Loyola University Chicago
Loyola eCommons

Master's Theses

Theses and Dissertations

1981

Cross Sectional Geometry and Dimensions of Orthodontic Rectangular Wire

Mauricio A. Molina Rodriguez
Loyola University Chicago

Follow this and additional works at: https://ecommons.luc.edu/luc_theses

Part of the Orthodontics and Orthodontology Commons

Recommended Citation

Rodriguez, Mauricio A. Molina, "Cross Sectional Geometry and Dimensions of Orthodontic Rectangular Wire" (1981). *Master's Theses*. 3163.
https://ecommons.luc.edu/luc_theses/3163

This Thesis is brought to you for free and open access by the Theses and Dissertations at Loyola eCommons. It has been accepted for inclusion in Master's Theses by an authorized administrator of Loyola eCommons. For more information, please contact ecommons@luc.edu.

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 3.0 License.
Copyright © 1981 Mauricio A. Molina Rodriguez

CROSS SECTIONAL GEOMETRY AND DIMENSIONS OF ORTHODONTIC RECTANGULAR WIRE

by

Mauricio A. Molina Rodriguez, D.D.S.

A Thesis Submitted to the Faculty of the Graduate School
of Loyola University in Partial Fulfillment
of the Requirements for the Degree of
Master of Science
August
1981

DEDICATION

To my parents, with love and gratitude.

Your love and support throughout my life,
have been my inspiration in achieving
all my goals and expectations

To my sister Aurora, for always being my best friend

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to all those who have helped in making this investigation possible. I would like to extend a special thank you to the following persons:

To James L. Sandrik, Ph.D, who, as my advisor, gave his valuable time and assistance in reviewing the material and most of all for guiding me through this investigation.

To Lewis Klapper, D.M.D., M.Sc.D., D.Sc., for his encouragement, as my advisor and also as my teacher during my Orthodontic education.

To Douglas Bowman, Ph.D., for his time in helping me complete this investigation.

To Richard L. Lang, D.D.S., M.S., for his enthusiastic support in pursuing this research and for his assistance in proofreading this manuscript.

To Preston Bricker, whose knowledge in mathematics was invaluable for the completion of this project.

To Jim Cockerill and Elizabeth Fink, for their assistance in the photography necessary for this work.

A very special thank you is extended to Bernie Ciamarichello for typing this manuscript and also for her constant encouragement as a friend in the process of putting together this project.

Gratitude must be acknowledged to James G. Beery, D.D.S., M.Sc.D., and all my teachers at Loyola University, for their guidance and advice during my Orthodontic education.

I would also like to express my gratitude to all the companies involved for providing materials and information for this investigation.

VITA

Mauricio A. Molina Rodriguez was born on September 21, 1956, the first of two children to Jose Antonio Molina and Ines Imelda Rodriguez in Esteli, Nicaragua.

His elementary education was obtained at Colegio Felix Ruben Dario Sarmiento and Centro Escolar Berta Briones in Esteli, Nicaragua. He attended the Instituto Rio Piedra in Esteli for his secondary education where he graduated in November of 1972. In November of 1972, he attended Sierra Joint Union High School, in Tollhouse California as an exchange student where he studied English.

In June of 1973, he enrolled at the Universidad Nacional Autonoma de Nicaragua in Leon, for his predentistry requirements. One year later, he began his dental studies at the same university. He received his Doctor of Dental Surgery degree in November of 1978.

In July, 1979, he entered Loyola University School of Dentistry for a two year post-graduate course in Orthodontics, leading to a certificate of specialty and a Masters of Science in Oral Biology.

TABLE OF CONTENTS

Chapter

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Contemporary orthodontic philosophy favors the edgewise appliance to correct dental malocclusions. Since its conception, by Edward H. Angle, this mechanism has gone through numerous changes to improve its efficiency, although the following two principles have remained the same: (1) to provide control of the teeth in three planes of space, and (2) to provide control of the roots of the teeth throughout treatment. This can be accomplished through the use of torquing forces.

In classical orthodontic terminology, torque force is defined as a force that creates a moment to the tooth, producing controlled movement of the root.

This force can be produced with spring auxiliaries and round wires, but the most effective method is with the use of rectangular wire, twisted parallel to the long axis and placed in the standard edgewise bracket. Recent orthodontic advances eliminate the need for twisting the rectangular wire by incorporating the mechanism in the bracket, thereby allowing the placement of an unbent or "straight" rectangular wire into the bracket or tube.

Movements of third order, accomplished by torquing forces, are dependent on the bracket-wire relationship. The accuracy of the fit of the wire within the bracket or tube will dictate the amount of torque force that is transmitted to the tooth.

The amount of force dissipated through rotation of the rectangular wire before binding (play) will depend on the size and shape of the brackets or tubes and on the size and shape of the rectangular wires. The less the rectangular wire rotates in the bracket or tube, the sooner the engagement will occur. This enables more efficient transmittal of force to the tooth.

The size and shape of the bracket or tube has been known to greatly influence the amount of force dissipated through this rotation[19]. Similarly, the size and shape of the rectangular wires is of great importance. The corners of the rectangular wire are of special consideration, since these are the points at which binding would occur within the brackets or tubes. The cross sectional dimensions of the rectangular wire are also of importance. An undersized wire would experience increased rotation within the bracket or tube, thereby reducing its torquing effectiveness. Conversely, a wire of larger cross sectional dimension would be more efficient in producing torquing moments. However, this would occur at the expense of ease of manipulation.

This research deals with the cross sectional geometry and dimensions of rectangular orthodontic wire. Specifically, the purpose of this investigation is to find the actual shape or "squareness" of the corners of the rectangular wires and the effect this would have on the transmittal of torque force to the teeth.

CHAPTER II

REVIEW OF LITERATURE

The rectangular wire was introduced to orthodontics by Edward H. Angle[5] as the main component of his pin and tube appliance. This new mechanism permitted proper control and distribution of force for the movement of roots of teeth singularly or collectively, and simultaneously with or independently of their crown movements. As means of force transmittal to the teeth, he used the ribbon expansion arch which consisted of a rectangular arch wire .022 inch in thickness and .036 inch in width applied to the brackets in a sidewise or flatwise manner (ribbon arch). The direction of the force upon the root depended on the angle of inclination given to the parallel sides of the ribbon arch wire before it was deflected into the brackets.

Angle emphasized that the correct positions of the roots of the teeth depended upon the permanence of the normal relation of their crowns. For this reason, when labial or lingual movement of the root was desired, bends were placed in the ribbon arch in the region of the bracket of the tooth involved which would flare the arch wire either inward or outward prior to bracket engagement.

Robert H. Strang[28] stated the change in the position of tooth roots was possible by means of a new force in orthodontics that was not available until the ribbon arch was invented. This force, or "torque" as he called it is the "...twisting force of a spring wire when turned upon itself...."

The labial and lingual root movement of individual teeth could now be accomplished by employing this torque force because of the mechanical fit of the rectangular wire into its bracket. These brackets were so stabilized and of such form that the flat wire accurately fit into them and was unable to turn upon itself without exerting the force. This was not available with the use of round wires.

Edward Angle[6] introduced the Edgewise mechanism, so called edgewise because the rectangular arch wire was applied on edge rather than sidewise as it was in the ribbon arch appliance. The rectangular wire used was .022 inch thickness and .028 inch in width. This was to become the foundation of modern day orthodontics. Angle believed:

> "...more delicate and graceful in appearance, the rectangular arch wire used in this manner had greater elasticity of operating force under others as in widening dental arches, effecting some forms of root movement, tipping teeth into their correct upright axial relations, etc...."

Allan G. Brodie[10], discussing torque force described if the rectangular arch wire is held so it cannot move, the result will be root movement. On the other hand, if the arch wire is encouraged to move with the tooth, a tipping will result. He concluded, since torque is applied in a labio or bucco-lingual plane by twisting the arch wire, torque force becomes elevation or depression when it travels into another plane of space. Thus the edgewise appliance enabled better control of tooth movements in all three planes of space.

Cecil Steiner[27] noted it is obvious that if force were to be applied evenly to all teeth in the dental arch over a period of time, the cross section of the arch wire would have to vary throughout its length. This being impractical, it follows that the arch wire should be of such cross section and strength throughout as would most nearly meet all demands made upon it in storing and delivering power and providing at least the minimum requirements of stability. Further, he stated the maximum cross section should be determined by the requirements of torque, tip and particularly rotational movements.

When examining the accuracy in the sizes of the wires, Steiner found stainless steel in particular was extremely difficult to obtain in accurate sizes and uniformity with consistent degrees of hardness, stiffness and elasticity. He found great variations in these qualities throughout the length of the stainless steel pieces examined and a much higher degree of accuracy in precious metal.

Erman D. Rauch[21] noted when the torque force is delivered by a twisted rectangular wire, the amount of twist was not an indication of actual torque force applied to the teeth, since the amount of force is determined only by the relationship of the wire to the bracket that is engaged. Some force was dissipated in the transition from wire to tooth due to rotation of wire within the bracket.

C.J. Burstone et al[11], described the third order bend (twist) in an edgewise wire. The force is obtained from the twisting or torsional properties of the wire. When evaluating the cross sectional geometry of orthodontic wires, in the application of continous force in orthodontics, the most advantageous cross section for unidirectional bending is flat wire. It can be demonstrated that the flatter the wire, the more desirable will be its spring properties. They stated in square or rectangular wire, the spring rate is directly proportional not only to the width of the cross section, but also increases directly as the cube of the depth. They concluded a change in height rather than in width, has a much more pronounced effect on the amount of force required for a given deflection.

Joseph Jarabak[17] found the rectangular or square cross sections were not superior sections functionally than round ones because the metal in the corners of square or rectangular wire accepts little of the stress; but that its use for torquing purposes was widespread probably due to the ease with which a rectangular wire can be held and stressed in torsion.

He noted a small rotation of the wire was needed before the two diagonally opposite points of the wire could contact the inner surface of the slot. This two point contact was the means whereby the square or rectangular wire, could transmit its torque to the bracket.

Jarabak[17] discussed the influence, the geometry of the wire cross section has on the force that the wire can tolerate. He concluded the force is directly proportional to the square of the height and the first power of the breadth of the section. Maximum shearing stress developed in square wire subjected to twisting occurred in the middle of the flat sides.

G.B. Blodgett and G.F. Andreasen[7] agreed with Jarabak in that to create torque there must be two point contact between the bracket, which is the holding device, and the active force member which is the wire. In the edgewise appliance, the precise fit of the rectangular arch wire in the bracket slot makes it impossible for the wire to turn upon itself without exerting a torquing force on the tooth. They emphasized this was the reason why the edgewise bracket was ideal for the production and use of torque force. Also, the mechanical ease with which rectangular wires could be used to apply torque to teeth had been one of the principal advantages of this bracket.

Lawrence P. Andrews[4] introduced the straight wire appliance to orthodontics. This new form of edgewise mechanism had several innovations such as torque built into the base of all the brackets, tip built into the bracket and in/out and molar offset built into the appliance. The advantage of this new appliance, he noted, was straight arch wires without bends (except for the proper arch form) were used throughout treatment; being progressively larger from the first wire to the last which was a full size rectangular arch wire. He concluded each arch wire then seeks to regain its original passive form and the built-in preangulated slots individually and collectively contribute to the achievement of normal occlusion.

G.F. Andreasen[2], when discussing the selection of the square and rectangular wires in clinical practice stated the majority of rectangular wires are used primarily after leveling for their torsion characteristics. In other words, they were used mainly to "torque" or "upright" roots that have been tipped in all three planes of space.

Factors of importance in selecting these wires, he noted, were first the relations of the buccal-lingual and labial-lingual natural inclinations of the maxillary and mandibular dentitions and secondly the wire's stiffness, its range and torsion slot freedom.

Analyzing the torsion slot freedom, he concluded any square or rectangular wire aside from one that almost completely filled the slot (e.g. .0215 x .028 in .022 inch slot) and seated in the brackets, will exert little or no torque because of the freedom of rotation the smaller square and rectangular wires have when seated in the slot. He stated the wire's performance would differ as a function of its shape and size, and the clinician's selection would depend upon his clinical needs relative to the wire's stiffness, range, or torquing ability. Also, when choosing a wire to produce torque movements, he believed as the wire becomes thicker, i.e., .018 inch to .022 inch to .025 inch in the horizontal plane, a much greater ability to effectively exert torque force exists in the wire without placing any twist in the wire itself because the stiffness is increased in the edgewise plane.

Raymond Thurow[29] found the elastic behavior of wires when they are bent or twisted depended on the size and shape of their cross section. The process of forming the rectangular wire had an effect on the wire's torquing ability. Wires are manufactured either by drawing the material through a rectangular die, or by rolling round wire to a rectangular shape. He concluded the drawing method produced sharper corners on rectangular wires, and the engagement of these edges in a rectangular slot can be an advantage in the application of torque.

He also noted torque control with rectangular wires was the only movement that required close engagement of the wire and bracket slot, thus the thickness of any rectangular wire used for torque should be maintained within .002 inches of the width of the slot.

Thurow also stated rectangular wires stressed in torsion should be seated with their outer working edges fully engaged in the slot and the deeper slot helped to ensure such full engagement. When torquing individual teeth, the wires should be sufficiently undersized to allow the adjusted wire to rotate in the slot of the adjacent tooth with no torque action on that tooth. A freedom of .001 inch or .002 inch should provide this margin.

Ronald Anderson[1] described, when large straight rectangular arch wires were used (e.g. 0.021 x 0.025 inches), the resiliency is minimized causing the arch wire in the bracket to bind before any significant tipping takes place. He concluded arch wires vary in their resiliency according to their hardness, cross sectional diameter, and the length of the wire between any two attachments. This in turn will affect the direction of force applied to the tooth.

Bernard Schwaninger[25] found the size ratio of arch wire to bracket slot has an important effect on third order control (torque). The "play" that exists for different sizes of arch wires in the slot was even larger when arch wires with rounded corners were used. Thus whether conventional or "pretorqued" appliances were used, torque adjustments had to be incorporated to the arch wire.

In evaluating the straight wire appliance, Eugene L. Dellinger[15] studied the effect of tooth morphology on torquing requirements. He used the occlusal portions of fifty wax set-ups (25 extraction and 25 non-extraction cases). Establishing a plane called the HOL line (horizontal occlusal line) by connecting left and right midcrown points of first molars and clinical crown average of the right and left central incisor, he measured the tangents to the intersection of this plane at the labial or buccal surface with the aid of an optical comparator. These measurements may be thought as planes of surface adaptation. His findings revealed these measurements to be in a totally inconsistent and erratic manner and represented great ranges. He concluded this great variation in tooth morphology precluded the use of a single straight wire appliance with average torque adjustments built into the brackets for all cases.

Thomas Creekmore[14] noted to evaluate an appliance, not only the brackets should be considered but also the arch wires used during treatment. He cited for torque movements, wire dimensions were critical in establishing the finishing root positions, whether single or twin brackets were used. This was because there was so much "play between the wire and the slot" that even finishing with a full size wire in the slot, adjustments had to be made to compensate for the play of the wire in the slot to get the teeth in proper axial inclination.

Eliezer Raphael[20] did a laboratory study to measure the amount of rotation of orthodontic rectangular wires in conventional standard edgewise buccal tubes using a metallographic microscope. He rotated various sized rectangular wires in buccal tubes until binding occurred and measured this amount of rotation. He used three types of buccal tubes: drilled, mandrel formed and cast. Four sizes of rectangular wires were used. No mention was made of the manufacturer of the wire. Additionally, he examined the internal lumen configuration and dimensions of the buccal tubes. He found the configuration to be inconsistent ranging from egg shaped to rectangular. The measured lumen dimensions were compared to the manufacturers stated dimensions.

Richard Lang[19] measured the rotation of rectangular wire in pretorqued ("Straight Wire") appliance buccal tubes, using the same methods and apparatus as Raphael. Testing the tubes of five manufacturers, he found the internal lumen dimensions of the tube vary greatly, even outside the manufacturers stated tolerance. The amount of rotation found was compared to previously published charts, which were based on theoretical calculations. His experimental values were greater than theoretical calculated values. The rectangular wires used were Rocky Mountain tru-chrome. These were chosen because, as stated by Dellinger, they were the only wires manufactured with actual square corners. According to Lang[19], Dellinger states, the corner radius (i.e. squareness of the corners) is the most critical factor in determining the amount of rotation of a wire within the tube.

CHAPTER III

MATERIALS AND METHODS

This research studied the cross sectional geometry and dimensions of rectangular orthodontic wire. The rectangular orthodontic wires used in this study were procured from eight different manufacturers (Tables I, II), with the exception of Rocky Mountain's blue elgiloy and yellow elgiloy and Unitek's Nitinol that were provided by the Loyola University Dental School, Department of Orthodontics.

The wire dimensions selected were those commonly used for torquing purposes (Table I).

Five wires of each size were selected at random from straight lengths (American Orthodontics, Rocky Mountain Orthodontics, Auning and Lancer Pacific) and preformed blanks ("A" Company, American Ormco, Masel Orthodontics and Unitek). Sections were made from the ends of these wires to be examined.

The five wire sections, once selected, were welded to a frame in such a way that the wires were perpendicular to the surface of the mount. The shape of the frame was

TABLE I

MANUFACTURER'S CONTROL DATA FOR WIRES USED IN THIS STUDY

MANUFACTURER	WIRE TYPE	WIRE SIZE	CATALOGUE NO.	BATCH NO.	CODE
AMERICAN ORTHODONTICS(1)	EDGEWISE WIRE REGULAR	.016 x .016	856-001	---	AR1
"	"	.016 x .022	856-002	---	AR2
"	"	.017 x .025	856-006	---	AR3
"	"	.018 x .022	856-008	---	AR5
"	"	.019 x .025	856-011	---	AR6
"	"	.021 x .025	856-014	---	AR8
"	EDGEWISE WIRE MULTIPHASE	.016 x .016	854-701	---	AM1
"	"	.016 x .022	854-702	---	AM2
"	"	.017 x .025	854-706	---	AM3
"	"	.018 x .022	854-708	---	AM5
"	"	.018 x .025	854-709	---	AM4
"	"	.021 x .025	854-714	---	AM8
"	EDGEWISE WIRE GOLD TONE	.016 x .016	856-021	---	AG1
"	"	.016 x .022	856-022	---	AG2
"	"	.017 x .025	856-026	---	AG3
"	"	.018 x .022	856-028	---	AG5
"	"	.019 x .025	856-031	---	AG6
"	"	.021 x .025	856-034	---	AG8

TABLE I (cont'd.)

MANUFACTURER	WIRE TYPE	WIRE SIZE	CATALOGUE NO.	BATCH NO.	CODE
"A" COMPANY(2)	TRU-ARCH GOLD TM	.016 x .016	---	---	AC1
"	"	.016 x .022	---	---	AC2
"	"	.017 x .025	---	---	AC3
"	"	.018 x .025	---	---	AC4
"	"	.019 x .025	---	---	AC6
"	"	.021 x .025	---	---	AC8
MASEL ORTHODONTICS(3)	EDGEWISE WIRE RESILIENT	.016 x .016	4999-202	---	M1
"	"	.016 x .022	4999-207	---	M2
"	"	.017 x .025	4999-109	---	M3
"	"	.018 x .022	4999-110	---	M5
"	"	.019 x .026	4999-213	---	M7
"	"	.021 x .025	4999-114	---	M8
UNITEK(4)	HI-T SQUARE WIRE ARCH	.016 x .016	319-112	456	U1
"	RECT. ARCH	.016 x .022	300-171	428	U2
"	RECT. ARCH	.017 x .025	300-281	259	U3
"	RECT. ARCH	.018 x .022	300-371	268	U5
"	HI-T RECT. ARCH	.018 x .025	319-381	209	U4
"	RECT. ARCH	.021 x .025	300-581	328	U8
"	NITINOL	.016 x .022	---	---	UN2
"	NITINOL	.021 x .025	---	---	UN8

TABLE I (cont'd.)

MANUFACTURER	WIRE TYPE	WIRE SIZE	CATALOGUE NO.	BATCH NO.	CODE
ROCKY MOUNTAIN(5)	TRU-CHROME	.016 x .016	NO. E-313	1270	R1
"	"	.016 x .022	NO. E-98	3080	R2
"	"	.017 x .025	NO. E-311	6039	R3
"	"	.018 x .022	NO. E-96	5603	R5
"	"	.019 x .026	NO. E-95	2760	R7
"	"	.021 x .025	NO. E-90	2940	R8
"	YELLOW ELGILOY	.016 x .022	NO. A-870	2730	RYE2
"	"	.017 x .025	NO. A-872	2730	RYE3
"	BLUE ELGILOY	.016 x .022	NO. A-888	3120	RBE2
"	"	.017 x .025	NO. A-890	0161	RBE3
AMERICAN ORMCO(6)	EDGEWISE WIRE	.016 x .016	209-1616	---	OR1
"	"	.016 x .022	254-1622	---	OR2
"	"	.017 x .025	254-1725	---	OR3
"	"	.018 x .022	254-1822	---	OR5
"	"	.019 x .025	254-1925	---	OR6
"	"	.021 x .025	254-2125	---	OR8
"	D-RECT BRAIDED	.016 x .022	201-0011	---	OB2
"	"	.017 x .025	201-0012	---	OB3
"	"	.018 x .025	201-0013	---	OB4
"	TMA	.019 x .025	202-0010	---	OT6
AUNING CO.(7)	REGULAR S.S.	.018 x .022	---	---	AU5
"	"	.019 x .026	---	---	AU7

TABLE I (cont'd.)

MANUFACTURER	WIRE TYPE	WIRE SIZE	CATALOGUE NO.	BATCH NO.	CODE
LANCER PACIFIC(8)	STAINLESS STEEL EXTRA RESILIENT	.016 x .016	---	---	L1
"	"	.016 x .022	---	---	L2
"	"	.017 x .025	---	---	L3
"	"	.018 x .025	---	---	L4
"	"	.018 x .022	---	---	L5
"	"	.021 x .025	---	---	L8

(1) - AMERICAN ORTHODONTICS, 1714 Cambridge Ave., Sheboygan, Wisconsin 53081
(2) - "A" COMPANY, P.O. Box 81247, San Diego, California 92138
(3) - MASEL ORTHODONTICS, 3021 Darnell Road, Philadelphia, Pennsylvania 19154
(4) - UNITEK, 2724 So. Peck Road, Monrovia, California 91016
(5) - ROCKY MOUNTAIN, P.O. Box 17085, Denver Colorado 80217
(6) - AMERICAN ORMCO, 1332 So. Lane Hill Ave., Glendora, California 91740
(7) - AUNING CORPORATION, 2601 W. Lincoln Highway, Olympia Fields, Illinois. 60461
(8) - LANCER PACIFIC, 6050 Avenida Encinas, Carlsbad, California 92008

TABLE II

METALLURGICAL DESCRIPTION OF ALLOYS USED IN THIS STUDY

MANUFACTURER	WIRE TYPE	ALLOY TYPE	CONDITION
AMERICAN ORTHODONTICS	EDGEWISE WIRE REGULAR	304 STAINLESS STEEL	ROLLED FROM ROUND
AMERICAN ORTHODONTICS	EDGEWISE WIRE MULTIPHASE	MP-35 Co-Ni-Cr	ROLLED FROM ROUND
AMERICAN ORTHODONTICS	EDGEWISE WIRE GOLD TONE	304 S.S. HEAT TREATED	ROLLED FROM ROUND
"A" COMPANY	TRU-ARCH GOLD	302 S.S. HIGH TEMPERED	ROLLED FROM ROUND
MASEL ORTHODONTICS	EDGEWISE WIRE RESILIENT	300 SERIES S.S.	DRAWN TO RECT. SHAPE
UNITEK	HI-T-RECT. ARCH	NOT AVAILABLE	ROLLED FROM ROUND
UNITEK	RECT. ARCH	304 STAINLESS STEEL	ROLLED FROM ROUND
UNITEK	NITINOL	52 Ni- 45 Ti - 3 Co	ROLLED FROM ROUND

TABLE II (cont'd.)

MANUFACTURER	WIRE TYPE	ALLOY TYPE	CONDITION
ROCKY MOUNTAIN	TRU-CHROME	304 STAINLESS STEEL	ROLLED FROM ROUND
ROCKY MOUNTAIN	YELLOW ELGILOY	40 Co - 20 Cr - 15 Ni - 7 Mo - bal. Fe	---
ROCKY MOUNTAIN	BLUE ELGILOY	40 Co - 20 Cr - 15 Ni - 7 Mo - bal. Fe	---
AMERICAN ORMCO	EDGEWISE WIRE	302 or 304 S.S.	ROLLED FROM ROUND
AMERICAN ORMCO	D-RECT BRAIDED	302 or 304 S.S.	ROLLED FROM ROUND
AMERICAN ORMCO	TMA	79 Ti - 11 Mo - 6 Zr - 4 Sn	ROLLED FROM ROUND
AUNING	REGULAR S. STEEL	302 STAINLESS STEEL	---
LANCER PACIFIC	STAINLESS STEEL EXTRA RESILIENT	306 STAINLESS STEEL	ROLLED FROM ROUND

that of a cross and three wires were welded in one direction and two in the other direction at about 4 mm. distance between the wires (Figure 1).

Once the wires were welded, the next step was to mix the cold cure acrylic (Coe Tray Plastic) and mount the specimen metallographically. This procedure took 20 minutes from the start of the mix until it was cured and ready to be precision ground. The pressure used in the metallographic press (Buehler Ltd. 9-22-67) was 4200 PSI.

The mounted specimen was precision ground on a No. 39-1070B Handimet Grinder (Buehler Ltd.) on silicon carbide paper (200, 320, 400, 600 mesh); then it was polished with .01 micron diamond, using AB Automet lapping oil as lubricant (Cat. No. 60-3250 Buehler Ltd.) and finally the last polishing was done with Cerium oxide polishing compound (Cat. No. 6355 Buehler Ltd.) on a Buehler Metallographic polishing wheel, Model R-1138A.

Each specimen consisted of five wires of each size, with the exception of Rocky Mountain's yellow Elgiloy and blue Elgiloy, where three .016 x .022 inch and two .017 x .025 inch wires were mounted; and Unitek's Nitinol, where three .016 x .022 inch and two .021 x .025 inch wires were prepared in the same mount.

Once the specimen was prepared, it was wiped clean with ethanol and measurements of the width, height and diagonal were made with a Gaertner traveling micrometer microscope (Figure 2) to the nearest ± 0.00004 inch. In all, a total of 920 measurements were made.

To assess the precise definition of the cross sectional shape, macro-photographs were taken using a Unitron metallographic microscope (Figure 3), model N, equipped with 10X objective, 2.5X eye piece and an Olympus OM-2 photo adaptor using a Xenon light source.

The theoretical rotation, assuming the wires have square corners, was based on the formula[15]:

$$\text{eq. \#1} \qquad \sin^{-1}\theta = \frac{bc - a\sqrt{a^2+b^2-c^2}}{(a^2+b^2)}$$

Where: θ = deflection angle
a = vertical measured wire dimension (height)
b = horizontal measured wire dimension (width)
c = vertical measured lumen dimension

The theoretical rotation taking the actual measured wire dimensions was based on the formula[8]:

$$\text{eq. \#2} \qquad \sin^{-1}\theta = \frac{(b-2r)(c) - a\sqrt{a^2+(b-2r)^2-c^2}}{(a^2)+(b-2r)^2}$$

Where: θ = deflection angle
a = vertical measured wire dimension (height)
b = horizontal measured wire dimension (width)
c = vertical measured lumen dimension
r = radius of curvature of the corners of the wire

To calculate the radius of curvature of the corners of wire, the following formula was used[8]:

$$\text{eq. \#3} \qquad r = \frac{d-d'}{2(\sqrt{2}-1)}$$

Where: r = radius of curvature of the corners of the wire
d = diagonal (theoretical) of wire
d'= actual diagonal (measured) of wire

To test the validity of eq. #2, a trial rotation was performed, taking the wire dimensions from the obtained data. This procedure was done by drawing the cross section of the wires in cardboard reproducing as close as possible, the dimensions found with the microscope. Once the cross section was drawn, it was cut with a No. 15 scalpel blade. Special attention was given to the accuracy of the diagonal. The rotation was performed manually on another piece of cardboard where both tube slots .018 inch and .022 inch had been drawn to scale. For this, it was assumed that the lumen configuration was perfectly uniform and square. Rotating the wire cross sections manually until both corners were touching the inner surfaces of the slot; the angles (deflection angles) were measured and recorded. The results of this procedure are listed in Table VI and VII.

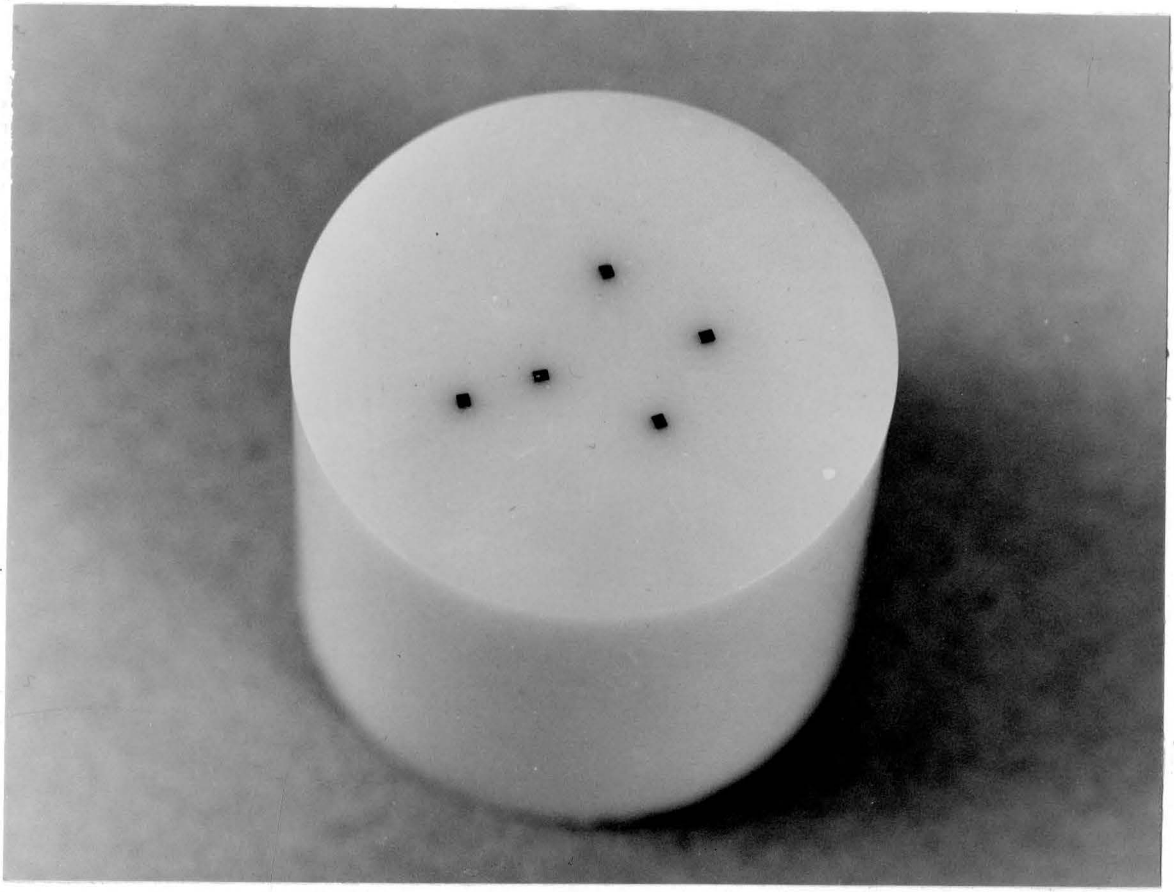

Figure 1: Orthodontic rectangular wires mounted in cold cured acrylic prior to measurement.

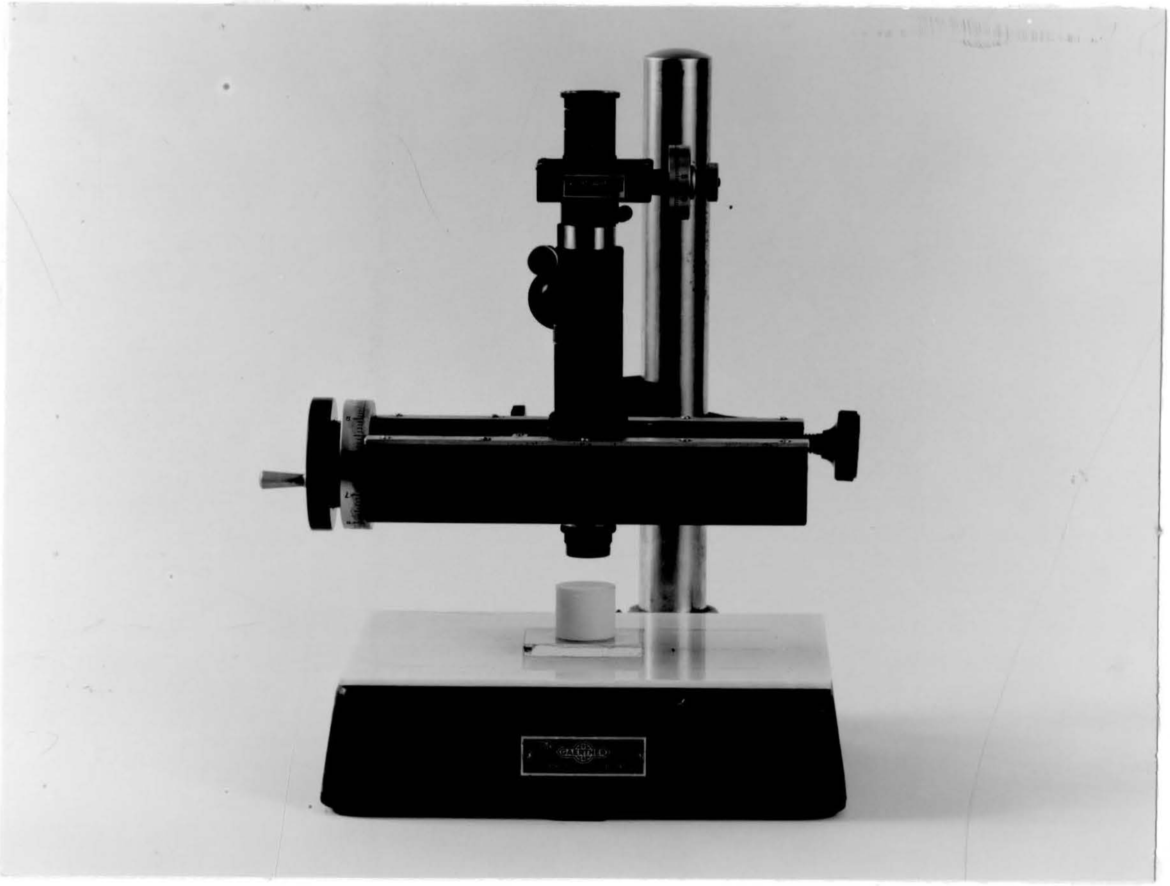

Figure 2: Gaertner traveling micrometer microscope with specimen in position to be measured.

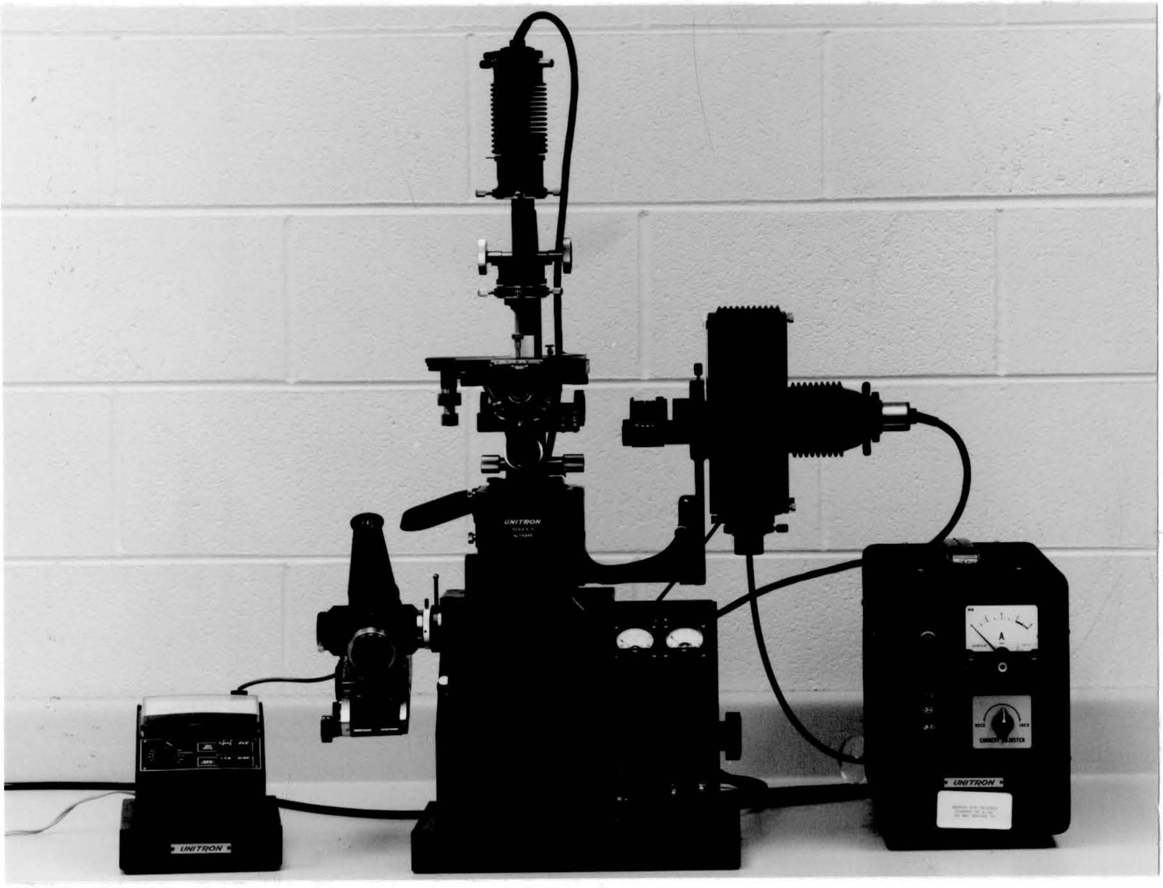

Figure 3: Unitron Metallographic microscope (Model N) equipped with 10X objective, 2.5X eye piece and an Olympus OM-2 photo adaptor, using a Xenon light source.

CHAPTER IV

RESULTS

Table I indicates the manufacturer's control data for the wires used in this study.

Table II shows the metallurgical description of the alloys used in this research.

Table III displays the theoretical dimensions of rectangular orthodontic wire (inches), compared to the measured dimensions.

Table IV compares the theoretical rotation (deflection angles) of rectangular orthodontic wire in .018 inch slot buccal tubes ($^{o}\theta$) assuming the wires have square corners to the calculated rotation of rectangular wires using the actual measured wire dimensions.

Table V is similar to Table IV but shows the results for the .022 inch slot buccal tubes.

Table VI shows the deflection angles found by manual trial rotation of selected wire cross sections in .018 inch slot buccal tube.

Table VII is similar to Table VI but displays the results for the .022 inch slot buccal tube.

TABLE III

THEORETICAL AND MEASURED DIMENSIONS OF RECTANGULAR ORTHODONTIC WIRE (INCHES)

WIRE CODE*	NOMINAL SIZE	MEASURED HEIGHT (a)	MEASURED WIDTH (b)	THEORETICAL DIAGONAL (d)	MEASURED DIAGONAL (d')
AR1	0.016 x 0.016	0.016 ± 0.0001**	0.016 ± 0.0002**	0.0226	0.020 ± 0.0002**
AR2	0.016 x 0.022	0.0157 ± 0.0003	0.0215 ± 0.0003	0.0272	0.0234 ± 0.0002
AR3	0.017 x 0.025	0.017 ± 0.0002	0.025 ± 0.0001	0.0302	0.0277 ± 0.0004
AR5	0.018 x 0.022	0.0179 ± 0.0002	0.0219 ± 0.0002	0.0284	0.0252 ± 0.0001
AR6	0.019 x 0.025	0.0192 ± 0.0002	0.025 ± 0.0002	0.0314	0.0296 ± 0.0001
AR8	0.021 x 0.025	0.0211 ± 0.0002	0.025 ± 0.00004	0.0326	0.031 ± 0.0001
AM1	0.016 x 0.016	0.0161 ± 0.0002	0.016 ± 0.0001	0.0226	0.0211 ± 0.0005
AM2	0.016 x 0.022	0.0162 ± 0.0001	0.0222 ± 0.0001	0.0272	0.0248 ± 0.0001
AM3	0.017 x 0.025	0.0171 ± 0.0002	0.0251 ± 0.0003	0.0302	0.0269 ± 0.0002
AM4	0.018 x 0.025	0.0181 ± 0.0002	0.0252 ± 0.0001	0.0308	0.0269 ± 0.0002
AM5	0.018 x 0.022	0.0179 ± 0.0001	0.0221 ± 0.0001	0.0284	0.0262 ± 0.0002
AM8	0.021 x 0.025	0.0211 ± 0.0002	0.025 ± 0.00009	0.0326	0.0298 ± 0.00003
AG1	0.016 x 0.016	0.016 ± 0.0001	0.0161 ± 0.0001	0.0226	0.0201 ± 0.0002
AG2	0.016 x 0.022	0.0161 ± 0.0002	0.0219 ± 0.0001	0.0272	0.0257 ± 0.00001
AG3	0.017 x 0.025	0.0168 ± 0.0001	0.025 ± 0.0001	0.0302	0.0269 ± 0.0001
AG5	0.018 x 0.022	0.018 ± 0.00005	0.0223 ± 0.00005	0.0284	0.0259 ± 0.00009
AG6	0.019 x 0.025	0.0191 ± 0.00008	0.0252 ± 0.00006	0.0314	0.0299 ± 0.0002
AG8	0.021 x 0.025	0.021 ± 0.0001	0.025 ± 0.0001	0.0326	0.0308 ± 0.0002

TABLE III (cont'd.)

WIRE CODE*	NOMINAL SIZE	MEASURED HEIGHT (a)	MEASURED WIDTH (b)	THEORETICAL DIAGONAL (d)	MEASURED DIAGONAL (d')
AC1	0.016 x 0.016	0.016 ± 0.0001	0.0159 ± 0.0002	0.0226	0.021 ± 0.0002
AC2	0.016 x 0.022	0.0161 ± 0.00007	0.022 ± 0.0002	0.0272	0.0254 ± 0.0005
AC3	0.017 x 0.025	0.0168 ± 0.0002	0.0249 ± 0.0002	0.0302	0.0275 ± 0.0001
AC4	0.018 x 0.025	0.0181 ± 0.0002	0.0249 ± 0.0001	0.0308	0.0286 ± 0.00008
AC6	0.019 x 0.025	0.0192 ± 0.0001	0.0252 ± 0.0002	0.0314	0.0288 ± 0.0001
AC8	0.021 x 0.025	0.0211 ± 0.0001	0.0251 ± 0.00009	0.0326	0.031 ± 0.00007
M1	0.016 x 0.016	0.016 ± 0.00009	0.0161 ± 0.0001	0.0226	0.021 ± 0.0002
M2	0.016 x 0.022	0.0159 ± 0.0002	0.022 ± 0.00008	0.0272	0.0254 ± 0.00008
M3	0.017 x 0.025	0.0169 ± 0.0002	0.0252 ± 0.00002	0.0302	0.028 ± 0.0002
M5	0.018 x 0.022	0.018 ± 0.0002	0.0223 ± 0.00002	0.0284	0.0264 ± 0.00009
M7	0.019 x 0.026	0.019 ± 0.0001	0.0261 ± 0.0002	0.0322	0.0298 ± 0.0002
M8	0.021 x 0.025	0.0208 ± 0.0002	0.0248 ± 0.0002	0.0326	0.0290 ± 0.0002
U1	0.016 x 0.016	0.0161 ± 0.0002	0.0161 ± 0.0001	0.0226	0.021 ± 0.0002
U2	0.016 x 0.022	0.016 ± 0.0002	0.0221 ± 0.0002	0.0272	0.0229 ± 0.0001
U3	0.017 x 0.025	0.0172 ± 0.0001	0.0251 ± 0.0001	0.0302	0.0270 ± 0.0002
U4	0.018 x 0.025	0.0180 ± 0.0001	0.0250 ± 0.0001	0.0308	0.0262 ± 0.00007
U5	0.018 x 0.022	0.0178 ± 0.0002	0.0223 ± 0.0001	0.0284	0.0247 ± 0.0001
U8	0.021 x 0.025	0.0211 ± 0.0003	0.0251 ± 0.0002	0.0326	0.278 ± 0.0003
UN2	0.016 x 0.022	0.0161 ± 0.0002	0.022 ± 0.0002	0.0272	0.024 ± 0.0002
UN8	0.021 x 0.025	0.0209 ± 0.00001	0.0247 ± 0.00003	0.0326	0.0268 ± 0.0001

TABLE III (cont'd.)

WIRE CODE*	NOMINAL SIZE	MEASURED HEIGHT (a)	MEASURED WIDTH (b)	THEORETICAL DIAGONAL (d)	MEASURED DIAGONAL (d')
R1	0.016 x 0.016	0.016 ± 0.0001	0.0162 ± 0.0001	0.0226	0.0213 ± 0.0003
R2	0.016 x 0.022	0.0161 ± 0.0002	0.0221 ± 0.0002	0.0272	0.0251 ± 0.0002
R3	0.017 x 0.025	0.0167 ± 0.0003	0.0251 ± 0.00007	0.0302	0.029 ± 0.0004
R5	0.018 x 0.022	0.0181 ± 0.0002	0.0221 ± 0.0002	0.0284	0.0262 ± 0.000003
R7	0.019 x 0.026	0.0191 ± 0.0002	0.0258 ± 0.00004	0.0322	0.029 ± 0.00008
R8	0.021 x 0.25	0.0210 ± 0.00008	0.0250 ± 0.0002	0.0326	0.0292 ± 0.0005
RYE2	0.016 x 0.022	0.0160 ± 0.0001	0.022 ± 0.0002	0.0272	0.0253 ± 0.00002
RYE3	0.017 x 0.025	0.0170 ± 0.0002	0.0251 ± 0.0003	0.0302	0.0282 ± 0.0002
RBE2	0.016 x 0.022	0.0162 ± 0.0002	0.0221 ± 0.0002	0.0272	0.0252 ± 0.0002
RBE3	0.017 x 0.025	0.0171 ± 0.00003	0.0253 ± 0.00005	0.0302	0.0279 ± 0.0002
OR1	0.016 x 0.016	0.016 ± 0.0002	0.0161 ± 0.0002	0.0226	0.021 ± 0.00031
OR2	0.016 x 0.022	0.0161 ± 0.0001	0.0217 ± 0.0002	0.0272	A) 0.026 ± 0.0003
					B) 0.0246 ± 0.00008
OR3	0.017 x 0.025	0.0167 ± 0.0002	0.0248 ± 0.0003	0.0302	A) 0.0286 ± 0.0002
					B) 0.0272 ± 0.0002
OR5	0.018 x 0.022	0.018 ± 0.0002	0.0220 ± 0.0002	0.0284	A) 0.0262 ± 0.0002
					B) 0.0248 ± 0.0002
OR6	0.019 x 0.025	0.0189 ± 0.0002	0.0253 ± 0.0002	0.0314	A) 0.0283 ± 0.00008
					B) 0.0271 ± 0.00008
OR8	0.021 x 0.025	0.0211 ± 0.0002	0.025 ± 0.0002	0.0326	A) 0.0294 ± 0.00009
					B) 0.0278 ± 0.0002
OT6	0.019 x 0.025	0.0191 ± 0.0002	0.0249 ± 0.0002	0.0314	0.0255 ± 0.0002

TABLE III (cont'd.)

WIRE CODE*	NOMINAL SIZE	MEASURED HEIGHT (a)	MEASURED WIDTH (b)	THEORETICAL DIAGONAL (d)	MEASURED DIAGONAL (d')
AU5	0.018 x 0.022	---	---	0.0284	0.0263 ± 0.0009
AU7	0.019 x 0.026	0.0191 ± 0.0001	0.0260 ± 0.0003	0.0322	0.030 ± 0.0002
L1	0.016 x 0.016	0.0160 ± 0.00009	0.0161 ± 0.0001	0.0226	0.0208 ± 0.0002
L2	0.016 x 0.022	0.0162 ± 0.0001	0.0223 ± 0.0001	0.0272	0.0255 ± 0.00007
L3	0.017 x 0.025	0.0171 ± 0.0001	0.025 ± 0.0002	0.0302	0.0272 ± 0.0002
L4	0.018 x 0.025	0.0179 ± 0.0003	0.0251 ± 0.0002	0.0308	0.0276 ± 0.0001
L5	0.018 x 0.022	0.0179 ± 0.0002	0.0221 ± 0.0001	0.0284	0.0260 ± 0.0001
L8	0.021 x 0.025	0.0210 ± 0.0002	0.0252 ± 0.0001	0.0326	0.0308 ± 0.0003

*See Table I for description.
**Mean ± 1 S.D.
A = Diagonal Number 1
B = Diagonal Number 2

TABLE IV

THEORETICAL ROTATION OF RECTANGULAR ORTHODONTIC WIRE IN 0.018 INCH SLOT BUCCAL TUBES (°θ)

WIRE CODE*	WIRE SIZE	THEORETICAL ROTATION**	CALCULATED ROTATION***
AR1	.016 x .016	7.7°	15.31°
AM1	"	"	9.97°
AG1	"	"	14.4°
AC1	"	"	10.98°
M1	"	"	10.74°
U1	"	"	10.12°
R1	"	"	9.86°
OR1	"	"	10.74°
L1	"	"	11.35°
AR2	.016 x .022	5.4°	12.53°
AM2	"	"	6.69°
AG2	"	"	6.27°
AC2	"	"	6.52°
M2	"	"	7.25°
U2	"	"	11.39°
UN2	"	"	8.34°
R2	"	"	6.79°
RYE2	"	"	6.99°
RBE2	"	"	6.31°
OR2	"	"	A) 6.08°
"	"	"	B) 7.61°
L2	"	"	5.95°
AR3	.017 x .025	2.32°	3.1°
AM3	"	"	3.09°
AG3	"	"	4.19°
AC3	"	"	3.86°
M3	"	"	3.25°
U3	"	"	2.7°

TABLE IV (cont'd.)

WIRE CODE*	WIRE SIZE	THEORETICAL ROTATION**		CALCULATED ROTATION***
R3	.017 x .025	2.32°		3.43°
RYE3	"	"		2.89°
RBE3	"	"		2.67°
OR3	"	"	A)	3.65°
"	"	"	B)	4.41°
L3	"	"		2.98°

*See Table I for description.
**Based on wires with square corners.
***Based on wires with rounded corners using actual measured dimensions.

A = Calculated rotation for diagonal Number 1
B = Calculated rotation for diagonal Number 2

TABLE V

THEORETICAL ROTATION OF RECTANGULAR ORTHODONTIC WIRE IN 0.022 INCH SLOT BUCCAL TUBES $(^{\circ}\theta)$

WIRE CODE*	WIRE SIZE	THEORETICAL ROTATION**	CALCULATED ROTATION***
AM4	.018 x .025	9.82°	17.45°
AC4	"	"	12.84°
U4	"	"	23.02°
L4	"	"	16.02°
AR5	.018 x .022	11.42°	22.85°
AM5	"	"	16.86°
AG5	"	"	17.17°
M5	"	"	15.43°
U5	"	"	28.13°
R5	"	"	15.86°
OR5	"	"	A) 16.51°
"	"	"	B) 25.82°
AU5	"	---	---
L5	"	11.42°	17.64°
AR6	.019 x .025	7.24°	8.36°
AG6	"	"	8.25°
AC6	"	"	9.28°
OR6	"	"	A) 11.2°
"	"	"	B) 14.3°
OT6	"	"	48.46°
M7	.019 x .026	6.93°	9.19°
R7	"	"	10.2°
AU7	"	"	8.67°

TABLE V (cont'd.)

WIRE CODE*	WIRE SIZE	THEORETICAL ROTATION**	CALCULATED ROTATION***
AR8	.021 x .025	2.33°	2.49°
AM8	"	"	3.25°
AG8	"	"	2.83°
AC8	"	"	2.48°
M8	"	"	4.5°
U8	"	"	4.04°
UN8	"	"	6.66°
R8	"	"	3.55°
OR8	"	"	A) 3.09°
"	"	"	B) 4.08°
L8	"	"	2.82°

*See Table I for description.
**Based on wires with square corners.
***Based on wires with rounded corners using actual measured dimensions.

A = Calculated rotation for diagonal Number 1
B = Calculated rotation for diagonal Number 2

TABLE VI

DEFLECTION ANGLES FOUND BY MANUAL TRIAL ROTATION OF SELECTED RECTANGULAR WIRE CROSS SECTIONS IN .018 INCH SLOT BUCCAL TUBE

WIRE CODE*	WIRE SIZE	TRIAL ROTATION NO. 1**	TRIAL ROTATION NO. 2***
AR1	.016 x .016	7°	11° both directions
U2	.016 x .022	5°	8° both directions
AR2	"	"	7° one direction
"	"	"	9° other direction
AG2	"	"	5° both directions
OR2	"	"	6° one direction
"	"	"	5° other direction
M3	.017 x .025	2°	3° both directions
AG3	"	"	2° one direction
"	"	"	4° other direction
L3	"	"	2.5° both directions
R3	"	"	2° both directions
OR3	"	"	0° one direction
"	"	"	2° other direction

*See Table I for description.

**Rotation with the wires with square corners.

***Rotation with actual configuration of wires using the measured dimensions.

TABLE VII

DEFLECTION ANGLES FOUND BY MANUAL TRIAL ROTATION OF SELECTED RECTANGULAR WIRE CROSS SECTIONS IN .022 INCH SLOT BUCCAL TUBE

WIRE CODE*	WIRE SIZE	TRIAL ROTATION NO. 1**	TRIAL ROTATION NO. 2***
OR5	.018 x .022	10°	12° one direction
"	"	"	16° other direction
U4	.018 x .025	9°	16° both directions
OT6	.019 x .025	7°	17° both directions
AU7	.019 x .026	6°	8° both directions
AC8	.021 x .025	2°	2° both directions
U8	"	"	3° both directions
UN8	"	"	3° one direction
"	"	"	2° other direction

*See Table I for description.

**Rotation with the wires with square corners.

***Rotation with actual configuration of wires using the measured dimensions.

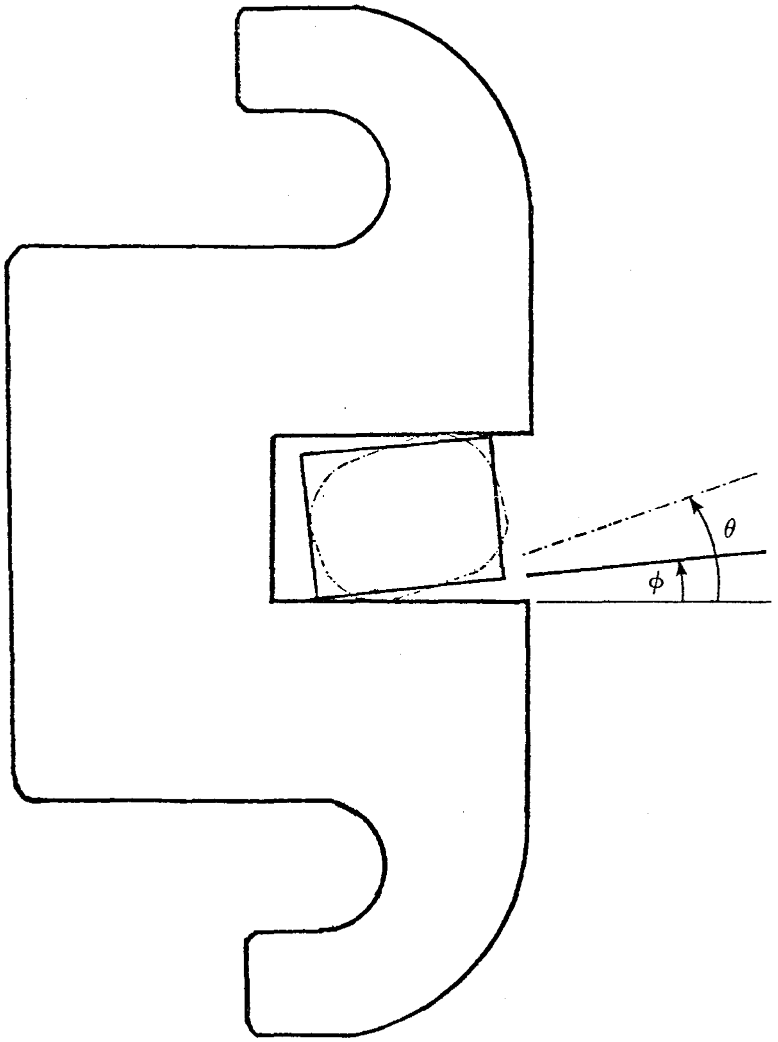

Figure 4: Diagramatic representation of the effect of rounded corners on deflection of rectangular orthodontic wire. This illustration depicts a .019 x .025 inch wire in .022 inch slot. Note that a perfectly square wire will deflect ϕ degrees, whereas a wire with rounded corners may rotate θ degrees. This represents a difference of 10° in this particular case.

CHAPTER V

DISCUSSION

In the field of orthodontic materials, very little research has been done in regard to the geometry of the cross section of rectangular orthodontic wire.

The main purpose of this investigation was to find the actual dimensions of rectangular orthodontic wire (width, height, diagonal) and also their geometry, especially the corners, which are the means of transmittal of torquing force to the bracket, to produce the desired tooth movements.

When correcting the axial inclination of teeth to get the most adequate orthodontic result, torquing movements must be used. In the edgewise technique, this can be accomplished by using round wires with the aid of spring auxiliaries, but the most effective method is with the use of rectangular wires, by twisting them when using the standard appliances or by inserting them flat in the new generation of pretorqued appliances.

To transmit the torquing force to the bracket, the rectangular wire has to bind at some point within the bracket or tube. The amount of rotation this wire will have before binding will depend on the shape and size of the tubes and on the shape and size of the rectangular wires. Lang[19] found that inconsistency in shape and size greatly affected the degree of torque, however, the degree of difference was a function of the manufacturer.

In this research, the size and geometry of the cross section of orthodontic rectangular wire, of eight different manufacturers, were studied (Tables I, II).

Table III shows the dimensions of the rectangular wires examined in this study. Compared to the nominal size, very little variation was found in regard to the width and height of the wires with the exception of Auning Corporation's .018 x .022 inch wire, which was very irregular in shape and could not be measured (Fig. 9-B,C,D). When examining the diagonal of the rectangular wire's cross sections, variation between manufacturers and within the same manufacturers were found, depending on the wire type.

<u>0.016 x 0.016 inch wire</u>

In the .016 x .016 inch wire, (Fig. 5) the theoretical diagonal of the .016 x .016 inch was found to be 0.0226 inches. The measured diagonal of five brands of wires (American Multiphase, "A" Company, Masel, Unitek, Rocky Mountain and American Ormco) was found to be .021 inches. Lancer Pacific measured diagonal was .0208 inch and American Gold Tone and Regular was .020 inch. This indicates there is very little difference between companies in the .016 x .016 inch wire with the exception of Masel, which was slightly irregular in shape (Fig. 5-D,E). The diagonal is smaller due to the roundness of the corners of this square wire.

0.016 x 0.022 inch wire

In the .016 x .022 inch rectangular wire, with a theoretical diagonal of .0272 inch, noticeable variations were found between the manufacturers. The measured diagonal of Unitek's Regular Stainless Steel for this specific size was .0229 inch. The reason for this large discrepancy was the wire had extremely rounded corners (Fig. 6-C). American Regular Stainless Steel had a diagonal of .0234 inch with very irregular corners. This wire varied in shape within the same size, type and manufacturer (Fig. 6-A,B). Unitek's Nitinol was also irregular in shape (Fig. 6-D,E) within the same size. Its diagonal measured .024 inch.

The American Ormco rectangular wire had a typical shape (Fig. 6-G), two corners being more rounded than the other two. For this reason, both diagonals were measured in all the sizes, except for the square wire. In this particular size (.016 x .022 inch), one of the diagonals measured .026 inch and the other .0246 inch. Logically this wire would bind sooner where the diagonal is larger.

The remaining companies had comparable results (American Gold Tone, "A" Company, Masel, Rocky Mountain, Lancer Pacific) ranging from .0248 inch to .0257 inch in measured diagonal.

0.017 x 0.025 inch wire

In the .017 x .025 inch wire, with a theoretical diagonal of .302 inch, variations were also found between the manufacturers, especially in shape.

American Gold Tone and Multiphase had a diagonal of .0269 inch. The corners were found inconsistent in shape for the Gold Tone wire (Fig. 7-D,E). Unitek had the second least accurate diagonal, being .0270 inch and Lancer Pacific third with .0272 inch. The Lancer Pacific wire had two corners on the same side more rounded than the two of the opposite side (Fig. 7-G).

The four other companies tested ("A" Company, American Regular, Masel, Rocky Mountain Blue and Yellow Elgiloy) more uniformily ranging from .0275 inch to .0282 inch in measured diagonal. As previously noted, Ormco was found to have an irregular shape with two corners of different radii from the other two, but this case, .017 x .025 inch was found particularly irregular in the two sharper corners (Fig. 7-F). Rocky Mountain's Tru-chrome had the most accurate diagonal compared to the rest being .0290 inch, although there was some variation in shape within the same wire (Fig. 8-E,F).

0.018 x 0.025 inch wire

For the .018 x .025 inch wire, where the theoretical diagonal was .0308 inch, Unitek was found to have the smallest measured diagonal, .0262 inch. Very similar values were recorded for American Multiphase and Lancer Pacific with measured diagonals of .0269 inch and .0276 inch respectively. "A" Company had the least roundness of the corners with a value of .0286 inch in measured diagonal. Very little difference between companies in this wire size was observed (Fig. 8-G,H,I & Fig. 9-A).

<u>0.018 x 0.022 inch wire</u>

In the .018 x .022 inch rectangular wire with a theoretical diagonal of .0284 inch, obvious differences were found between the manufacturers. Unitek again tested poorly, being the one with the most rounded corners and a measured diagonal of .0247 inch. American regular also had very rounded corners with a diagonal of .0252 inch.

The five other companies tested more consistently (American Gold Tone, Lancer Pacific, American Multiphase, Rocky Mountain's Tru-chrome and Masel) with measured diagonals ranging from .0259 inch to .0264 inch.

The .018 x .022 inch Auning Corporation rectangular wire was found the most irregular in shape of all the wires to the point where width, height and diagonal could not be measured. There were great variations in shape within the same size, some corners were missing and didn't have a definite geometry (Fig. 9-B,C,D). American Ormco followed the same pattern with one diagonal measuring .0248 inch and the other .0262 inch in this specific size.

0.019 x 0.025 inch wire

The .019 x .025 inch wire, with a theoretical diagonal of .0314 inch, was the size where the most rounded corners of all manufacturers was found. American Ormco TMA was found to have a measured diagonal of .0255 inch, (Fig. 10-C,D). The American Ormco Regular Stainless Steel was second least accurate. One diagonal measured .0271 inch and the other .0283 inch due to the peculiarity of its shape, which is the same for all the sizes. "A" Company had a .0288 inch diagonal being the third most rounded. American Orthodontics had the best wires in this size with a .0296 inch diagonal for the regular and a .0299 inch diagonal for the Gold Tone, which values are very close to the theoretical diagonal (Fig. 10-G,H).

0.019 x 0.026 inch wire

For the .019 x .026 inch only three manufacturers sent samples (Rocky Mountain, Masel and Auning). All of these wires tested more consistently with measured diagonals ranging from .029 inch to .030 inch where the theoretical diagonal was .0322. In the Rocky Mountain's specimen of this wire size, some difference in shape was found (Fig. 10-I & Fig. 11-A).

0.021 x 0.025 inch wire

Lastly, the .021 x .025 inch rectangular wire, with a theoretical diagonal of .0326 inch, also presented variations between manufacturers. Once more, Unitek had the most rounded corners, both in Nitinol, with a measured diagonal of .0268 inch and Regular Stainless Steel with a diagonal of .0278 inch. American Ormco was second least accurate, with one diagonal being .0278 inch and the other .0294 inch. The remaining manufacturers tested more uniformly (Rocky Mountain, Masel, American Gold Tone, American Multiphase, Lancer Pacific, "A" Company, American regular) with measured diagonals ranging from .029 inch to .031 inch (Fig. 11-D thru I & Fig. 12-A thru E).

Since it was found that wires are made with rounded corners to various degrees, depending on the manufacturer, a further investigation was done. An equation was derived (equation number 2) to determine the theoretical rotation of rounded corner wires in order to show the difference in rotation between perfectly square wires. It was assumed the buccal tube dimensions were ideal. However, from Lang's[19] data this is known to be false.

Table IV displays the results for the rectangular wires commonly used for torquing purposes in the .018 inch buccal tubes, comparing the theoretical rotation of these rectangular wires with presumably perfectly square corners versus the calculated rotation of the rectangular wires with their actual cross sectional geometry.

0.016 x 0.016 wire in 0.018 slot

In the case of the .016 x .016 inch square wire, assuming its corners are perfectly square and also that the tubes are uniform, the theoretical rotation was 7.7°. However, when the corners of these wires are rounded, the actual rotation was found to be almost twice as great. American regular rotated 15.31° at binding, American Gold Tone 14.4°. In this instance, in order for the wire to produce torquing movement upon the bracket to move the tooth, twice the additional twist is needed to be incorporated in the wire to accomplish the desired movement of the tooth and or teeth.

The other manufacturers (Lancer Pacific, "A" Company, American Ormco, Masel, Unitek, American Multiphase, Rocky Mountain) also had greater values in calculated rotation within the tube, ranging from to 2° to 4° more deflection, than the wire with the ideal geometry.

0.016 x 0.022 wire in 0.018 slot

For the .016 x .022 inch wire in the .018 inch slot, American Regular once more tested poorly, rotating 12.53° before binding, compared to the .016 x .022 inch rectangular wire with perfectly square corners that rotated 5.4°. Unitek's Regular Stainless Steel was second, with larger values of rotation with a deflection angle of 11.39°. Comparable results were found for five other manufacturers (Lancer Pacific, American Gold Tone, Rocky Mountain Blue Elgiloy, "A" Company, Rocky Mountain Yellow Elgiloy, Masel, and Unitek Nitinol) with calculated rotation in the

.018 inch tube ranging from 8.34^{0} to 5.95^{0}.

The American Ormco .016 x .022 inch wire had two values, depending on the side with which the wire would bind inside the tube, with an almost 2^{0} difference rotating 7.61^{0} in one direction and 6.08^{0} in the other direction.

0.017 x 0.025 wire 0.018 slot

The results for the .017 x .025 inch rectangular wire demonstrated that an increase in the size of the wire would reduce the amount of rotation, and therefore, the shape of the corners would have little effect on the torque delivery. An example of this is Unitek's Rectangular Stainless Steel wire that showed rotation of only 2.7^{0},compared to the theoretical rotation of 2.32^{0}. When examining the cross section, Unitek had one of the most rounded corners with only American Gold Tone being more irregular. A possible explanation for this discrepancy is that these wires would bind sooner because they had larger dimensions: .0251 inch in width and .0172 inch in height, thus being a little oversized. Very small differences were found for the rest of the companies in values for calculated rotation ranging from 4.41^{0} to 2.98^{0} compared to the 2.32^{0} theoretical rotation in this specific wire size.

0.018 x 0.025 wire in 0.022 slot

Examination of Table V shows the theoretical rotation of .018 x .025 inch wire with square corners rotated 9.82^{0}. Unitek showed a difference of 13.2^{0} with a calculated rotation of 23.02^{0} for this particular wire size. Clinically this would mean a lot of additional torsion in the wire, e.g. to place 10^{0} of torque in the central incisors, this wire would have to be twisted an extra 30^{0} to get the desired tooth movement. American Multiphase and Lancer Pacific would also lack efficiency when used for torquing, since they showed calculated rotations of 17.45^{0} and 16.02^{0} respectively. "A" Company showed the least amount of rotation (12.84^{0}) compared to the theoretical value.

0.018 x 0.022 wire in 0.022 slot

The .018 x .022 inch wire size with square corners, showed a rotation 11.42^{0} at binding. Unitek again was found to have the largest amount of rotation with a deflection angle of 28.13^{0}. American regular also was found to rotate a great amount, with a 22.85^{0} calculated rotation. American Ormco wire produced a deflection angle of 25.82^{0} when rotated in one direction and a 16.51^{0} when rotated in the other direction. A difference of 9.31^{0} in the same wire, depending on the direction where the binding would occur. This phenomena was true for all the samples of this manufactuer with the exception of the .016 x .016 inch square wire. Other than the Auning Corporation rectangular wire, which in this size was impossible to measure, due to gross irregularities, the rest of the companies (Lancer Pacific, American Gold Tone, American Multiphase, Rocky Mountain and Masel) proved more efficient when used for torquing since the amount of rotation ranged from 17.64° to 15.43°.

0.019 x 0.025 wire in 0.022 slot

In the size .019 x .025 inch wire with a theoretical rotation of 7.24° the American Ormco TMA was found to have the greatest amount of rotation being 48.46°. For torquing, this particular wire would be of very little use since its cross sectional geometry is inadequate for such intentions (Fig. 10-C,D). American Ormco Stainless Steel also had large deflection angles of 14.2° in one direction and 11.2° in the other direction due to the differences in radii of two of the four corners. "A" Company had only a 2° difference with a calculated rotation of 9.28° and American Orthodontics was the most accurate for both the Regular Stainless Steel and the Gold Tone, with deflection angles of 8.36° and 8.25° respectively.

0.019 x 0.026 wire in 0.022 slot

For the .019 x .026 inch wire, the three manufacturers (Rocky Mountain, Masel and Auning) had comparable results. With a theoretical rotation of 6.93°, their calculated rotation values ranged from 10.2° to 8.67°.

0.021 x 0.025 wire in 0.022 slot

With a full size wire, or .021 x .025 inch in .022 inch slot, the amount of rotation before binding is negligible being 2.33° for the square cornered wire. Unitek's Nitinol had the highest deflection angle of 6.66°, which is not so critical since the cross section is bigger. Logically it would bind much sooner.

Masel, Unitek's Stainless Steel and American Ormco also had comparably larger values, but of very little importance, since it was in the order of 2° difference from the theoretical rotation. Values for calculated rotation of these rectangular wires were from 4.5° to 4.08°.

The six other companies (Rocky Mountain, American Multiphase, American Gold Tone, Lancer Pacific, American Regular and "A" Company) had even smaller values ranging from 3.55° to 2.48° in deflection angles. Therefore, very little torque is lost due to rotation of these wires in the brackets and or buccal tubes.

The rotation of the wire within the tube before binding, or deflection angles for the rounded cornered wire, was calculated with the equation number 2 (Page 23). Two assumptions were done to generate the formula. (1) That the wires were square in cross section which indicates the more rectangular the wire, the less accurate this eouation would be. (2) It was assumed the configuration of the slot was uniform and consistent in size. A third experiment was divised to eliminate the first element of error, trial rotations of selected wire cross sections were performed manually. This in turn tested the validity of equation number 2. Figure 4 shows what occurs when two rectangular wires of the same width and height are rotated where one has perfectly square corners and the other has rounded corners. In this instance, a difference of 10° was found in the deflection angles, 7° for the square cornered and 17° for the rounded cornered wire. Again, it is assumed that the slot has a consistent shape and size. Lang[19] found the tubes were inconsistent in shape, depending on the manufacturer, which indicates a further study is needed where the tube with the best configuration and geometry would be used to rotate the wires from different manufacturers to find their deflection angles.

The results found in Table VI are those from the manual rotation performed in the .018 inch slot. Only selected wires were used.

0.016 x 0.016 wire in 0.018 slot

The .016 x .016 inch wires with square corners rotated 7°, American Regular rotated 11°. A difference of 4° was found compared to the 7° difference found with the formula. This shows the results can be considered having a certain degree of accuracy, because the rotation done manually in itself had incorporated error.

0.016 x 0.022 wire in 0.018 slot

For the .016 x .022 inch wire with sharp corners, the manual rotation showed a deflection angle of 5°.

American regular had two different values, depending on the direction it was rotated, 9^{o} in one direction and 7^{o} in the other direction. This demonstrated the effect the irregularities of these wires would have on the amount of torsion needed to be incorporated in the wire to get the proper torque action on the teeth.

Other cross sections manually rotated were Unitek with 8^{o} deflection angle, American Gold Tone with 5^{o} and American Ormco with 6^{o} in one direction and 5^{o} in the other direction.

0.017 x 0.025 wire in 0.018 slot

In the .017 x .025 inch wire, very little difference between the square cornered and the chosen cross sections were found, the first having 2^{o} in deflection angle and the highest value being American Gold Tone with a 4^{o} deflection angle in one direction and 2^{o} in the other direction. In this specific size, the accuracy of the equation was proven to be acceptable since the values found by trial rotations were very similar to those calculated with the equation (Table IV).

Table VII displays manual rotations performed in the .022 inch slot of some chosen wire cross sections. Again, difference between the sharp cornered cross section, when rotated compared to the wires as they actually are, was found. It was interesting to note that the highest value was credited to American Ormco TMA .019 x .025 inch wire, with a deflection angle 10° higher than the square cornered cross section. With the equation, this wire also had the highest value, but comparing both values, there was a great discrepancy since its calculated rotation was 48.46°.

From this, it could be stated that even though the validity of the equation can be questioned, certain generalizations could be made about the effect, the shape and size of the cross section of the rectangular wires have in the delivery of torque. The lack of rigid control when torquing, is aggravated by rounding the corners of the wires, or having an irregular shape, which leaves to chance the precision of the movements required. Clinically, where torquing individual or groups of teeth, it takes sometimes several visits and a lot of bending to get any action from the wire.

This in part, is also due to the inconsistency of the tubes. The size is also very important. It was found as expected, that the greater cross sections logically showed the smallest deflection angles (.017 x .025 for the .018 slot and .021 x .025 for the .022 slot). For these two particular sizes, very little difference in values for deflection angles was found between the manufacturers, even though they were different in shape. Therefore, the shape of the corner, would have less importance as the size of the wire is increased. Although a large wire will rotate 50%

more than would be expected from theoretical considerations, this difference translates to only a few degrees, that is from 2^{o} theoretical to 4^{o} actual rotation. This degree of difference is probably not clinically significant. It is apparent that a much greater degree of quality control is necessary with smaller than larger wires.

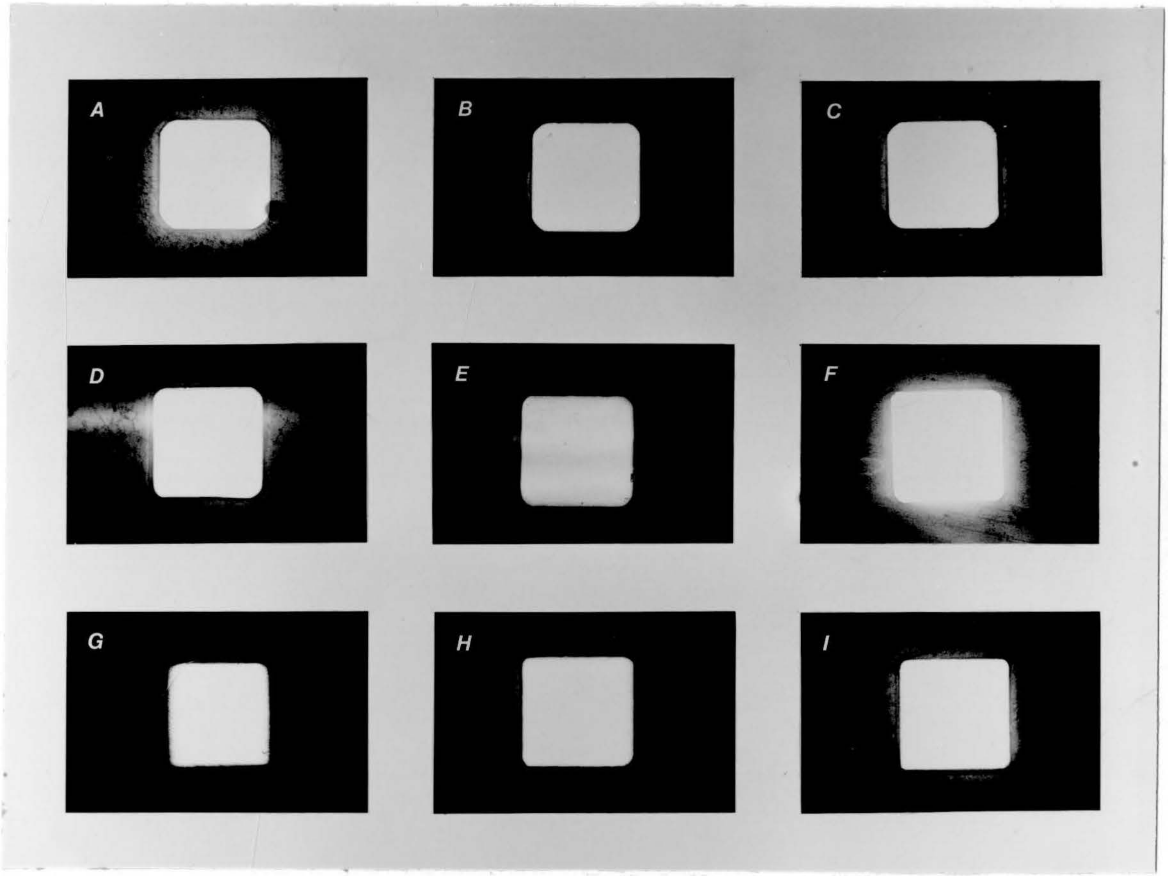

Figure 5: Photomicrographs of orthodontic rectangular wires shown in cross section, 40X.

A: .016 x .016 inch American Regular
B: .016 x .016 inch Lancer Pacific
C: .016 x .016 inch American Gold Tone
D: .016 x .016 inch Masel Orthodontics
E: .016 x .016 inch Masel Orthodontics
F: .016 x .016 inch Unitek Hi-T Square Wire
G: .016 x .016 inch American Ormco
H: .016 x .016 inch American Multiphase
I: .016 x .016 inch American Multiphase

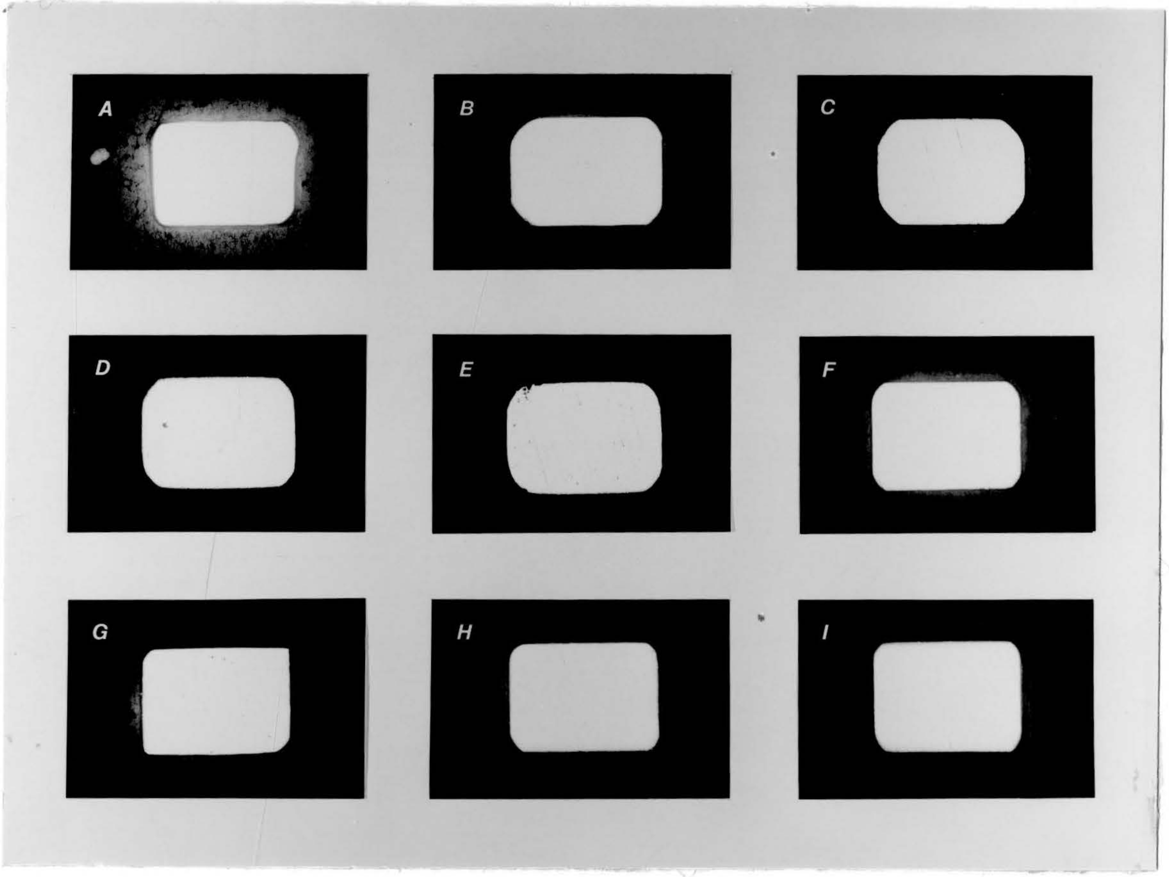

Figure 6: Photomicrographs of orthodontic rectangular wires shown in cross section, 40X.

A: .016 x .022 inch American Regular
B: .016 x .022 inch American Regular
C: .016 x .022 inch Unitek Rect Arch
D: .016 x .022 inch Unitek Nitinol
E: .016 x .022 inch Unitek Nitinol
F: .016 x .022 inch American Multiphase
G: .016 x .022 inch American Ormco
H: .016 x .022 inch Rocky Mountain Yellow Elgiloy
I: .016 x .022 inch Rocky Mountain Blue Elgiloy

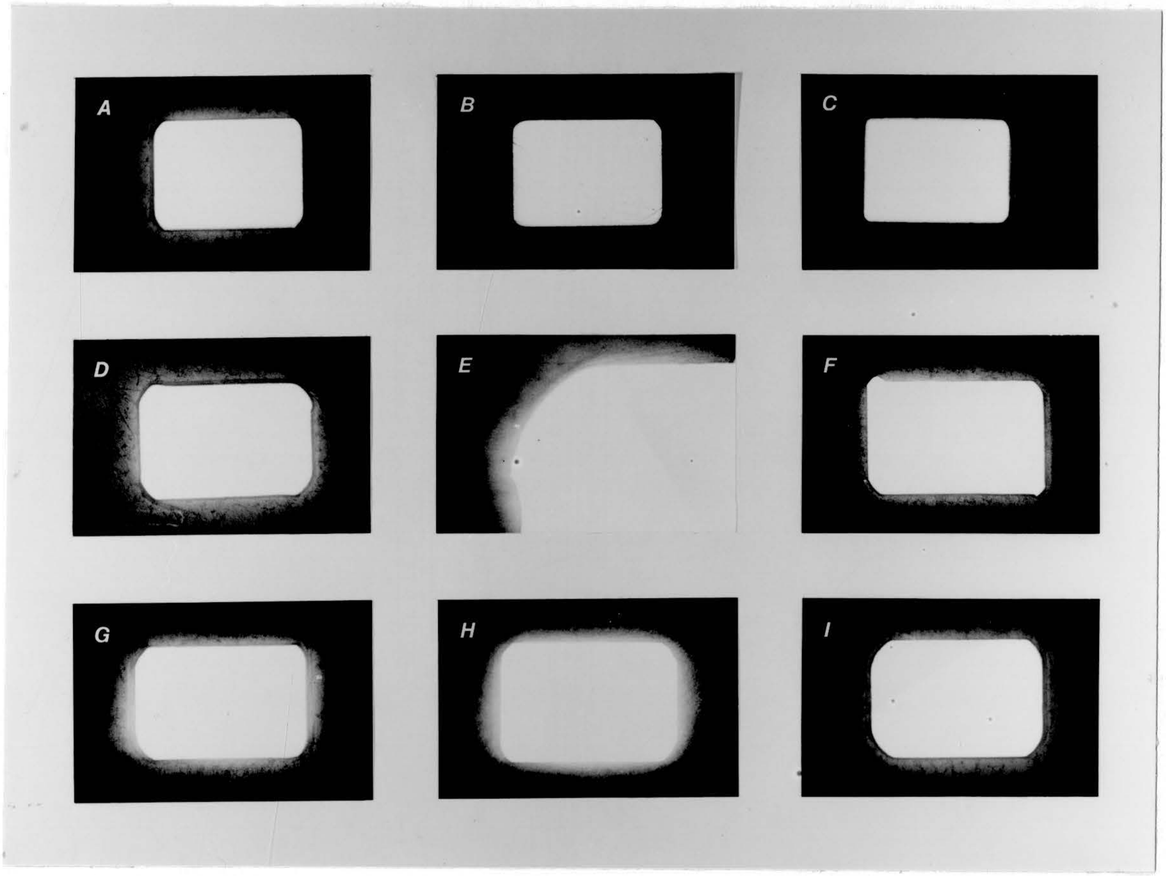

Figure 7: Photomicrographs of orthodontic rectangular wires shown in cross section, 40X.

A: .016 x .022 inch Rocky Mountain Tru-Chrome
B: .016 x .022 inch Masel Orthodontics
C: .016 x .022 inch American Gold Tone
D: .017 x .025 inch American Gold Tone
E: .017 x .025 inch American Gold Tone (80X)
F: .017 x .025 inch American Ormco
G: .017 x .025 inch Lancer Pacific
H: .017 x .025 inch "A" Company
I: .017 x .025 inch American Multiphase

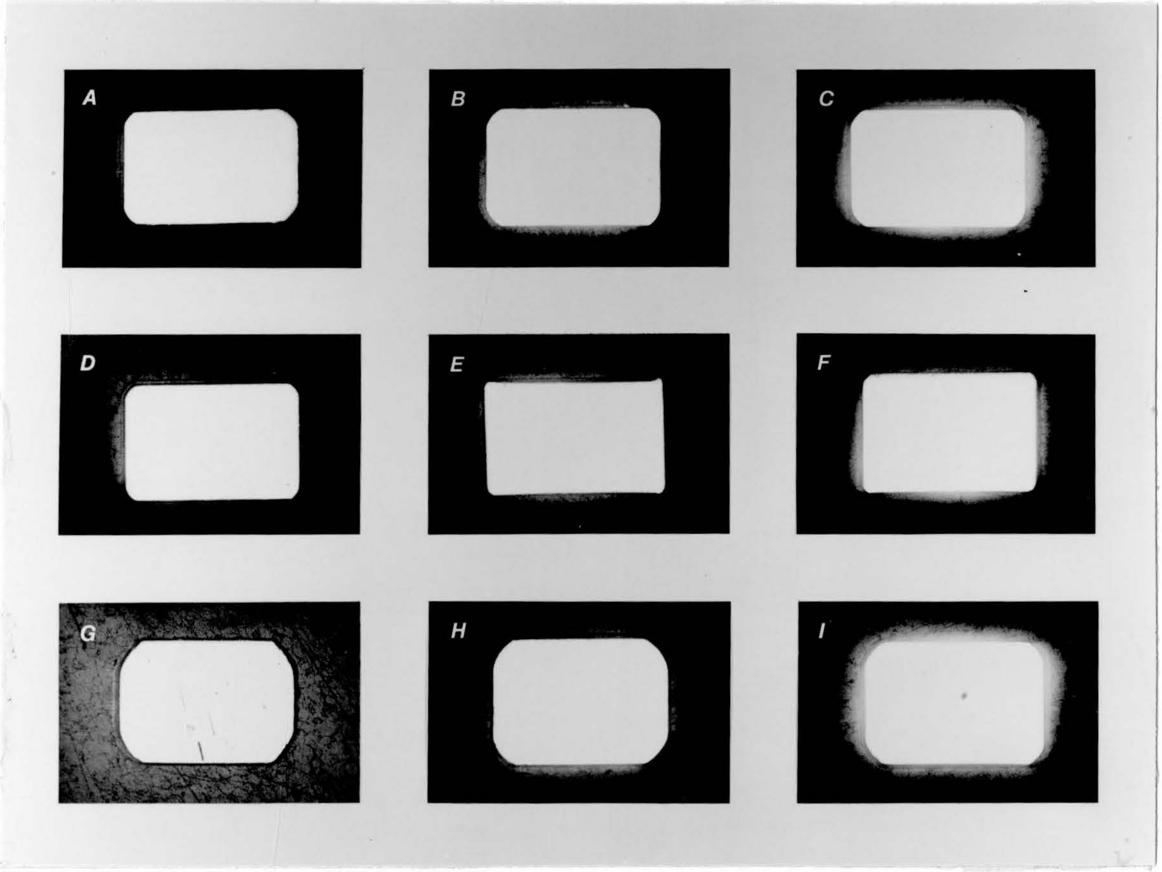

Figure 8: Photomicrographs of orthodontic rectangular wires shown in cross section, 40X.

A: .017 x .025 inch Rocky Mountain Blue Elgiloy
B: .017 x .025 inch American Regular
C: .017 x .025 inch Masel Orthodontics
D: .017 x .025 inch Rocky Mountain Yellow Elgiloy
E: .017 x .025 inch Rocky Mountain Tru-Chrome
F: .017 x .025 inch Rocky Muntain Tru-Chrome
G: .018 x .025 inch Unitek
H: .018 x .025 inch American Multiphase
I: .018 x .025 inch Lancer Pacific

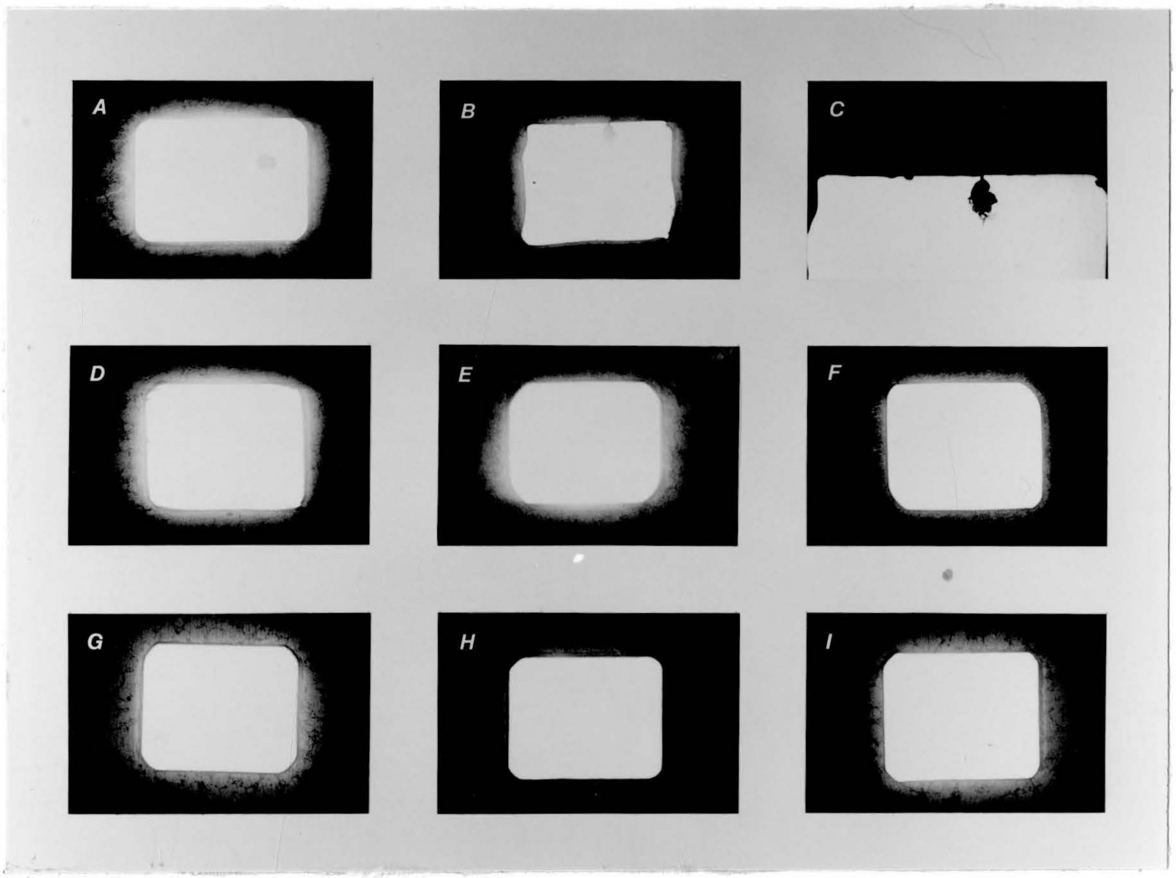

Figure 9: Photomicrographs of orthodontic rectangular wires shown in cross section, 40X.

A: .018 x .025 inch "A" Company
B: .018 x .022 inch Auning Corporation
C: .018 x .022 inch Auning Corporation (80X)
D: .018 x .022 inch Auning Corporation
E: .018 x .022 inch Unitek Rect Arch
F: .018 x .022 inch American Ormco
G: .018 x .022 inch American Gold Tone
H: .018 x .022 inch American Multiphase
I: .018 x .022 inch Masel Orthodontics

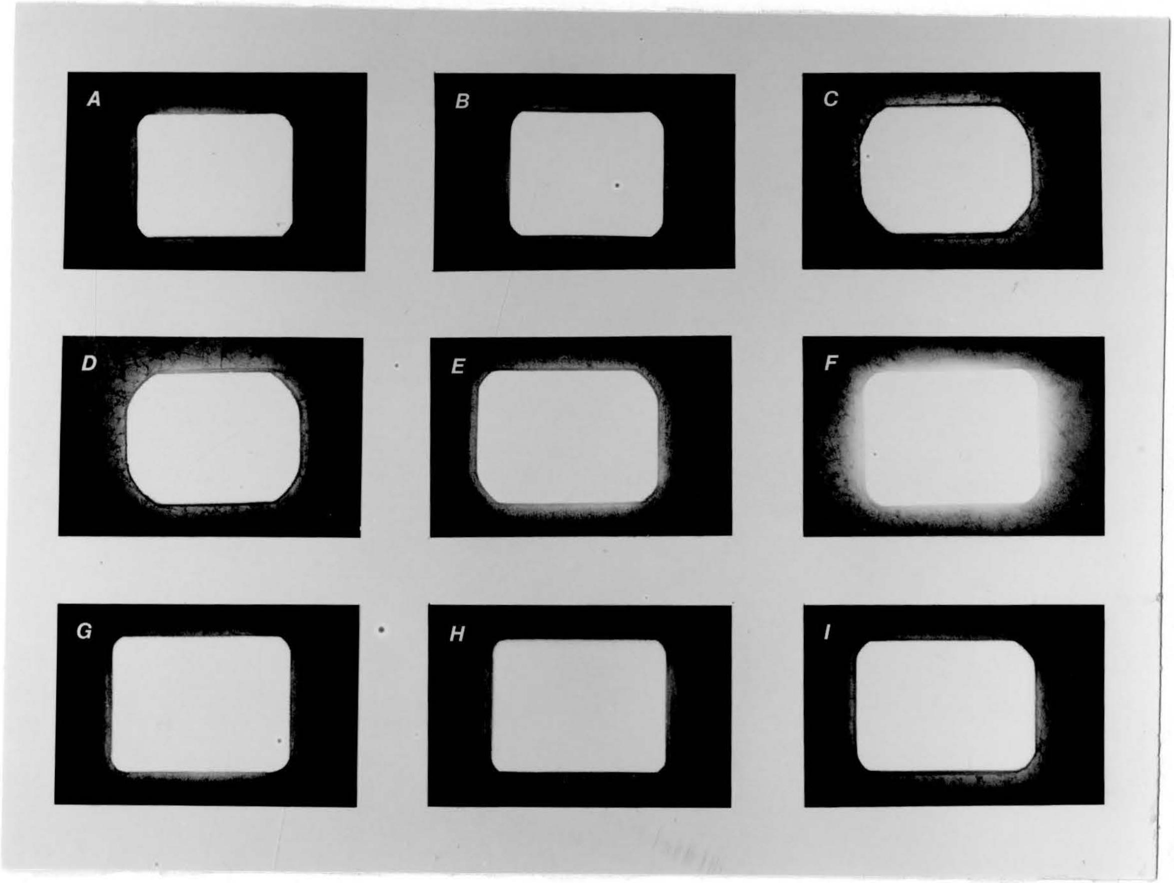

Figure 10: Photomicrographs of orthodontic rectangular wires shown in cross section, 40X.

A: .018 x .022 inch Lancer Pacific
B: .018 x .022 inch Rocky Mountain Tru-Chrome
C: .019 x .025 inch American Ormco TMA
D: .019 x .025 inch American Ormco TMA
E: .019 x .025 inch American Ormco Edgewise Wire
F: .019 x .025 inch "A" Company
G: .019 x .025 inch American Regular
H: .019 x .025 inch American Gold Tone
I: .019 x .026 inch Rocky Mountain Tru-Chrome

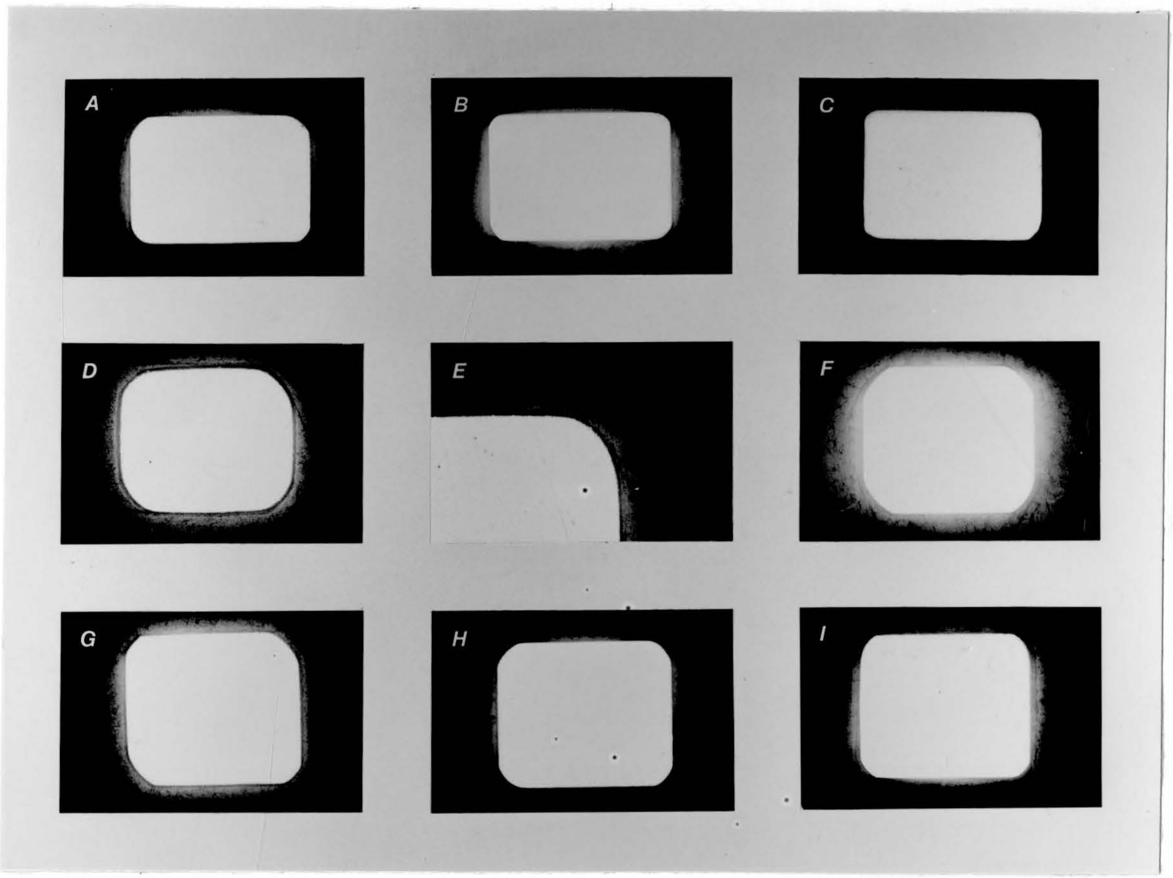

Figure 11: Photomicrographs of orthodontic rectangular wires shown in cross section, 40X.

A: .019 x .026 inch Rocky Mountain Tru-Chrome
B: .019 x .026 inch Masel Orthodontic
C: .019 x .026 inch Auning Corporation
D: .021 x .025 inch Unitek Nitinol
E: .021 x .025 inch Unitek Nitinol (80X)
F: .021 x .025 inch Unitek Rect Arch
G: .021 x .025 inch American Ormco Edgewise Wire
H: .021 x .025 inch Rocky Mountain Tru-Chrome
I: .021 x .025 inch Masel Orthodontics

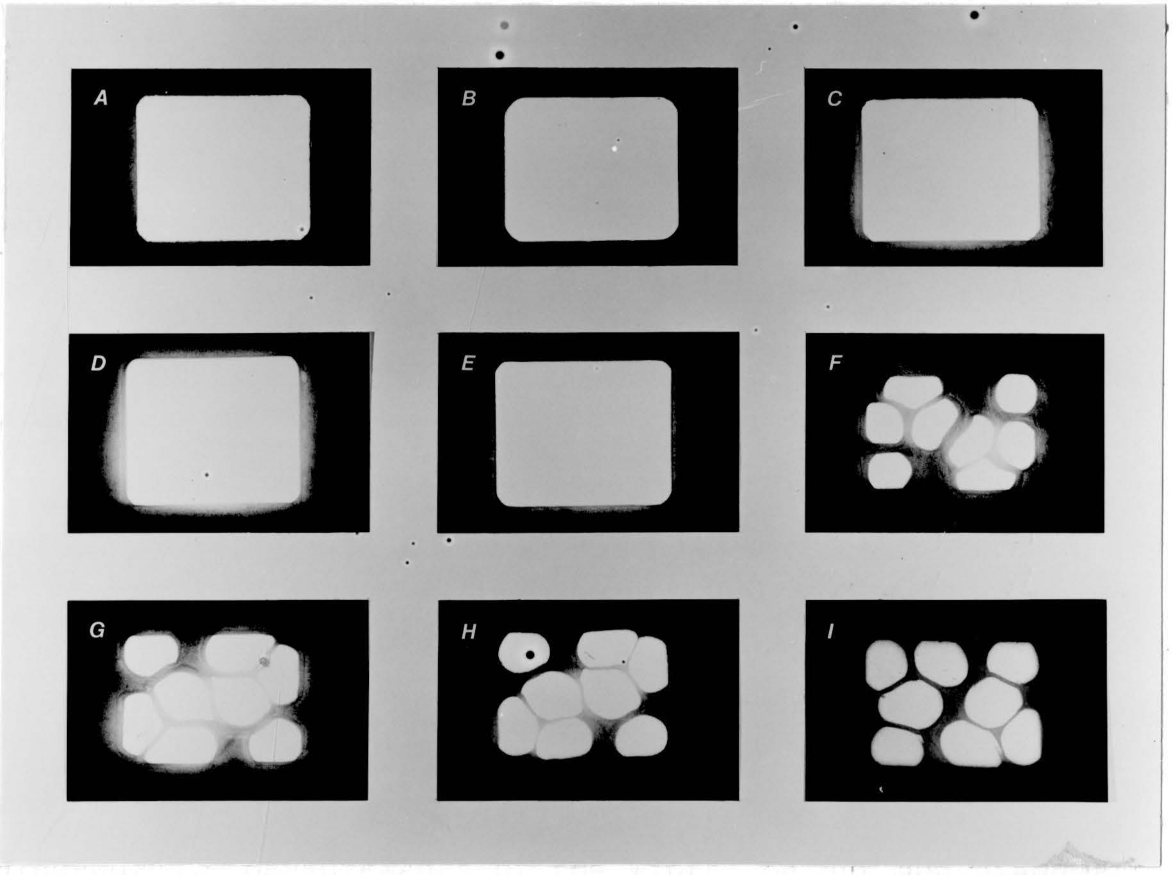

Figure 12: Photomicrographs of orthodontic rectangular wires shown in cross section, 40X.

A: .021 x .025 inch American Gold Tone
B: .021 x .025 inch American Multiphase
C: .021 x .025 inch Lancer Pacific
D: .021 x .025 inch "A" Company
E: .021 x .025 inch American Regular
F: .016 x .022 inch American Ormco D-Rect Braided
G: .017 x .025 inch American Ormco D-Rect Braided
H: .018 x .025 inch American Ormco D-Rect Braided
I: .018 x .025 inch American Ormco D-Rect Braided

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to find the actual cross sectional geometry of rectangular orthodontic wire, and to determine the amount of rotation (deflection angles) these rectangular wires would experience within the bracket or buccal tubes, based on theoretical calculations.

Eight manufacturers were examined: American Orthodontics, American Ormco, "A" Company, Auning Corporation, Lancer Pacific, Masel Orthodontics, Rocky Mountain and Unitek.

Specimens consisting of five rectangular wires of each size were prepared, using conventional metallographic procedures. Measurements of the width, height and diagonal were performed. The wire dimensions examined were those commonly used for torquing purposes.

The measurements were made on a Gaertner Traveling Micrometer Microscope. Assessment of the shape of the rectangular wire's cross section was made from microphotographs taken with the Unitron Metallographic Microscope.

Theoretical calculation of the deflection angles or rotation at binding, departing from the obtained (measured) dimensions of the rectangular wire was performed. Calculation of the rotation was done for both .018 inch and .022 inch slot buccal tubes, assuming these were perfectly uniform in shape and size.

Based on the analysis of the attained data, the following conclusions are made:

The amount of rotation (play) the rectangular wires will experience at binding is dependent on the size and shape of their cross section.

There is variation between manufacturers in the diagonal dimensions where all were smaller than the theoretical for all sizes, due to rounding of the corners.

Rectangular wires with smaller diagonals than theoretical, will rotate a greater amount than those of longer diagonals of the same size. This means the addition of torsion to the rectangular wire will vary depending on the manufacturer.

There is little variation between the nominal size and that obtained experimentally for all the wire sizes and manufacturers, with the exception of Auning Corporation's .018 x .022 inch rectangular wire.

There is little variation between manufacturers in the .016 x .016 inch square wire in shape and size.

There is variation in the shape of the corners of the orthodontic rectangular wire depending in the manufacturer, which can affect the efficacy of the appliance to produce torquing moments on the teeth.

The effect on torquing efficiency of rounded versus square cornered wires becomes clinically less significant as the size of the wire increases, although the percentage difference remains essentially unchanged.

Greater degree of quality control in the shape and size is needed for the rectangular wires of smaller dimensions.

REFERENCES

1. Anderson, Ronald M.: "A Return to Large Nonresilient Straight Arch Wires", Am. J. of Orthod., 66:9-39, July 1974.

2. Andreasen, G.F.: "Seclection of Square and Rectangular Wires in Clinical Practice", Angle Orthod., 42:81-84, Jan. 1972.

3. Andrews, Lawrence F.: "The Six Keys to Normal Occlusion", Am. J. of Orthod., 62:296-309, Sept. 1972.

4. Andrews, Lawrence F.: "The Straight Wire Appliance - Origin, Controversy, Commentary", J. of Clin. Orthod., 10:99-116, Feb. 1976.

5. Angle, Edward H.: "Some New Forms of Orthodontic Mechanism and the Reason for Their Introduction", Dent. Cos., 43:969-994, Sept. 1916.

6. Angle, Edward H.: "The Latest and Best in Orthodontic Mechanism", Dent. Cos., 70:1143-1158, Dec. 1928.

7. Blodgett, G.B., Andreasen, G.F.: "Comparison of Two Methods of Applying Lingual Root Torque to Maxillary Incisors", Angle Orthod., 38:216-224, July 1968.

8. Bricker, Preston: Personal Communication, 1981.

9. Brodie, Allen G.: "An Appraisal of Present Day Orthodontic Procedure", Dent. Cos., 69:810-815, Aug. 1927.

10. Brodie, Allen G.: "A Discussion of Torque Force", Angle Orthod., 3:263-265, March 1933.

11. Burstone, C.J., Baldwin, J.J., Lawless, D.T.: "The Application of Continuous Forces to Orthodontics", Angle Orthod., 31:1-14, Jan. 1961.

12. Burstone, C.J.: "Rationale of the Segmented Arch", Am. J. of Orthod., 48:805-822, Nov. 1962.

13. Burstone, C.J., Goldberg, J. A.: "Beta Titanium: A New Orthodontic Alloy", Am. J. of Orthod., 77:121-132, Feb. 1980.

14. Creekmore, Thomas D.: "On Torque", J. of Clin. Orthod., 13:305-310, May 1979.

15. Dellinger, Eugene L.: "A Scientific Assessment of the Straight Wire Appliance", Am. J. of Orthod., 73:290-299, March 1978.

16. Jarabak, Joseph: "Development of Treatment Plan in the Light of One's Concepts of Treatment Objectives", Am. J. of Orthod., 46:481-494, July 1960.

17. Jarabak, Joseph: "Technique and Treatment with the Light Wire Appliance", The C.V. Mosby Co., 1963.

18. Kohl, R.W.: "Metallurgy in Orthodontics", Angle Orthod., 34:37-52, Jan. 1964.

19. Lang, Richard L.: "Torque as Related to Tolerance in Pretorqued Buccal Tubes", Masters Thesis, Loyola University School of Dentistry, Maywood, IL., 1980.

20. Raphael, Eliezer: "Angular Rotation of Rectangular Wire in Rectangular Buccal Tubes", Masters Thesis, Loyola University School of Dentistry, Maywood, IL., 1978.

21. Rauch, Erman D.: "Torque and Its Applications to Orthodontics", Am. J. of Orthod., 45:817-830, Nov. 1956.

22. Reitan, Kier: "Some Factors Determining the Evaluation of Force in Orthodontics", Am. J. of Orthod., 43:32-45, Nov. 1956.

23. Roth, Ronald H.: "The Maintenance System and Occlusal Dynamics", Dent. Clin. of No. Am., 20:761-788, Oct. 1976.

24. Schrody, David W.: "A Mechanical Evaluation of Buccal Segment Reaction to Edgewise Torque", Angle Orthod., 44:120-126, April 1974.

25. Schwaninger, Bernhard: "Evaluation of the Straight Arch Wire Concept", Am. J. of Orthod., 74:188-196, Aug. 1978.

26. Steiner, Cecil C.: "Force Control in Orthodontia", Angle Orthod., 2:252-259, 1932.

27. Steiner, Cecil C.: "Power Storage and Delivery in Orthodontic Appliances", Am. J. of Orthod., 39:859-880, Nov. 1953.

28. Strang, Robert H.: "A Definite Technique Applied to Ribbon Arch Modifications for Tooth Movements", Dent. Cos., 67:779-796, Aug. 1925.

29. Thurow, Raymond C.: Edgewise Orthodontics, The C.V. Mosby Co., 1972.

30. Wilkinson, J.V.: "Some Metallurgical Aspects of Orthodontic Stainless Steel", Am. J. of Orthod., 48:192-206, March 1962.

APPROVAL SHEET

The thesis submitted by Mauricio A. Molina Rodriguez, D.D.S. has been read and approved by the following committee:

Sandrik, James L., Ph.D.
Chairman, Dental Materials, Loyola

Klapper, Lewis, D.M.D., M.Sc.D., D.Sc.
Assistant Professor and Chairman, Orthodontic Department, Loyola

Bowman, Douglas C., Ph.D.
Associate Professor, Physiology and Pharmacology, Loyola

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the Committee with reference to content and form.

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

September 9, 1981
Date

James L. Sandrik
Director's Signature