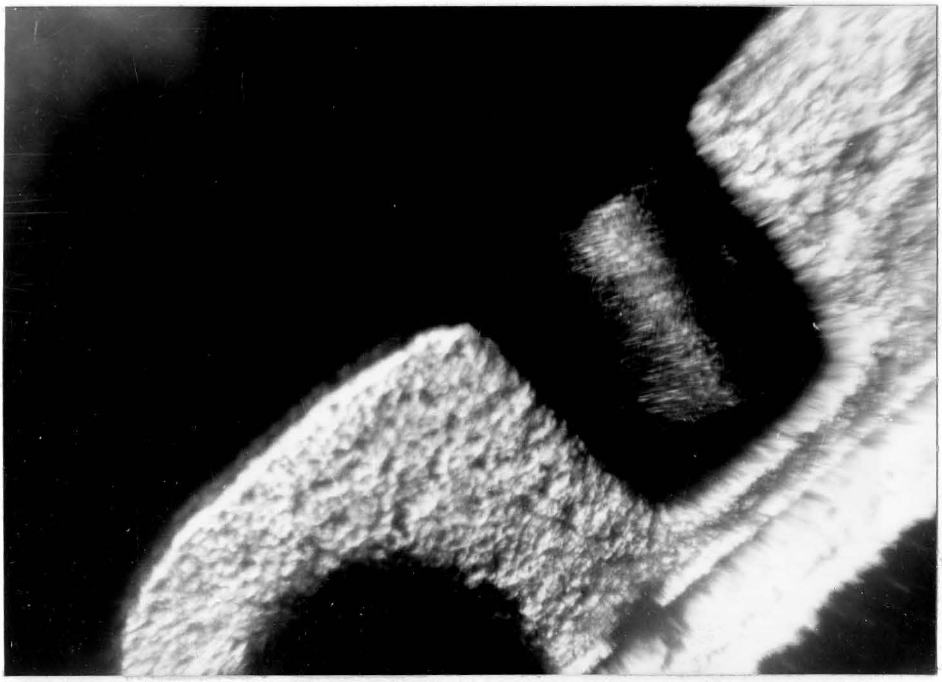

Fig. 19. .018 inch x .025 inch wire in GAC.
.022 inch x .028 inch Allure bracket.
(binding)

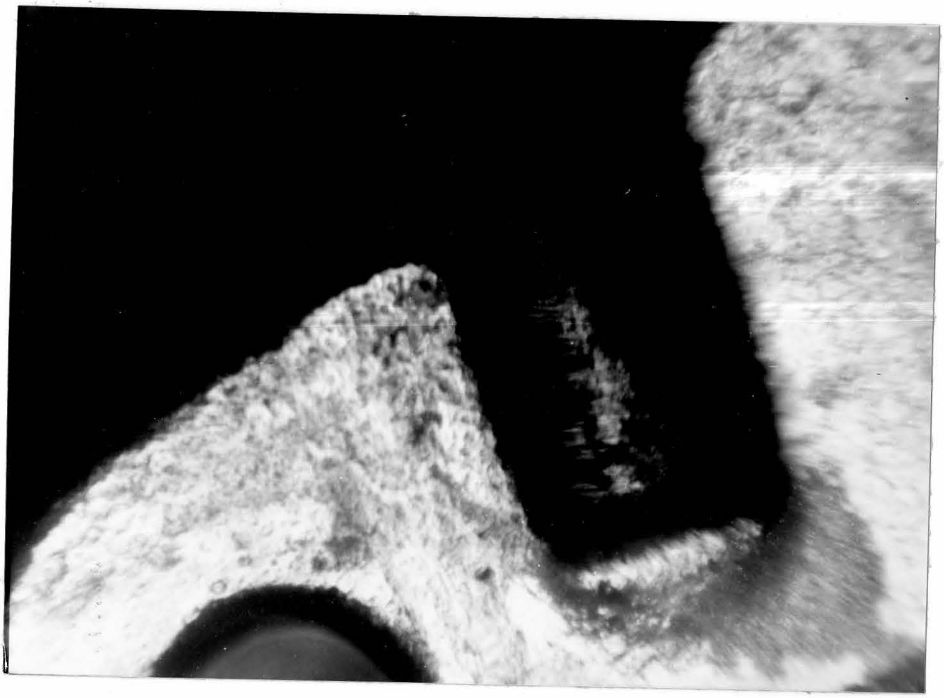

Fig. 20. .018 inch x .025 inch wire in Ormco.
.022 inch x .028 inch stainless steel bracket.
(passive)

Fig. 21. .018 inch x .025 inch wire in Ormco.
.022 inch x .028 inch stainless steel bracket.
(binding)

FIGURES 22 THROUGH 29

REPRESENTATIVE PHOTOGRAPHS OF RECTANGULAR WIRES ROTATING IN THE CERAMIC, SAPPHIRE, AND STAINLESS STEEL BRACKETS TESTED IN THIS STUDY FROM EMBEDDED METHOD.

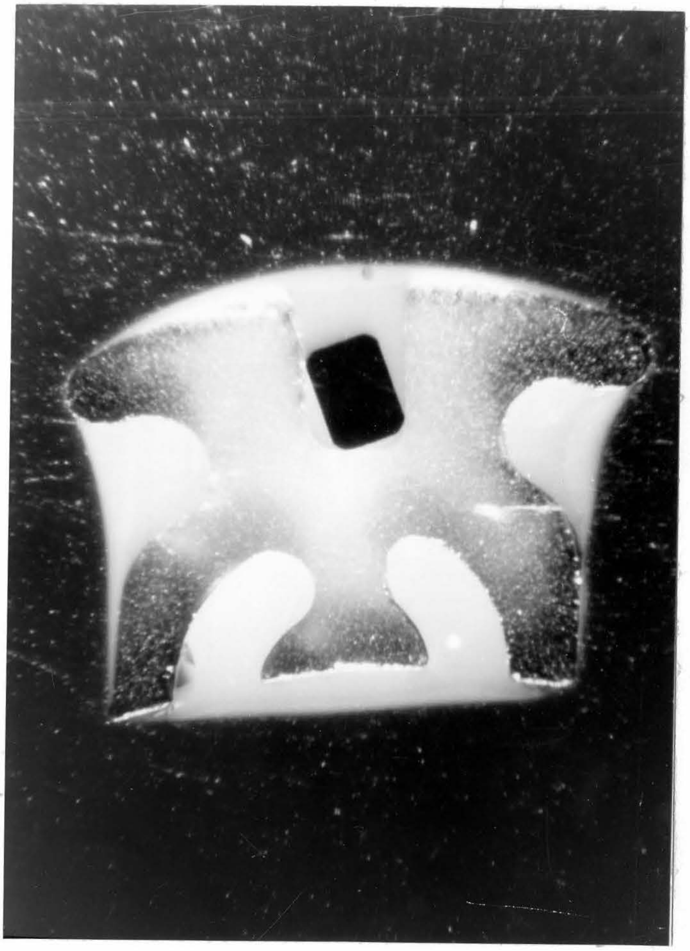

Fig. 22. .018 inch x .025 inch wire in Ormco.
.022 inch x .028 inch Sapphire bracket.
(binding; 2.4x)

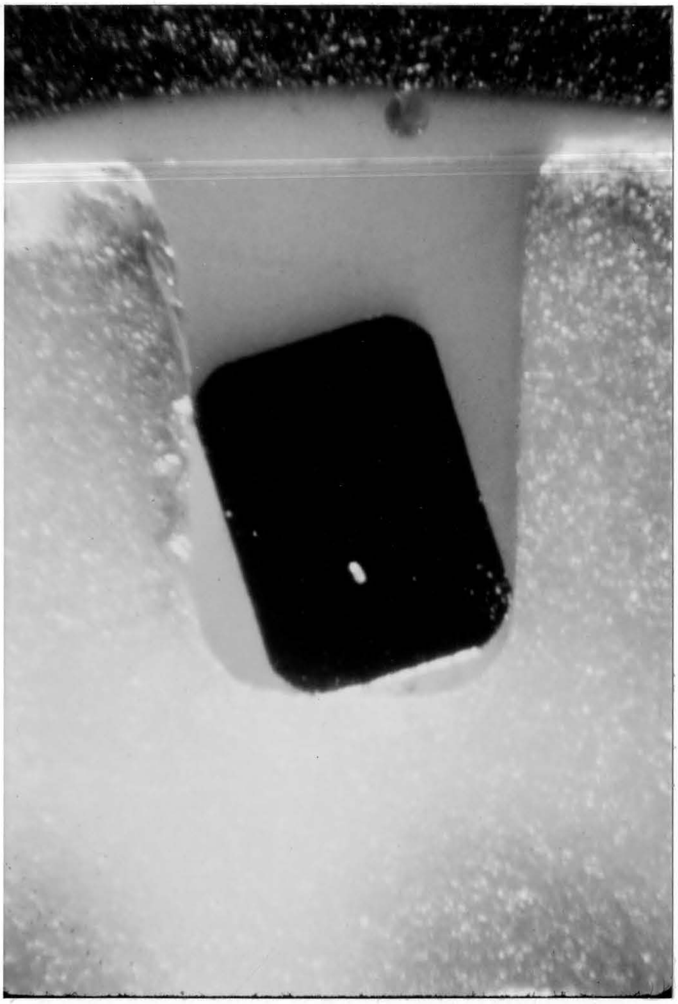

Fig. 23. .018 inch x .025 inch wire in Ormco.
.022 inch x .028 inch Sapphire bracket.
(binding; 7.2x)

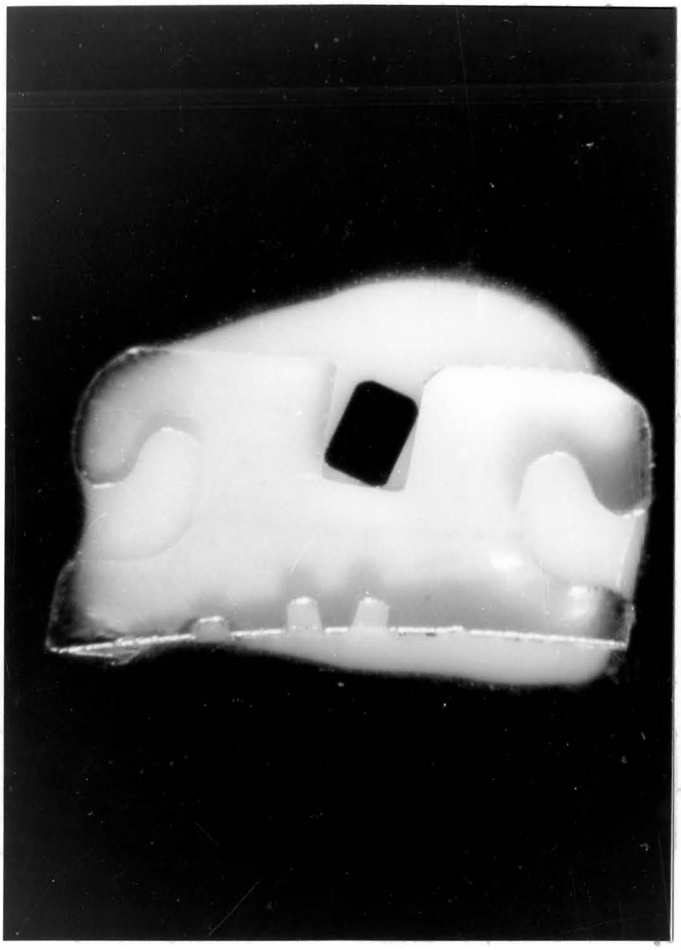

Fig. 24. .018 inch x .025 inch wire in A-company. .022 inch x .028 inch Starfire bracket. (binding; 2.4x)

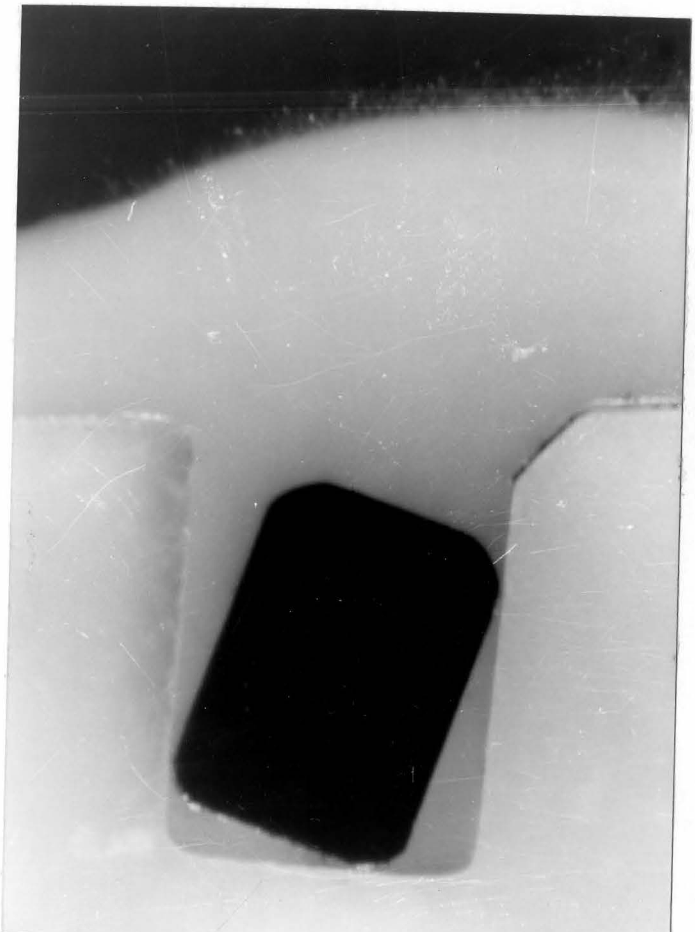

Fig. 25. .018 inch x .025 inch wire in A-company.
.022 inch x .028 inch Starfire bracket.
(binding; 7.2X)

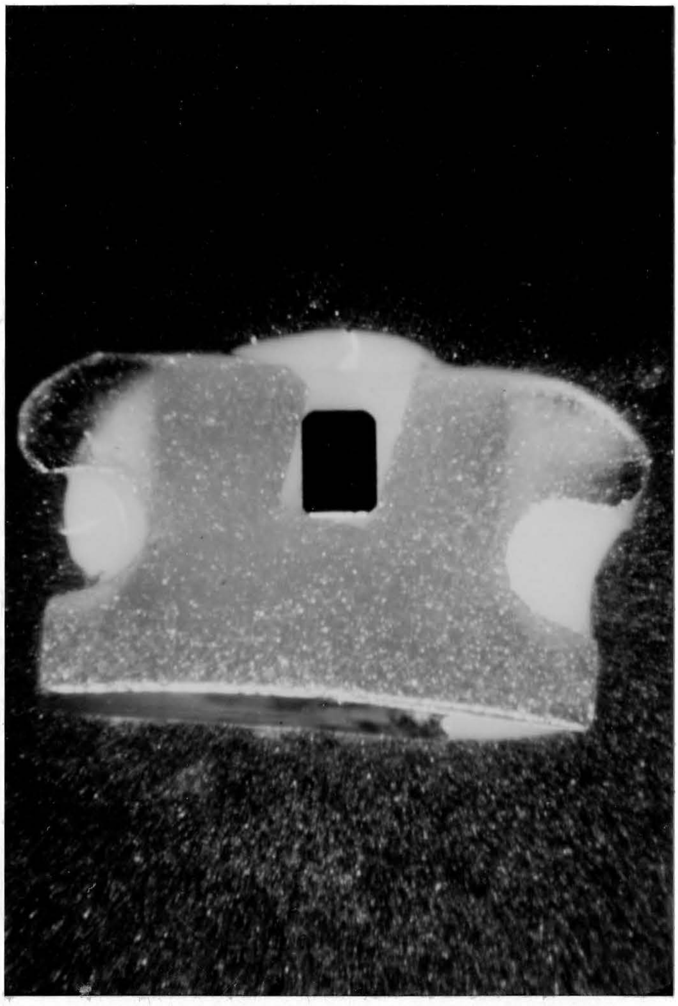

Fig. 26. .018 inch x .025 inch wire in Unitek.
.022 inch x .028 inch Transcend bracket.
(binding; 2.4X)

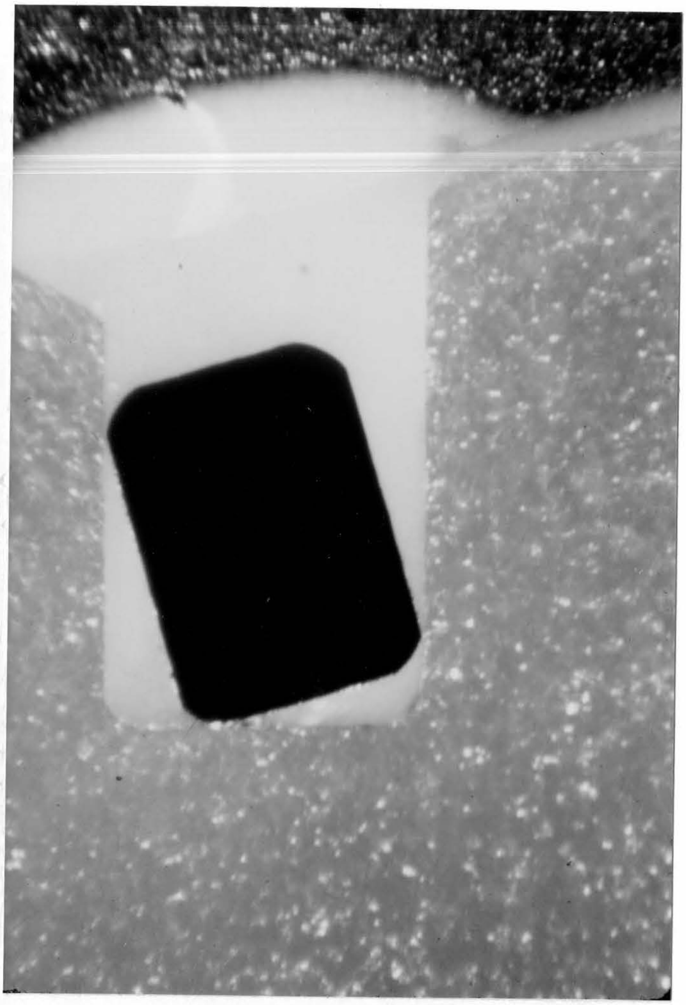

Fig. 27. .018 inch x .025 inch wire in Unitek.
.022 inch x .028 inch Transcend bracket.
(binding; 7.2X)

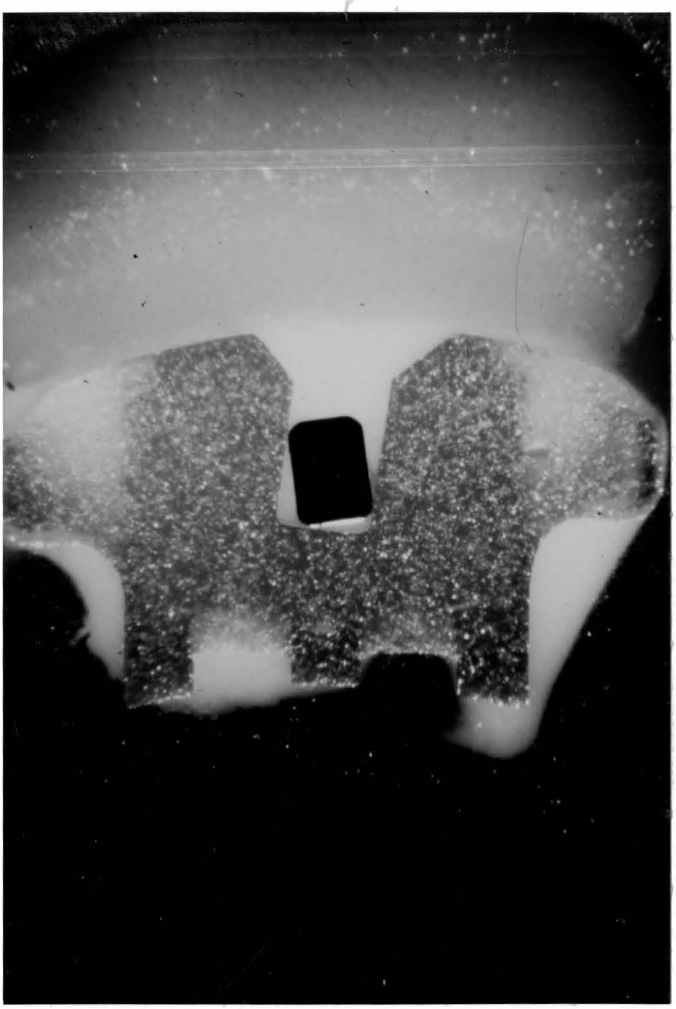

Fig. 28. .018 inch x .025 inch wire in GAC.
.022 inch x .028 inch Allure bracket.
(binding; 2.4X)

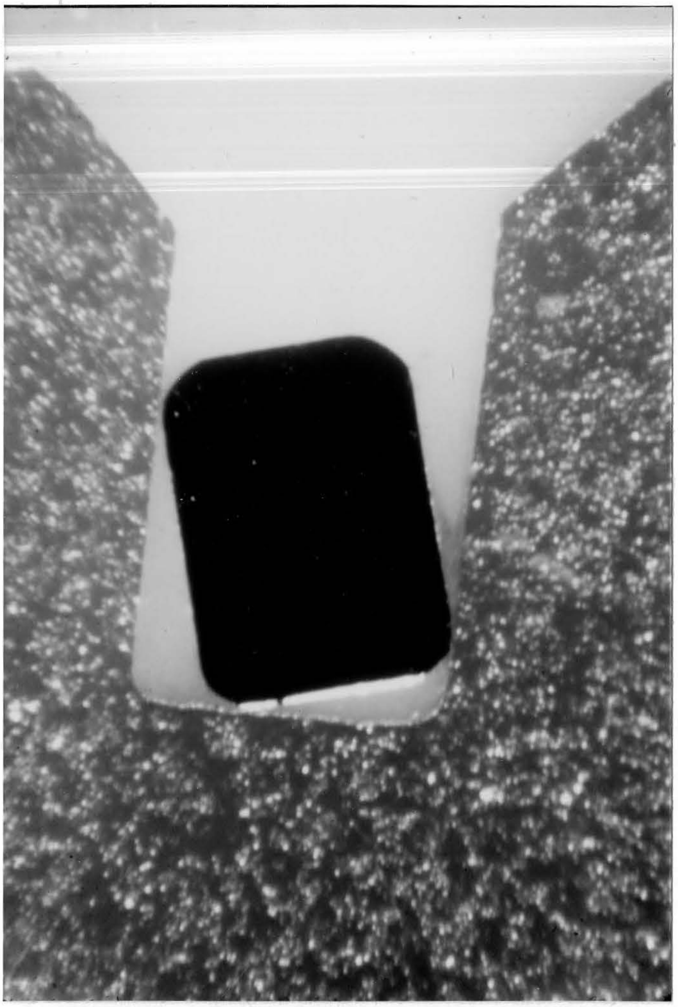

Fig. 29. .018 inch x .025 inch wire in GAC.
.022 inch x .028 inch Allure bracket.
(binding; 7.2X)

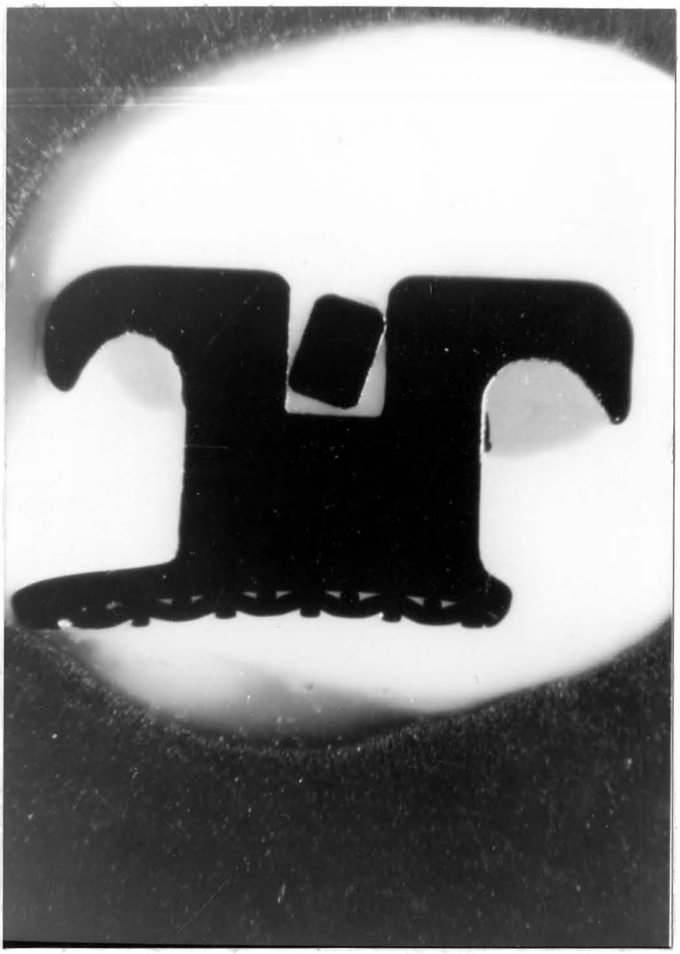

Fig. 30. .018 inch x .025 inch wire in Ormco
.022 inch x .028 inch stainless steel bracket.
(binding; 2.4X)

Fig. 31. .018 inch x .025 inch wire in Ormco.
.022 inch x .028 inch stainless steel bracket.
(binding; 7.2X)

APPENDIX 8

Table XXIV

Dimensions of Bracket Slot (0.022 inch)
mm (inch), five replicates; each slot

GEM	Contact Point 1	Contact Point 2	Top of Slot
	0.0566 (0.0223)	0.0578 (0.0228)	0.0595 (0.0234)
	0.0567 (0.0223)	0.0578 (0.0228)	0.0595 (0.0234)
3|	0.0567 (0.0223)	0.0579 (0.0228)	0.0596 (0.0235)
	0.0568 (0.0224)	0.0579 (0.0228)	0.0596 (0.0235)
	0.0568 (0.0224)	0.0579 (0.0228)	0.0596 (0.0235)
	0.0575 (0.0226)	0.0593 (0.0233)	0.0653 (0.0257)
	0.0575 (0.0226)	0.0593 (0.0233)	0.0653 (0.0257)
2|	0.0575 (0.0226)	0.0593 (0.0233)	0.0654 (0.0257)
	0.0576 (0.0227)	0.0594 (0.0234)	0.0654 (0.0257)
	0.0576 (0.0227)	0.0594 (0.0234)	0.0654 (0.0257)
	0.0558 (0.0220)	0.0570 (0.0224)	0.0598 (0.0235)
	0.0558 (0.0220)	0.0571 (0.0225)	0.0599 (0.0236)
1|	0.0559 (0.0220)	0.0571 (0.0225)	0.0600 (0.0236)
	0.0559 (0.0220)	0.0571 (0.0225)	0.0600 (0.0236)
	0.0560 (0.0220)	0.0572 (0.0225)	0.0600 (0.0236)
	0.0565 (0.0222)	0.0566 (0.0223)	0.0567 (0.0223)
	0.0565 (0.0222)	0.0566 (0.0223)	0.0567 (0.0223)
|1	0.0566 (0.0223)	0.0567 (0.0223)	0.0567 (0.0223)
	0.0566 (0.0223)	0.0567 (0.0223)	0.0567 (0.0223)
	0.0567 (0.0223)	0.0567 (0.0223)	0.0568 (0.0224)
	0.0574 (0.0226)	0.0589 (0.0232)	0.0591 (0.0233)
	0.0575 (0.0226)	0.0590 (0.0232)	0.0592 (0.0233)
|2	0.0575 (0.0226)	0.0590 (0.0232)	0.0592 (0.0233)
	0.0575 (0.0226)	0.0590 (0.0232)	0.0593 (0.0233)
	0.0576 (0.0227)	0.0591 (0.0233)	0.0593 (0.0233)
	0.0530 (0.0209)	0.0581 (0.0229)	0.0590 (0.0232)
	0.0530 (0.0209)	0.0582 (0.0229)	0.0591 (0.0233)
|3	0.0531 (0.0209)	0.0582 (0.0229)	0.0591 (0.0233)
	0.0531 (0.0209)	0.0583 (0.0230)	0.0591 (0.0233)
	0.0531 (0.0209)	0.0583 (0.0230)	0.0592 (0.0233)

Table XXV

Dimensions of Bracket slot (0.022)
mm (inch), five replicates; each slot

A-C*	Contact Point 1	Contact Point 2	Top of Slot
	0.0567 (0.0223)	0.0573 (0.0226)	0.0577 (0.0227)
	0.0567 (0.0223)	0.0573 (0.0226)	0.0577 (0.0227)
3|	0.0568 (0.0224)	0.0574 (0.0226)	0.0578 (0.0228)
	0.0568 (0.0224)	0.0574 (0.0226)	0.0578 (0.0228)
	0.0569 (0.0224)	0.0575 (0.0226)	0.0578 (0.0228)
	0.0558 (0.0220)	0.0578 (0.0228)	0.0593 (0.0233)
	0.0559 (0.0220)	0.0578 (0.0228)	0.0593 (0.0233)
2|	0.0559 (0.0220)	0.0578 (0.0228)	0.0594 (0.0234)
	0.0559 (0.0220)	0.0579 (0.0228)	0.0594 (0.0234)
	0.0560 (0.0220)	0.0580 (0.0228)	0.0595 (0.0234)
	0.0558 (0.0220)	0.0569 (0.0224)	0.0570 (0.0224)
	0.0559 (0.0220)	0.0570 (0.0224)	0.0571 (0.0225)
1|	0.0559 (0.0220)	0.0570 (0.0224)	0.0571 (0.0225)
	0.0560 (0.0220)	0.0570 (0.0224)	0.0572 (0.0225)
	0.0561 (0.0221)	0.0570 (0.0224)	0.0572 (0.0225)
	0.0552 (0.0217)	0.0567 (0.0223)	0.0573 (0.0226)
	0.0553 (0.0218)	0.0567 (0.0223)	0.0573 (0.0226)
|1	0.0554 (0.0218)	0.0567 (0.0223)	0.0574 (0.0226)
	0.0554 (0.0218)	0.0567 (0.0223)	0.0575 (0.0226)
	0.0555 (0.0219)	0.0568 (0.0224)	0.0575 (0.0226)
	0.0565 (0.0222)	0.0574 (0.0226)	0.0578 (0.0228)
	0.0565 (0.0222)	0.0575 (0.0226)	0.0578 (0.0228)
|2	0.0565 (0.0222)	0.0575 (0.0226)	0.0578 (0.0228)
	0.0566 (0.0223)	0.0576 (0.0227)	0.0579 (0.0228)
	0.0567 (0.0223)	0.0576 (0.0227)	0.0580 (0.0228)
	0.0567 (0.0223)	0.0572 (0.0225)	0.0574 (0.0226)
	0.0568 (0.0224)	0.0572 (0.0225)	0.0574 (0.0226)
|3	0.0568 (0.0224)	0.0572 (0.0225)	0.0575 (0.0226)
	0.0568 (0.0224)	0.0573 (0.0226)	0.0575 (0.0226)
	0.0569 (0.0224)	0.0573 (0.0226)	0.0576 (0.0227)

*A-Company

Table XXVI
Dimensions of Bracket slot (0.022 inch)
mm (inch), five replicates; each slot

*Uni.	Contact point 1	Contact point 2	Top of slot
	0.0564 (0.0222)	0.0570 (0.0224)	0.0571 (0.0225)
	0.0565 (0.0222)	0.0570 (0.0224)	0.0572 (0.0225)
5|	0.0566 (0.0223)	0.0570 (0.0224)	0.0572 (0.0225)
	0.0566 (0.0223)	0.0570 (0.0224)	0.0573 (0.0226)
	0.0566 (0.0223)	0.0571 (0.0225)	0.0573 (0.0226)
	0.0564 (0.0222)	0.0567 (0.0223)	0.0570 (0.0224)
	0.0565 (0.0222)	0.0567 (0.0223)	0.0570 (0.0224)
4|	0.0565 (0.0222)	0.0567 (0.0223)	0.0571 (0.0225)
	0.0566 (0.0223)	0.0568 (0.0224)	0.0571 (0.0225)
	0.0566 (0.0223)	0.0569 (0.0224)	0.0572 (0.0225)
	0.0577 (0.0227)	0.0578 (0.0228)	0.0579 (0.0228)
	0.0577 (0.0227)	0.0578 (0.0228)	0.0579 (0.0228)
1|	0.0578 (0.0228)	0.0578 (0.0228)	0.0580 (0.0228)
	0.0578 (0.0228)	0.0578 (0.0228)	0.0580 (0.0228)
	0.0578 (0.0228)	0.0579 (0.0228)	0.0580 (0.0228)
	0.0568 (0.0224)	0.0571 (0.0225)	0.0578 (0.0228)
	0.0569 (0.0224)	0.0571 (0.0225)	0.0578 (0.0228)
|1	0.0569 (0.0224)	0.0571 (0.0225)	0.0579 (0.0228)
	0.0569 (0.0224)	0.0572 (0.0225)	0.0579 (0.0228)
	0.0570 (0.0224)	0.0572 (0.0225)	0.0579 (0.0228)
	0.0566 (0.0223)	0.0569 (0.0224)	0.0571 (0.0225)
	0.0567 (0.0223)	0.0570 (0.0224)	0.0571 (0.0225)
|3	0.0568 (0.0224)	0.0570 (0.0224)	0.0572 (0.0225)
	0.0568 (0.0224)	0.0571 (0.0225)	0.0572 (0.0225)
	0.0569 (0.0224)	0.0571 (0.0225)	0.0573 (0.0226)
	0.0566 (0.0223)	0.0572 (0.0225)	0.0577 (0.0227)
	0.0567 (0.0223)	0.0572 (0.0225)	0.0577 (0.0227)
|4	0.0567 (0.0223)	0.0572 (0.0225)	0.0577 (0.0227)
	0.0567 (0.0223)	0.0572 (0.0225)	0.0578 (0.0228)
	0.0568 (0.0224)	0.0573 (0.0226)	0.0578 (0.0228)
	0.0571 (0.0225)	0.0572 (0.0225)	0.0574 (0.0226)
	0.0571 (0.0225)	0.0572 (0.0225)	0.0574 (0.0226)
|5	0.0571 (0.0225)	0.0572 (0.0225)	0.0575 (0.0226)
	0.0572 (0.0225)	0.0573 (0.0226)	0.0575 (0.0226)
	0.0572 (0.0225)	0.0573 (0.0226)	0.0575 (0.0226)

*Unitek

Table XXVII

Dimensions of bracket slot (0.022 inch)
mm (inch), five replicates; each slot

GAC	Contact point 1	Contact point 2	Top of slot
	0.0566 (0.0223)	0.0567 (0.0223)	0.0569 (0.0224)
	0.0566 (0.0223)	0.0567 (0.0223)	0.0569 (0.0224)
5⌋	0.0566 (0.0223)	0.0567 (0.0223)	0.0570 (0.0224)
	0.0567 (0.0223)	0.0567 (0.0223)	0.0570 (0.0224)
	0.0567 (0.0223)	0.0568 (0.0224)	0.0570 (0.0224)
	0.0570 (0.0224)	0.0572 (0.0225)	0.0575 (0.0226)
	0.0570 (0.0224)	0.0572 (0.0225)	0.0576 (0.0227)
4⌋	0.0570 (0.0224)	0.0573 (0.0226)	0.0576 (0.0227)
	0.0570 (0.0224)	0.0573 (0.0226)	0.0576 (0.0227)
	0.0571 (0.0225)	0.0573 (0.0226)	0.0577 (0.0227)
	0.0567 (0.0223)	0.0569 (0.0224)	0.0571 (0.0225)
	0.0567 (0.0223)	0.0570 (0.0224)	0.0571 (0.0225)
3⌋	0.0567 (0.0223)	0.0570 (0.0224)	0.0572 (0.0225)
	0.0568 (0.0224)	0.0571 (0.0225)	0.0572 (0.0225)
	0.0568 (0.0224)	0.0571 (0.0225)	0.0573 (0.0226)
	0.0569 (0.0224)	0.0573 (0.0226)	0.0577 (0.0227)
	0.0569 (0.0224)	0.0573 (0.0226)	0.0577 (0.0227)
2⌋	0.0570 (0.0224)	0.0574 (0.0226)	0.0578 (0.0228)
	0.0570 (0.0224)	0.0574 (0.0226)	0.0578 (0.0228)
	0.0571 (0.0225)	0.0575 (0.0226)	0.0579 (0.0228)
	0.0568 (0.0224)	0.0572 (0.0225)	0.0575 (0.0226)
	0.0568 (0.0224)	0.0572 (0.0225)	0.0575 (0.0226)
⌊2	0.0569 (0.0224)	0.0572 (0.0225)	0.0576(0.0227)
	0.0570 (0.0224)	0.0573 (0.0226)	0.0576 (0.0227)
	0.0570 (0.0224)	0.0573 (0.0226)	0.0576 (0.0227)
	0.0566 (0.0223)	0.0567 (0.0223)	0.0569 (0.0224)
	0.0566 (0.0223)	0.0567 (0.0223)	0.0570 (0.0224)
⌊3	0.0566 (0.0223)	0.0567 (0.0223)	0.0570 (0.0224)
	0.0567 (0.0223)	0.0568 (0.0224)	0.0571 (0.0225)
	0.0567 (0.0223)	0.0568 (0.0224)	0.0571 (0.0225)
	0.0564 (0.0222)	0.0567 (0.0223)	0.0569 (0.0224)
	0.0565 (0.0222)	0.0567 (0.0223)	0.0570 (0.0224)
⌊5	0.0566 (0.0223)	0.0567 (0.0223)	0.0570 (0.0224)
	0.0566 (0.0223)	0.0568 (0.0224)	0.0571 (0.0225)
	0.0567 (0.0223)	0.0568 (0.0224)	0.0571 (0.0225)

Table XXVIII

dimensions of Bracket slot (0.022 inch)
mm (inch), five replicates; each slot

*OSS	Contact point 1	Contact point 2	Top of slot
	#0.0597 (0.0235)	0.0587 (0.0231)	0.0588 (0.0231)
	#0.0598 (0.0235)	0.0587 (0.0231)	0.0588 (0.0231)
3/0	#0.0599 (0.0236)	0.0588 (0.0231)	0.0588 (0.0231)
	#0.0599 (0.0236)	0.0588 (0.0231)	0.0589 (0.0232)
	#0.0600 (0.0236)	0.0589 (0.0232)	0.0589 (0.0232)
	0.0570 (0.0224)	0.0588 (0.0231)	0.0592 (0.0233)
	0.0570 (0.0224)	0.0589 (0.0232)	0.0593 (0.0233)
3/1	0.0571 (0.0225)	0.0589 (0.0232)	0.0593 (0.0233)
	0.0571 (0.0225)	0.0589 (0.0232)	0.0593 (0.0233)
	0.0572 (0.0225)	0.0590 (0.0232)	0.0594 (0.0234)
	0.0584 (0.0230)	0.0589 (0.0232)	0.0592 (0.0233)
	0.0585 (0.0230)	0.0589 (0.0232)	0.0592 (0.0233)
3/2	0.0585 (0.0230)	0.0589 (0.0232)	0.0593 (0.0233)
	0.0586 (0.0231)	0.0590 (0.0232)	0.0593 (0.0233)
	0.0586 (0.0231	0.0590 (0.0232)	0.0594 (0.0234)
	0.0584 (0.0230)	0.0585 (0.0230)	0.0593 (0.0233)
	0.0584 (0.0230)	0.0585 (0.0230)	0.0593 (0.0233)
1/k	0.0584 (0.0230)	0.0585 (0.0230)	0.0593 (0.0233)
	0.0585 (0.0230)	0.0586 (0.0231)	0.0594 (0.0234)
	0.0586 (0.0231)	0.0586 (0.0231)	0.0594 (0.0234)
	0.0575 (0.0226)	0.0578 (0.0228)	0.0590 (0.0232)
	0.0576 (0.0227)	0.0579 (0.0228)	0.0590 (0.0232)
4/2	0.0576 (0.0227)	0.0581 (0.0229)	0.0591 (0.0233)
	0.0576 (0.0227)	0.0581 (0.0229)	0.0591 (0.0233)
	0.0577 (0.0227)	0.0581 (0.0229)	0.0591 (0.0233)
	0.0579 (0.0228)	0.0586 (0.0231)	0.0590 (0.0232)
	0.0580 (0.0228)	0.0586 (0.0231)	0.0590 (0.0232)
4/3	0.0581 (0.0229)	0.0586 (0.0231)	0.0590 (0.0232)
	0.0581 (0.0229)	0.0587 (0.0231)	0.0591 (0.0233)
	0.0581 (0.0229)	0.0587 (0.0231)	0.0581 (0.0233)

*OSS =ormco stainless steel
There is a concave surface near to the base of slot due to the machine error during the rolling process.

Table XXIX

Measured wire dimensions (0.018 x 0.025 inch wire in 0.022 inch ORMCO brackets) mm (inch), five replicates; each wire

Ormco (Gem)	width	length
	0.0453 (0.0178)	0.0631 (0.0248)
upper	0.0453 (0.0178)	0.0631 (0.0248)
right	0.0453 (0.0178)	0.0631 (0.0248)
cuspid	0.0454 (0.0179)	0.0632 (0.0249)
	0.0454 (0.0179)	0.0632 (0.0249)
upper	0.0449 (0.0177)	0.0627 (0.0247)
right	0.0449 (0.0177)	0.0628 (0.0247)
lateral	0.0450 (0.0177)	0.0628 (0.0247)
incisor	0.0451 (0.0178)	0.0629 (0.0248)
	0.0451 (0.0178)	0.0629 (0.0248)
upper	0.0450 (0.0177)	0.0629 (0.0248)
right	0.0450 (0.0177)	0.0629 (0.0248)
central	0.0451 (0.0178)	0.0630 (0.0248)
incisor	0.0451 (0.0178)	0.0630 (0.0248)
	0.0451 (0.0178)	0.0631 (0.0248)
upper	0.0450 (0.0177)	0.0626 (0.0246)
left	0.0450 (0.0177)	0.0628 (0.0247)
central	0.0451 (0.0178)	0.0629 (0.0248)
incisor	0.0452 (0.0178)	0.0630 (0.0248)
	0.0452 (0.0178)	0.0630 (0.0248)
upper	0.0452 (0.0178)	0.0626 (0.0246)
left	0.0452 (0.0178)	0.0627 (0.0247)
lateral	0.0452 (0.0178)	0.0628 (0.0247)
incisor	0.0452 (0.0178)	0.0628 (0.0247)
	0.0453 (0.0178)	0.0629 (0.0248)
	0.0451 (0.0178)	0.0632 (0.0249)
upper	0.0451 (0.0178)	0.0632 (0.0249)
left	0.0452 (0.0178)	0.0632 (0.0249)
cuspid	0.0452 (0.0178)	0.0633 (0.0249)
	0.0453 (0.0178)	0.0633 (0.0249)

Table XXX
Measured wire dimensions (0.018 x 0.025 inch wire in 0.022 inch A-Company brackets)
mm (inch), five replicates; each wire

A-Co.	width	length
	0.0451 (0.0178)	0.0627 (0.0247)
upper	0.0451 (0.0178)	0.0628 (0.0247)
right	0.0451 (0.0178)	0.0628 (0.0247)
cuspid	0.0451 (0.0178)	0.0629 (0.0248)
	0.0452 (0.0178)	0.0630 (0.0248)
upper	0.0451 (0.0178)	0.0626 (0.0246)
right	0.0452 (0.0178)	0.0627 (0.0247)
lateral	0.0452 (0.0178)	0.0627 (0.0247)
incisor	0.0453 (0.0178)	0.0628 (0.0247)
	0.0453 (0.0178)	0.0629 (0.0248)
upper	0.0449 (0.0177)	0.0627 (0.0247)
right	0.0450 (0.0177)	0.0627 (0.0247)
central	0.0452 (0.0178)	0.0628 (0.0247)
incisor	0.0452 (0.0178)	0.0628 (0.0247)
	0.0453 (0.0178)	0.0629 (0.0248)
upper	0.0449 (0.0177)	0.0630 (0.0248)
left	0.0449 (0.0177)	0.0631 (0.0248)
central	0.0450 (0.0177)	0.0631 (0.0248)
incisor	0.0451 (0.0178)	0.0631 (0.0248)
	0.0451 (0.0178)	0.0632 (0.0249)
upper	0.0454 (0.0179)	0.0630 (0.0248)
left	0.0454 (0.0179)	0.0631 (0.0248)
lateral	0.0454 (0.0179)	0.0631 (0.0248)
incisor	0.0454 (0.0179)	0.0632 (0.0249)
	0.0455 (0.0179)	0.0632 (0.0249)
	0.0445 (0.0175)	0.0627 (0.0247)
upper	0.0445 (0.0175)	0.0627 (0.0247)
left	0.0445 (0.0175)	0.0628 (0.0247)
cuspid	0.0446 (0.0176)	0.0629 (0.0248)
	0.0447 (0.0176)	0.0629 (0.0248)

Table XXXI
Measured wire dimensions (0.018 x 0.025)
inch wire in 0.022 inch UNITEK brackets)
mm (inch), five replicates; each wire

Unitek	width	length
upper	0.0451 (0.0178)	0.0623 (0.0245)
right	0.0452 (0.0178)	0.0625 (0.0246)
second	0.0453 (0.0178)	0.0626 (0.0246)
bicuspid	0.0453 (0.0178)	0.0627 (0.0247)
	0.0454 (0.0179)	0.0628 (0.0247)
upper	0.0448 (0.0176)	0.0627 (0.0247)
right	0.0449 (0.0177)	0.0628 (0.0247)
first	0.0449 (0.0177)	0.0628 (0.0247)
bicuspid	0.0450 (0.0177)	0.0629 (0.0248)
	0.0451 (0.0178)	0.0630 (0.0248)
upper	0.0452 (0.0178)	0.0629 (0.0248)
right	0.0453 (0.0178)	0.0630 (0.0248)
central	0.0453 (0.0178)	0.0630 (0.0248)
incisor	0.0453 (0.0178)	0.0630 (0.0248)
	0.0453 (0.0178)	0.0630 (0.0248)
upper	0.0450 (0.0177)	0.0628 (0.0247)
left	0.0451 (0.0178)	0.0629 (0.0248)
central	0.0451 (0.0178)	0.0629 (0.0248)
incisor	0.0452 (0.0178)	0.0630 (0.0248)
	0.0452 (0.0178)	0.0630 (0.0248)
	0.0450 (0.0177)	0.0624 (0.0246)
upper	0.0451 (0.0178)	0.0624 (0.0246)
right	0.0452 (0.0178)	0.0625 (0.0246)
cuspid	0.0452 (0.0178)	0.0625 (0.0246)
	0.0453 (0.0178)	0.0625 (0.0246)
upper	0.0453 (0.0178)	0.0631 (0.0248)
left	0.0453 (0.0178)	0.0632 (0.0249)
first	0.0453 (0.0178)	0.0632 (0.0249)
bicuspid	0.0454 (0.0179)	0.0632 (0.0249)
	0.0454 (0.0179)	0.0633 (0.0249)
upper	0.0453 (0.0178)	0.0629 (0.0248)
left	0.0453 (0.0178)	0.0629 (0.0248)
second	0.0453 (0.0178)	0.0629 (0.0248)
bicuspid	0.0454 (0.0179)	0.0630 (0.0248)
	0.0454 (0.0179)	0.0630 (0.0248)

Table XXXII
Measured wire dimensions (0.018 x 0.025 inch wire in 0.022 inch GAC brackets)
mm (inch), five replicates; each wire

GAC	width	length
upper	0.0454 (0.0179)	0.0628 (0.0247)
right	0.0455 (0.0179)	0.0628 (0.0247)
second	0.0455 (0.0179)	0.0629 (0.0248)
bicuspid	0.0455 (0.0179)	0.0629 (0.0248)
	0.0456 (0.0180)	0.0630 (0.0248)
upper	0.0451 (0.0178)	0.0631 (0.0248)
right	0.0451 (0.0178)	0.0631 (0.0248)
first	0.0451 (0.0178)	0.0632 (0.0249)
bicuspid	0.0452 (0.0178)	0.0632 (0.0249)
	0.0452 (0.0178)	0.0632 (0.0249)
	0.0453 (0.0178)	0.0630 (0.0248)
upper	0.0453 (0.0178)	0.0631 (0.0248)
right	0.0453 (0.0178)	0.0631 (0.0248)
cuspid	0.0454 (0.0179)	0.0631 (0.0248)
	0.0454 (0.0179)	0.0631 (0.0248)
upper	0.0453 (0.0178)	0.0625 (0.0246)
right	0.0453 (0.0178)	0.0626 (0.0246)
lateral	0.0453 (0.0178)	0.0626 (0.0246)
incisor	0.0453 (0.0178)	0.0627 (0.0247)
	0.0454 (0.0179)	0.0628 (0.0247)
upper	0.0449 (0.0177)	0.0623 (0.0245)
left	0.0449 (0.0177)	0.0624 (0.0246)
lateral	0.0449 (0.0177)	0.0625 (0.0246)
incisor	0.0450 (0.0177)	0.0625 (0.0246)
	0.0451 (0.0178)	0.0626 (0.0246)
	0.0451 (0.0178)	0.0629 (0.0248)
upper	0.0451 (0.0178)	0.0630 (0.0248)
left	0.0452 (0.0178)	0.0631 (0.0248)
cuspid	0.0452 (0.0178)	0.0632 (0.0249)
	0.0453 (0.0178)	0.0633 (0.0249)
upper	0.0451 (0.0178)	0.0626 (0.0246)
left	0.0451 (0.0178)	0.0627 (0.0247)
second	0.0451 (0.0178)	0.0628 (0.0247)
bicuspid	0.0452 (0.0178)	0.0628 (0.0247)
	0.0452 (0.0178)	0.0628 (0.0247)

Table XXXIII

Measured wire dimensions and deviation angle
(0.018 x 0.025 inch wire in 0.022 inch ORMCO brackets)
mm (inch), five replicates; each wire

Ormco (S.S)	width	length
	0.0447 (0.0176)	0.0629 (0.0248)
	0.0448 (0.0176)	0.0629 (0.0248)
3/0	0.0448 (0.0176)	0.0630 (0.0248)
	0.0449 (0.0177)	0.0630 (0.0248)
	0.0449 (0.0177)	0.0631 (0.0248)
	0.0449 (0.0177)	0.0631 (0.0248)
	0.0450 (0.0177)	0.0631 (0.0248)
3/1	0.0450 (0.0177)	0.0631 (0.0248)
	0.0451 (0.0178)	0.0632 (0.0249)
	0.0451 (0.0178)	0.0633 (0.0249)
	0.0451 (0.0178)	0.0631 (0.0248)
	0.0451 (0.0178)	0.0631 (0.0248)
3/2	0.0451 (0.0178)	0.0631 (0.0248)
	0.0452 (0.0178)	0.0632 (0.0249)
	0.0453 (0.0178)	0.0633 (0.0249)
	0.0450 (0.0177)	0.0631 (0.0248)
	0.0451 (0.0178)	0.0631 (0.0248)
1/k	0.0451 (0.0178)	0.0631 (0.0248)
	0.0452 (0.0178)	0.0632 (0.0249)
	0.0452 (0.0178)	0.0632 (0.0249)
	0.0449 (0.0177)	0.0630 (0.0248)
	0.0450 (0.0177)	0.0631 (0.0248)
4/2	0.0451 (0.0178)	0.0631 (0.0248)
	0.0451 (0.0178)	0.0632 (0.0249)
	0.0452 (0.0178)	0.0632 (0.0249)
	0.0450 (0.0177)	0.0631 (0.0248)
	0.0450 (0.0177)	0.0631 (0.0248)
4/3	0.0450 (0.0177)	0.0631 (0.0248)
	0.0451 (0.0178)	0.0632 (0.0249)
	0.0451 (0.0178)	0.0632 (0.0249)

* S.S= stainless steel

Table XXXIV

The measurements of deviation angle from metallographic microscope

Ormco (Gem)	*Clockwise	*Counterclockwise
	18.1	17.6
upper	18.2	17.6
right	18.2	17.7
cuspid	18.3	17.7
	18.3	17.8
upper	19.4	18.6
right	19.5	18.7
lateral	19.5	18.7
incisor	19.6	18.8
	19.6	18.8
upper	18.7	16.6
right	18.8	16.6
central	18.8	16.7
incisor	18.9	16.7
	18.9	16.7
upper	18.3	17.7
left	18.3	17.8
central	18.3	17.8
incisor	18.4	17.9
	18.4	17.9
upper	22.1	16.5
left	22.1	16.7
lateral	22.1	16.7
incisor	22.2	16.8
	22.3	16.8
	20.2	18.1
upper	20.3	18.2
left	20.3	18.2
cuspid	20.4	18.3
	20.5	18.3

* Entries are in degrees

Table XXXV

The measurements of deviation angle from metallographic microscope

A-Company	*Clockwise	*Counterclockwise
	18.3	18.0
upper	18.3	18.0
right	18.4	18.0
cuspid	18.4	18.1
	18.4	18.1
upper	18.5	18.3
right	18.5	18.4
lateral	18.6	18.4
incisor	18.6	18.5
	18.7	18.5
upper	21.0	14.5
right	21.0	14.6
central	21.1	14.6
incisor	21.1	14.7
	21.2	14.7
upper	18.2	16.8
left	18.3	16.8
central	18.4	16.9
incisor	18.4	16.9
	18.4	17.0
upper	20.0	17.2
left	20.1	17.2
lateral	20.1	17.3
incisor	20.2	17.3
	20.2	17.4
	18.6	19.2
upper	18.6	19.3
left	18.7	19.3
cuspid	18.7	19.4
	18.7	19.4

* Entries are in degrees.

Table XXXVI

The measurement of deviation angle from metallographic microscope

Unitek	*Clockwise	*Counterclockwise
upper	19.2	16.7
right	19.3	16.7
second	19.4	16.7
bicuspid	19.4	16.8
	19.5	16.9
upper	19.8	18.6
right	19.9	18.7
first	19.9	18.8
bicuspid	20.0	18.8
	20.0	19.0
upper	18.3	16.6
right	18.4	16.6
lateral	18.5	16.6
incisor	18.5	16.7
	18.5	16.7
upper	20.2	18.8
right	20.3	18.8
central	20.3	18.9
incisor	20.3	18.9
	20.4	18.9
upper	20.4	17.4
left	20.5	17.4
central	20.5	17.5
incisor	20.6	17.6
	20.7	17.6
	21.2	15.9
upper	21.3	15.9
left	21.3	16.0
cuspid	21.4	16.0
	21.4	16.1
upper	18.7	17.0
left	18.8	17.1
first	18.9	17.2
bicuspid	18.9	17.3
	19.0	17.3

upper	18.0	17.8
left	18.1	17.9
second	18.1	18.0
bicuspid	18.1	18.1
	18.1	18.1

* Entries are in degrees.

Table XXXVII

The measurements of deviation angle from metallographic microscope

GAC	*Clockwise	*Counterclockwise
upper	18.8	18.8
right	18.9	18.9
second	19.0	19.0
bicuspid	19.1	19.0
	19.1	19.1
upper	17.2	21.8
right	17.4	21.9
first	17.5	22.1
bicuspid	17.5	22.1
	17.6	22.1
	16.9	20.0
upper	16.9	20.1
right	17.0	20.1
cuspid	17.1	20.1
	17.3	20.2
upper	19.8	17.6
right	19.8	17.8
lateral	20.0	17.8
incisor	20.1	17.8
	20.1	17.8
upper	19.0	18.0
left	19.0	18.1
central	19.0	18.2
incisor	19.1	18.2
	19.1	18.3
upper	19.3	18.2
left	19.3	18.3
lateral	19.3	18.3
incisor	19.4	18.4
	19.5	18.4
	18.7	17.7
upper	18.8	17.7
left	18.8	17.7
cuspid	18.8	17.8
	18.9	18.0

upper	17.6	19.9
left	17.6	19.9
second	17.6	20.0
bicuspid	17.7	20.2
	17.8	20.3

* Entries are in degrees.

Table XXXVIII

The measurement of deviation angle from metallographic microscope

Ormco (*S.S)	**Clockwise	**Counterclockwise
	19.2	20.1
	19.2	20.1
3/0	19.2	20.2
	19.3	20.2
	19.3	20.2
	17.7	18.0
	17.7	18.0
3/1	17.8	18.1
	17.8	18.1
	17.9	18.2
	18.9	20.2
	18.9	20.3
3/2	19.0	20.3
	19.1	20.3
	19.1	20.4
	20.4	18.9
	20.4	18.9
1/k	20.4	18.9
	20.5	19.0
	20.5	19.0
	19.0	18.7
	19.1	18.7
4/2	19.1	18.8
	19.2	18.8
	19.2	18.9
	20.1	19.1
	20.1	19.2
4/3	20.1	19.2
	20.1	19.3
	20.2	19.3

* S.S= stainless steel Bracket Slot
** Entries are in degrees.

Table XXXIX

Angle of Rotation of 0.018 x 0.025 inch
wire in brackets 0.022 slot
X°. Y' (degrees)

Ormco (Gem)	A1	A2
	13.42 (13.70)	13.12 (13.20)
upper	13.45 (13.75)	13.12 (13.20)
right	13.45 (13.75)	13.15 (13.25)
cuspid	13.45 (13.75)	13.18 (13.30)
	13.48 (13.80)	13.18 (13.30)
upper	18.48 (18.80)	17.18 (17.30)
right	18.48 (18.80)	17.18 (17.30)
lateral	18.48 (18.80)	17.21 (17.35)
incisor	18.51 (18.85)	17.21 (17.35)
	18.51 (18.85)	17.21 (17.35)
upper	15.39 (15.65)	13.09 (13.15)
right	15.39 (15.65)	13.12 (13.20)
central	15.42 (15.70)	13.12 (13.20)
incisor	15.45 (15.75)	13.12 (13.20)
	15.45 (15.75)	13.15 (13.25)
upper	15.00 (15.00)	14.51 (14.85)
left	15.00 (15.00)	14.51 (14.85)
central	15.00 (15.00)	14.54 (14.90)
incisor	15.03 (15.05)	14.54 (14.90)
	15.03 (15.05)	14.57 (14.95)
upper	18.36 (18.60)	16.24 (16.40)
left	18.36 (18.60)	16.24 (16.40)
lateral	18.39 (18.65)	16.27 (16.45)
incisor	18.42 (18.70)	16.30 (16.50)
	18.42 (18.70)	16.30 (16.50)
	17.27 (17.45)	16.03 (16.05)
upper	17.30 (17.50)	16.03 (16.05)
left	17.30 (17.50)	16.03 (16.05)
cuspid	17.33 (17.55)	16.06 (16.10)
	17.33 (17.55)	16.06 (16.10)

Table XXXX
Angle of Rotation of 0.018 x 0.025 inch
wire in brackets 0.022 slot
X°. Y' (degrees)

A-Com.	A1	A2
	15.42 (15.70)	15.27 (15.45)
upper	15.42 (15.70)	15.27 (15.45)
right	15.45 (15.75)	15.30 (15.50)
cuspid	15.45 (15.75)	15.30 (15.50)
	15.48 (15.80)	15.30 (15.50)
upper	16.24 (16.40)	14.21 (14.35)
right	16.24 (16.40)	14.21 (14.35)
lateral	16.27 (16.45)	14.21 (14.35)
incisor	16.30 (16.50)	14.21 (14.35)
	16.30 (16.50)	14.24 (14.40)
upper	14.57 (14.95)	14.09 (14.15)
right	15.00 (15.00)	14.12 (14.20)
central	15.00 (15.00)	14.12 (14.20)
incisor	15.03 (15.05)	14.15 (14.25)
	15.03 (15.05)	14.15 (14.25)
upper	15.00 (15.00)	13.15 (13.25)
left	15.03 (15.05)	13.18 (13.30)
central	15.06 (15.10)	13.18 (13.30)
incisor	15.06 (15.10)	13.21 (13.35)
	15.09 (15.15)	13.21 (13.35)
upper	15.57 (15.95)	13.51 (13.85)
left	15.57 (15.95)	13.54 (13.90)
lateral	16.00 (16.00)	13.54 (13.90)
incisor	16.00 (16.00)	13.57 (13.95)
	16.03 (16.05)	13.57 (13.95)
	16.51 (16.85)	16.18 (16.30)
upper	16.51 (16.85)	16.18 (16.30)
left	16.54 (16.90)	16.21 (16.35)
cuspid	16.57 (16.95)	16.21 (16.35)
	16.57 (16.95)	16.21 (16.35)

Table XXXXI
Angle of Rotation of 0.018 x 0.025 inch
wire in brackets 0.022 slot
X°. Y' (degrees)

Unitek	A1	A2
upper	15.12 (15.20)	14.51 (14.85)
right	15.12 (15.20)	14.51 (14.85)
second	15.15 (15.25)	14.54 (14.90)
bicuspid	15.15 (15.25)	14.54 (14.90)
	15.15 (15.25)	14.54 (14.90)
upper	15.27 (15.45)	14.51 (14.85)
right	15.27 (15.45)	14.54 (14.90)
first	15.30 (15.50)	14.54 (14.90)
bicuspid	15.30 (15.50)	14.54 (14.90)
	15.30 (15.50)	14.57 (14.95)
upper	16.39 (16.65)	16.30 (16.50)
right	16.39 (16.65)	16.30 (16.50)
central	16.39 (16.65)	16.33 (16.55)
incisor	16.42 (16.70)	16.33 (16.55)
	16.42 (16.70)	16.33 (16.55)
upper	15.33 (15.55)	15.12 (15.20)
left	15.33 (15.55)	15.12 (15.20)
central	15.36 (15.60)	15.15 (15.25)
incisor	15.36 (15.60)	15.15 (15.25)
	16.36 (15.60)	15.15 (15.25)
	15.27 (15.45)	15.06 (15.10)
upper	15.27 (15.45)	15.06 (15.10)
left	15.30 (15.50)	15.09 (15.15)
cuspid	15.30 (15.50)	15.09 (15.15)
	15.30 (15.50)	15.09 (15.15)
upper	15.15 (15.25)	14.51 (14.85)
left	15.15 (15.25)	14.51 (14.85)
first	15.18 (15.30)	14.51 (14.85)
bicuspid	15.18 (15.30)	14.54 (14.90)
	15.18 (15.30)	14.54 (14.90)
upper	15.39 (15.65)	15.24 (15.40)
left	15.42 (15.70)	15.24 (15.40)
second	15.42 (15.70)	15.27 (15.45)
bicuspid	15.42 (15.70)	15.27 (15.45)
	15.45 (15.75)	15.27 (15.45)

Table XXXXII
Angle of Rotation of 0.018 x 0.025 inch
wire in brackets 0.022 slot
X°.Y' (degrees)

GAC	A1	A2
upper	14.27 (14.45)	14.18 (14.30)
right	14.30 (14.50)	14.18 (14.30)
second	14.30 (14.50)	14.21 (14.35)
bicuspid	14.33 (14.55)	14.21 (14.35)
	14.33 (14.55)	14.24 (14.40)
upper	15.57 (15.95)	15.12 (15.20)
right	15.57 (15.95)	15.15 (15.25)
first	15.57 (15.95)	15.15 (15.25)
bicuspid	15.57 (15.95)	15.15 (15.25)
	16.00 (16.00)	15.18 (15.30)
	15.18 (15.30)	14.57 (14.95)
upper	15.18 (15.30)	14.57 (14.95)
right	15.21 (15.35)	15.00 (15.00)
cuspid	15.21 (15.35)	15.03 (15.05)
	15.24 (15.40)	15.03 (15.05)
upper	15.42 (15.70)	15.12 (15.20)
right	15.42 (15.70)	15.12 (15.20)
lateral	15.45 (15.75)	15.15 (15.25)
incisor	15.45 (15.75)	15.15 (15.25)
	15.48 (15.80)	15.15 (15.25)
upper	15.57 (15.95)	15.39 (15.65)
left	16.00 (16.00)	15.39 (15.65)
lateral	16.00 (16.00)	15.39 (15.65)
incisor	16.03 (16.05)	15.42 (15.70)
	16.03 (16.05)	15.42 (15.70)
	14.57 (14.95)	14.48 (14.80)
upper	14.57 (14.95)	14.48 (14.80)
left	15.00 (15.00)	14.51 (14.85)
cuspid	15.00 (15.00)	14.51 (14.85)
	15.03 (15.05)	14.51 (14.85)
upper	14.51 (14.85)	14.36 (14.60)
left	14.51 (14.85)	14.39 (14.65)
second	14.54 (14.90)	14.42 (14.70)
bicuspid	14.54 (14.90)	14.42 (14.70)
	14.57 (14.95)	14.42 (14.70)

Table XXXXIII

Angle of Rotation of 0.018 x 0.025 inch
wire in brackets 0.022 slot
X°.Y'(degrees)

Ormco*(S.S)	A1	A2
	18.36 (18.60)	#18.51 (18.85)
	18.36 (18.60)	#18.51 (18.85)
3/0	18.36 (18.60)	#18.54 (18.90)
	18.39 (18.65)	#18.57 (18.95)
	18.39 (18.65)	#19.00 (19.00)
	17.24 (17.40)	16.51 (16.85)
	17.24 (17.40)	16.51 (16.85)
3/1	17.27 (17.45)	16.54 (16.90)
	17.27 (17.45)	16.54 (16.90)
	17.27 (17.45)	16.57 (16.95)
	17.57 (17.95)	17.24 (17.40)
	17.57 (17.95)	17.24 (17.40)
3/2	18.00 (18.00)	17.24 (17.40)
	18.03 (18.05)	17.27 (17.45)
	18.03 (18.05)	17.27 (17.45)
	17.36 (17.60)	17.21 (17.35)
	17.36 (17.60)	17.21 (17.35)
1/K	17.39 (17.65)	17.24 (17.40)
	17.39 (17.65)	17.24 (17.40)
	17.39 (17.65)	17.27 (17.45)
	17.12 (17.20)	15.57 (15.95)
	17.12 (17.20)	15.57 (15.95)
4/2	17.15 (17.25)	16.00 (16.00)
	17.18 (17.30)	16.00 (16.00)
	17.18 (17.30)	16.03 (16.05)
	17.48 (17.80)	17.12 (17.20)
	17.51 (17.85)	17.12 (17.20)
4/3	17.51 (17.85)	17.12 (17.20)
	17.54 (17.90)	17.15 (17.25)
	17.54 (17.90)	17.15 (17.25)

* S.S= stainless steel bracket slot
# This larger measurement is due to a concave curvature on the one of the inner walls of slot.

APPROVAL SHEET

The thesis submitted by Yuan-Chun Tseng, D.D.S. has been read and approved by the following committee:

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The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science.

April 21, 1989
Date

James L. Sandrik PhD
Director's Signature