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An Evaluation of Total and Projected Root Surface Areas of Maxillary Human Teeth

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AN EVALUATION OF TOTAL AND PROJECTED ROOT SURFACE AREAS OF MAXILLARY HUMAN TEETH

by

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LIFE

Clifton Y. Moromisato was born in Honolulu, Hawaii on April 19, 1934. He graduated from Kaimuki High School in June, 1952 and entered the University of Hawaii in September of the same year. He continued his undergraduate studies at the University of Illinois and Loyola University.

He entered the Loyola University School of Dentistry in 1956 and graduated in June, 1960 with the degree of Doctor of Dental Surgery.

He served as a commissioned dental officer in the United States Air Force from 1960 to 1965. He has been enrolled in the Department of Oral Biology at Loyola University working toward a degree of Master of Science since July of 1965.

The author is married and has two sons and a daughter.

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CHAPTER I

INTRODUCTION AND STATEMENT OF THE PROBLEM

A. Introductory Remarks

The determination of root surface area of human teeth has interested several investigators. This has catalyzed numerous pieces of research to correlate periodontal ligament area with masticatory pressure. A correlation of total and projected root surface area needs further clarification. The roots are of varying lengths, forms, and number. The significance of these variations is that the roots are designed to support the crowns subjected to a great variety of complex forces, pressures, and stresses.

Orthodontic appliances apply forces to the crowns of teeth, and the magnitude and direction of these forces can be controlled accurately in many instances. Yet, it is the distribution of the forces against the alveolar walls that determines the pattern of bone apposition and resorption making tooth movement possible. The magnitude and direction of the forces created by the appliances are important only to the extent that

they are related to the pressure and tension exerted upon the roots and alveoli. Equal forces applied to crowns of different teeth will not manifest themselves in equal pressures throughout the alveolar walls. The pressure distributed throughout the alveolar walls will be inversely proportional to the root surface area if the force is constant. The tooth with a greater root surface area will exert less pressure against its alveolus than one with a smaller surface.

Forces applied to the crowns of teeth create areas of pressure and areas of tension within the periodontal ligament which in turn stimulate bone apposition and resorption. There have been extensive investigations of tissue reaction to orthodontic forces, but research directed toward the analytical evaluation of force distribution in orthodontic movement has received little attention. Problems of this nature need further study, and there is a need for determining "effective root surface area" of each tooth as well as "effective root pressure" under different forces. "Effective root surface area" as defined by Jarabak and Fizzell (1963) is the projected area of the root of a

tooth on the pressure side and "effective root pressure" is the pressure needed to start the tooth moving.

The terms pressure and force have been loosely used in orthodontics and it might be noteworthy to clarify the difference. Force, as defined by the physicist is the action of one body upon another measured in ounces, pounds, grams, or kilograms. Pressure, on the other hand, is defined as force per unit area, be it grams per square mm. or pounds per square inch.

Jarabak and Fizzell (1963) in their study of the biophysics of orthodontic forces have concluded that "the first requirement is to accept the idea that root pressure is the important factor in determining tooth movement instead of the force applied to the crown of the teeth." The values of these pressures are still unknown at this time.

Root pressure cannot be accurately known without some knowledge of total root surface area and effective root surface area.

Renfroe (1951) was one of the first men to suggest that only a portion of the root surface is involved at one time in resisting the movement of the tooth in the direction of the applied force, thus, inferring to the existence of "effective root surface area." He states:

"The tooth with a purely round root when moved bodily presents fifty percent of its periodontal membrane fibers to resist the movement and relaxes the same number."

It can be concluded from the foregoing discussion that to achieve a clearer perspective and proper orientation in the biophysics of tooth movement, research should be directed toward clarification of projected root surface area, and total root surface area of each tooth and to establish ratios between the two values.

B. Statement of the Problem

The purpose of this project is to design and assess a method of measuring total and projected root surface areas of the maxillary teeth and to correlate total root surface area with projected root surface area. A material which can be coated on the root and easily removed will be used as the applied film on the teeth. The coating material must lay absolutely flat after removal from the root.

A light source will be used to project the area of the root on a photographic film to determine the projected area of the root. The outline will be measured with a compensating polar planimeter.

The techique developed in this thesis and the data collected will be useful in establishing and understanding the concept of biophysics of tooth movement.

CHAPTER II

REVIEW OF THE LITERATURE

The science of biophysics of orthodontic forces is relatively new and the search of the literature revealed the limited attention focused in the determination of projected root surface area and total root surface area.

Hanau (1917) determined projected root surface area of maxillary central incisor by mathematical formula. He assumed that the resisting pressure of the tooth to movement is uniformly distributed on the projected area of the root.

Jarabak and Fizzell (1963) used a parabola to represent the contour of the root of a mandibular canine and employed integral calculus to determine the projected area of the tooth.

Mathematical formulas have also been used to determine surface areas of teeth. Morelli (1920) considered roots as well defined geometric figures, as for example, maxillary central incisors, and upon this basis he

calculated surface areas using mathematics.

Brown (1950) measured the root surface area of maxillary central incisors using the so called membrane technique. He coated the root with a milky latex which after setting was pullled off as a membrane. This membrane was then laid flat on a grid paper. The area was obtained by counting the millimeter squares covered.

Boyd (1958) employing the membrane technique determined the average periodontal areas of molars, premolars, canines, lateral incisors, and central incisors. He obtained the average root surface area of five teeth in each category to correlate vertical loads to root surface area of teeth.

Jepsen (1962) used a similar method to find root surface area of 238 extracted teeth. The root was coated with a solution of polyvinyl chloride which was polymerized for 30 minutes at 130° C. The tooth was cooled and the membrane was removed, laid flat, and photographed. The image was enlarged and projected onto a drawing paper and the outline of the membrane was measured with a planimeter. Jepsen also investigated an X-ray photograph method to determine root surface area. He reported an accuracy of about ± 10-15% using this method.

Tylman and Tylman (1960) give values for periodontal area of the maxillary and mandibular dentition but fail to mention how they were determined. His measurements were low in comparison to those of Jepsen and Boyd.

Freeman (1965) computed root surface area of teeth utilizing the membrane technique. His study was related to anchorage preparation in a typical four premolar extraction treatment using the Begg technique. Therefore, the four first premolars were not included in his investigation. Also, the second and third molars were excluded. His measurements of "actual root surface area" are one-eighth of those values presented by Jepsen and Boyd.

Phillips (1955) used tin foil in his investigation of root surface area of teeth with root resorption. The apices of extracted anterior teeth were filed to similate root resorption. Tin foil was adapted to the roots and then were removed and measured with a planimeter.

Most of the work on root surface area has been done recently. Yet, there are significant differences of values arrived at by investigators. Boyd and Jepsen report similar figures unlike those given by Tylman and

Freeman. A reliable method of measuring total root surface area is a prerequisite to the determination of optimal force for tooth movement.

Some researchers have attempted to correlate force magnitude to tissue response in moving teeth. Schwarz (1932) found that a pressure of 20 to 26 gm/cm^2 was most favorable for tooth movement.

Orban (1936) concurred with Schwarz that there is a biologic optimum for tooth movement and that excessive forces crushed the periodontal ligament.

Moyers and Bauer (1950) agreed with Orban and concluded that any translatory force over 25 gm/cm^2 was excessive because blood supply to the periodontal ligament was halted and this in turn induced pathological changes in those areas.

Storey and Smith (1952) reported that the optimal magnitude of force for retraction of canine ranged from 150 to 200 grams and 300 to 500 grams for the movement of the anchor units. They mention that the force is not the significant factor in tooth movement, but, rather, the pressure exerted (i.e., force per unit area) on the root, periodontal membrane, and bone. They state: "It is this pressure and its distribution over the surface

of the root that will be difficult to estimate."

MacEwan (1954) found that the mandibular teeth were undisturbed throughout the length of treatment of a distocclusion case in which intermaxillary elastics were used. He had concluded that:

> This is possible because the amounts of force used are kept below the stability limit which is about 7 gm. per square centimeter of root surface...

He alluded to the existence of a subliminal pressure in tooth movement. MacEwan's theory, nevertheless, was an oversimplification because the root surface area was not measured, but, rather, estimated. In addition, he was not cognizant of what Renfroe had theorized. That is, only a portion of each root surface was actually involved in resisting the forward movement of the mandibular teeth.

Reitan (1957) in his study of tipping and translation found that the force exerted per square millimeter of root surface area was greater in tipping than in translation although equally high magnitude forces were applied to the teeth.

Jarabak and Fizzell (1963) have reasoned that the ultimate answer to physiologic tooth movement is the pressure per square millimeter of effective root surface

area of that tooth. In addition, they reason from available information that there must be three important values of root pressure: 1. Supramaximal pressure at which undermining resorption occurs, 2. Average root pressure needed to start translation of a tooth, 3. Subliminal pressure at which all movement ceases.

The value of these pressures are not known at this time but they assert that "an understanding of these critical pressures and of the boundary conditions expressing their relations provides a helpful means of analyzing biologic responses to the orthodontic forces."

CHAPTER III

METHODS AND MATERIALS

A. Selection of Membrane Material

Several methods were considered in appraising root surface area of the teeth. A number of materials such as polyvinyl alcohol, polyvinyl chloride, tin foil, and formvar were tried as membrane materials to coat the root surfaces of the teeth.

It was extremely difficult to use polyvinyl chloride and polyvinyl alcohol as a membrane material. The powder and liquid ratios for polyvinyl chloride were used as described by Jepsen (1960), but the material often became dry and powdery upon insertion of the tooth into the oven for polymerization of the material. This technique did not appear to work well for this worker.

Phillip's method of using tin foil to adapt to the surface of anterior teeth was not practical for posterior multirooted teeth. The adaptation of the foil between the bifurcation and trifurcation was awkward and difficult.

Formvar was selected as the membrane material to

be coated on the roots for several reasons. It was accurate and it could be air dried, whereas, polyvinyl chloride required that the tooth be placed in an oven for polymerization to occur. It was easier to paint a liquid material between the bifurcation and trifurcation of the premolars and molars. Formvar can be readily peeled off the roots after being air dried for fifteen minutes.

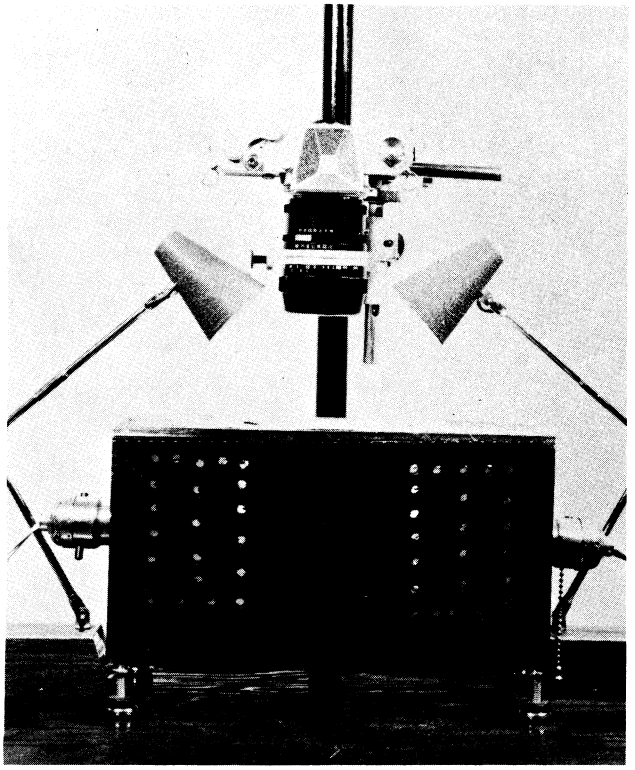
The solution was made by mixing five grams of powder with 50 cc. of 1, 2 ethylene dichloride. The powder was allowed to dissolve overnight. Formvar in liquid form is colorless. It would be a difficult process to use such a material to coat and remove from the roots of a tooth. In addition, the photographing of a clear membrane was not feasible. Therefore, three different dyes were tested to add color to the solution. Red amacid phloxine dye was selected because it readily dissolved in the mixture and it gave a bright red color to it. Two-tenths of a gram of this dye was added to every 25 cc. of formvar solution. The dye aided in the painting, peeling, and photographing of the membrane. The amounts of material used in making the above solution was determined by varying the combinations of

powder, liquid, and dye and testing them.

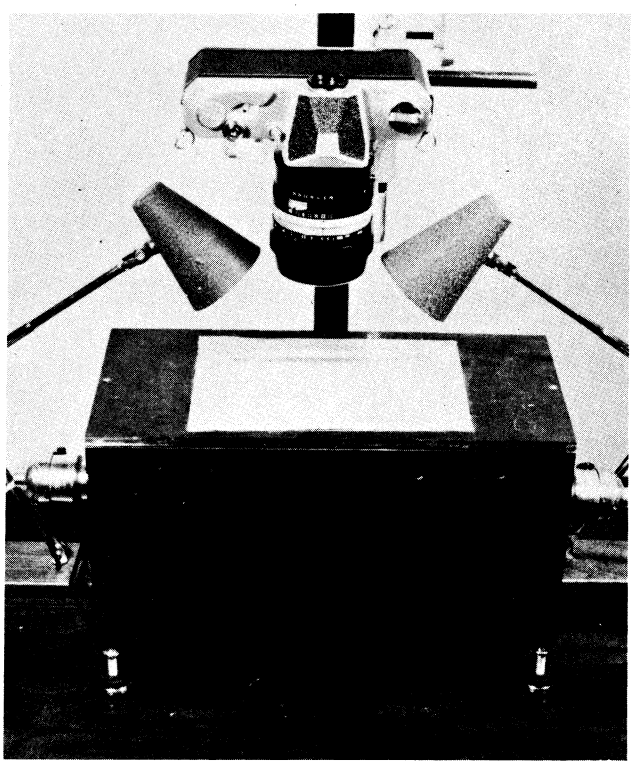
B. Photographing of Membrane

A special transilluminating apparatus was designed and built for this project. The dimensions of the rectangular box were 13" x 6" x 6" with two 100 watt lamps in each end. The inside was painted white and air holes were drilled to prevent overheating of the light bulbs. A window 6" x 4" was cut out at the top and plexiglass was placed over the opening. Four adjustable screw legs were attached to the bottom of the box to enable the operator to keep the apparatus level and parallel to the camera. (Figure 1).

An adjustable camera stand was made for photographing of the membranes and teeth. The camera attachment was adjustable in all planes. The camera and transilluminating apparatus were adjusted to be parallel to each other with a Stanley No. H 1292 level. The camera was a Nikkormat with a micro-NIKKOR Auto 1:35 f=55 mm. lens. The lens opening and shutter speed of the camera were determined for each exposure with a Honeywell One Twenty One Spot Meter. This meter was used because it has only a 1^{o} field of light making it possible to measure



(A)
FRONT VIEW



(B)
TOP VIEW

FIGURE 1. TRANSILLUMINATING APPARATUS

the light output precisely.

Three sources of light were used for film exposure. One light source was from within the light box and two tensor lamps were adjusted at 45^{o} angle from each side of the object to be photographed.

C. Accuracy of the Method

The accuracy of the method was determined in the following manner. A cylindrical test body measuring 3 mm. in diameter and 10 mm. in length was coated with the formvar solution. The membrane was air dried for 15 minutes. Then a longitudinal slit was made with a scalpel and the membrane was peeled off and laid flat on a microscope slide. A square measuring 5 mm. by 5 mm. was photographed together with the membrane. The square and test cylinder body were made by the Cameron-Miller Instrument Company. (Figure 2). These measurements were accurate to 99.998% of a mm. according to the manufacturer. The true value for total surface area of the cylinder was 157 mm^2 and the measured value was 153.8 mm^2.

The accuracy of measuring projected area was determined by photographing the cylinder and square together. The projected area of the cylinder body was calculated

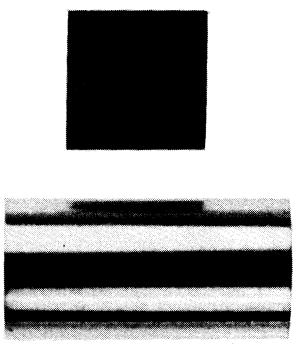


FIGURE 2.

CYLINDER AND SQUARE

mathematically to be 50 mm^2 and the measured projected area was 50.7 mm^2. The discrepancy between the true total surface area and measured value was 2%. The discrepancy of the mathematical projected area and measured value was 1.4%.

The precision of the method was checked by two measurements of two molar teeth. The procedure followed in the coating and photographing of the membrane will be described later in detail. The deviation in measurements of total root surface area in one case was 1.3% and 0.6% in the other. (Table I).

The compensating polar planimeter was used to measure all the teeth and membranes. The planimeter is an instrument designed to measure the area of an irregularly shaped object. (Figure 3). The square, projected areas, and membranes were each measured three times and averaged to avoid possible errors in measurement.

D. Selection of Samples

The teeth used in this research were collected from the Department of Oral Surgery of the Loyola University School of Dentistry, Fantus Clinic of Chicago, and from practicing dentists in Chicago.

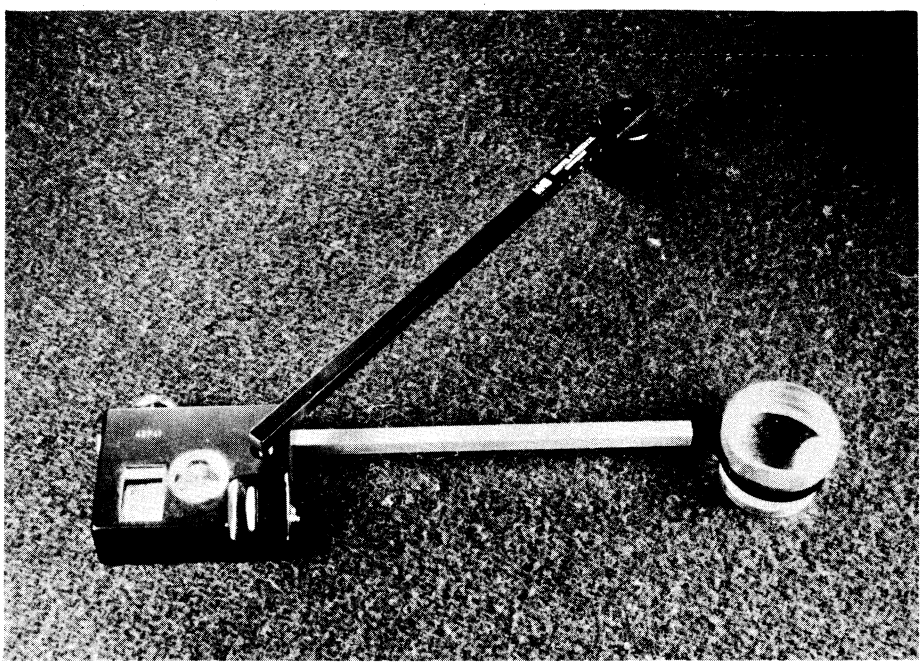


FIGURE 3.

COMPENSATING POLAR PLANIMETER

All the teeth collected were stored in 10% formalin solution. The teeth were cleaned with the cavitron unit and any soft tissues remaining were removed with a scalpel.

The criteria for selection of teeth were: 1. The root must be fully developed and intact. 2. The identity of the tooth must be clear and the cemento-enamel junction must be clearly outlined. 3. The root must be free of macroscopic pathological changes.

One hundred and twenty teeth were selected in this investigation. These were twenty maxillary central incisors, twenty lateral incisors, twenty canines, twenty first premolars, twenty second premolars, and twenty first molars.

Sicher (1952) found that more than 50% of the first premolar teeth examined were birooted and division of the second premolar is rare. All the first premolars utilized in this study were birooted and the second premolars were simple rooted. No distinction was made from which side of the mouth the teeth were extracted.

E. Coating and Photographing of the Teeth

The crown of each tooth was ligated with 0.012

orthodontic ligature wire as an attachment to be used as a handle and hanger while the tooth was being air dried. The cemento-enamel junction was clearly marked with a sharp pencil. A thin coat of formvar solution was painted with a small brush on the root and cervical one-third of the crown. This was allowed to dry for fifteen minutes. Then a scalpel was used to make a slit along the cemento-enamel junction and down to the apex. (Figures 4,5,6). In the case of multirooted teeth, additional slits were made because the membrane had to be removed in two or three pieces depending on the number of roots involved. (Figures 7,8,9,10). After the slits were made, the tooth was soaked in water for 10 seconds. The water facilitated the peeling of the membrane.

The membrane was laid flat on a microscope slide. Additional slits were made whenever necessary to flatten areas that had humps which usually were in the apical region. The square was included in every picture as a reference to determine exact magnification of the objects. (Figure 11). The microscope slide with membrane and square were photographed over the transilluminating box. The shutter speed and lens opening, as mentioned earlier, were determined with the light meter. The shutter speed

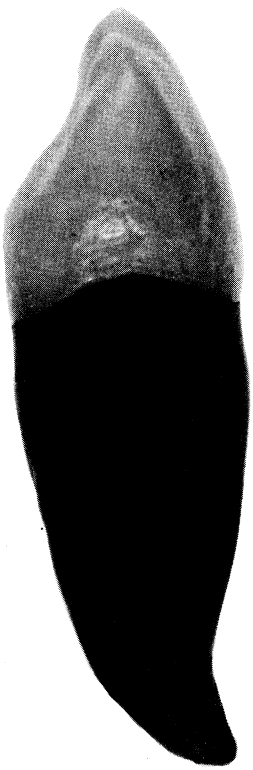


FIGURE 4.

FORMVAR MEMBRANE ON CANINE

FIGURE 5.

INITIAL SLITTING OF MEMBRANE

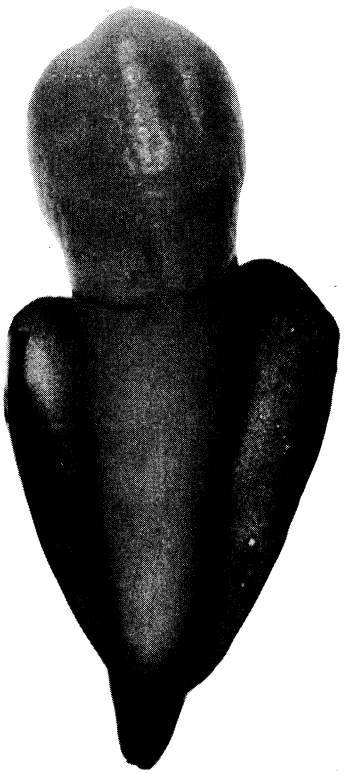


FIGURE 6.

PEELING OF MEMBRANE

FIGURE 7.

MEMBRANE ON MOLAR

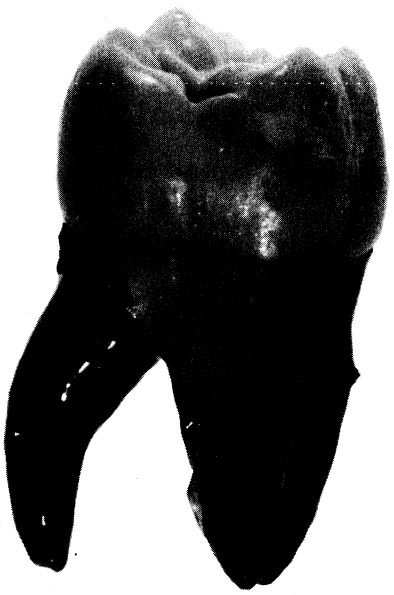


FIGURE 8.

SLITTING OF MEMBRANE

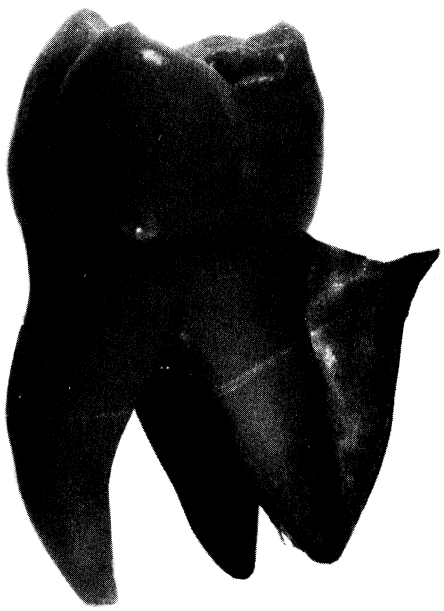


FIGURE 9.

PEELING OF MEMBRANE

FIGURE 10.

MEMBRANE OF MOLAR

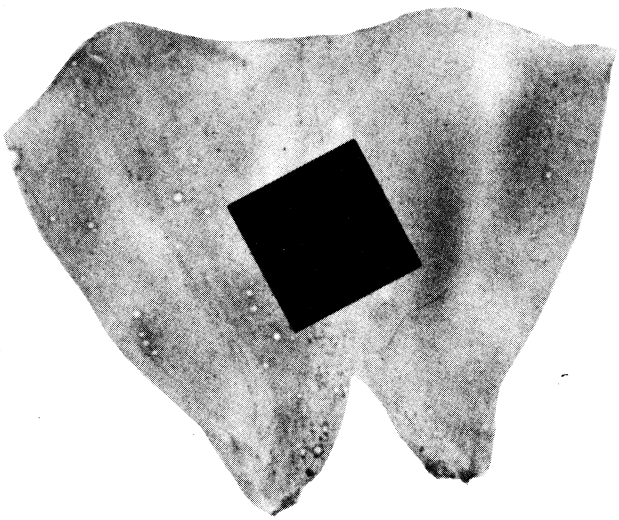


FIGURE 11.

FORMVAR MEMBRANE OF CANINE

was 1/60 second and the lens opening had an f/32 stop in most cases, including the photographing of the teeth.

The projected root surface areas of all the teeth were measured from mesial and buccal views of the roots. The teeth were fixed in mortite in such a manner that the long axis of the roots being photographed were parallel to the camera. (Figures 12, 13).

The multirooted teeth involved somewhat of a unique technique in measuring their projected root surface areas. The first premolar was photographed in the following way. The mesio-distal and bucco-lingual projected areas were photographed first. Then the junction of the buccal and lingual roots were marked with a sharp pencil and the roots were separated with a fine jeweler's saw blade. (Figure 14). The buccal view of the lingual root was then photographed. The mesio-distal projected area of the lingual root was determined to be through the long axis of the root from the bifurcation to the apex.

The maxillary molars were measured in a similar manner. First, the mesial and buccal views of the roots were photographed. Then the junction of the roots were marked with a sharp pencil and sectioned with the jewel-

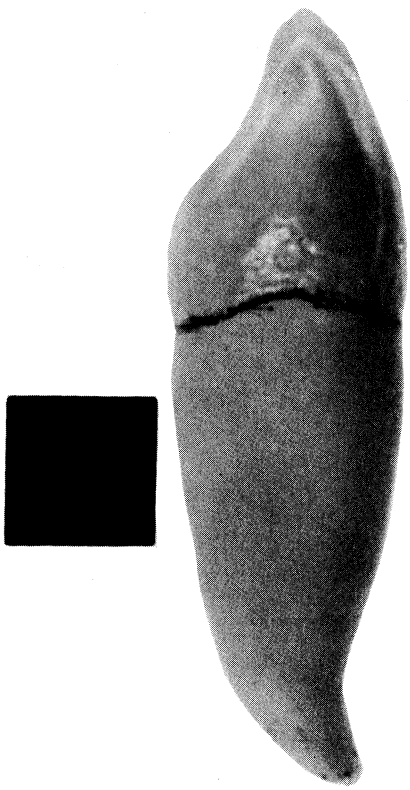


FIGURE 12.

BUCCO-LINGUAL PROJECTED AREA OF CANINE

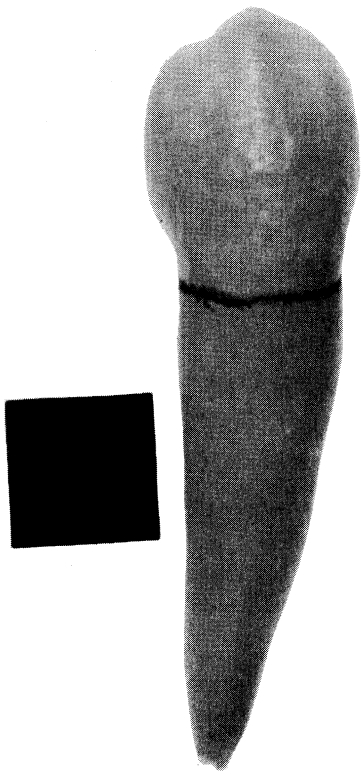


FIGURE 13.

MESIO-DISTAL PROJECTED AREA OF CANINE

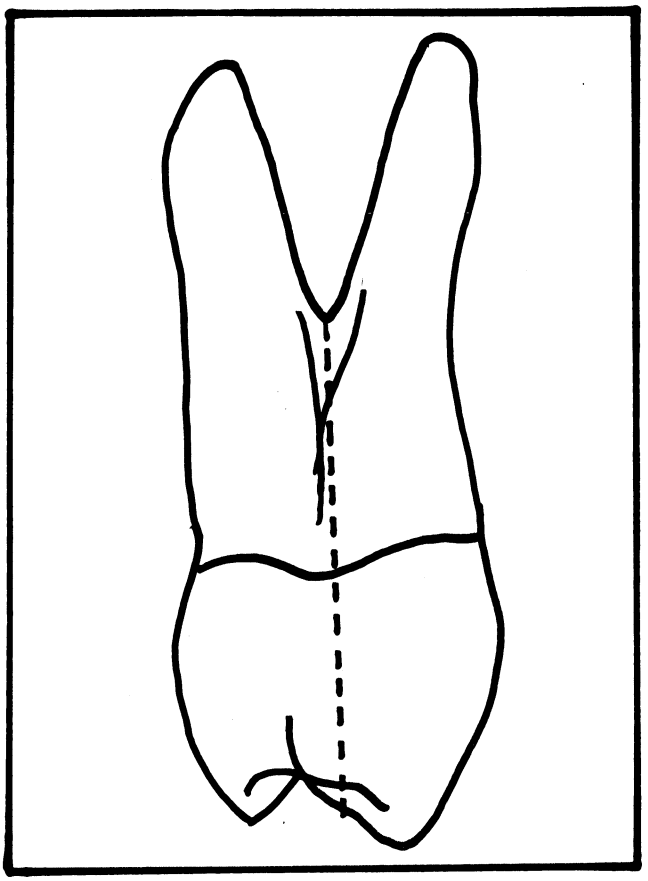


FIGURE 14.

SECTIONING OF FIRST PREMOLAR ROOTS

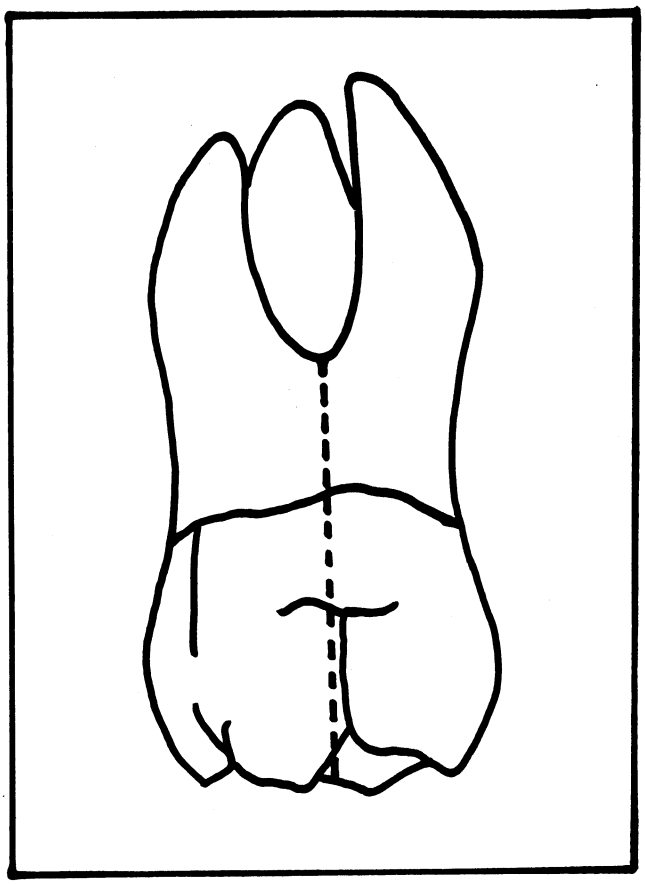


FIGURE 15.

BUCCAL VIEW

SECTIONING OF BUCCAL ROOTS

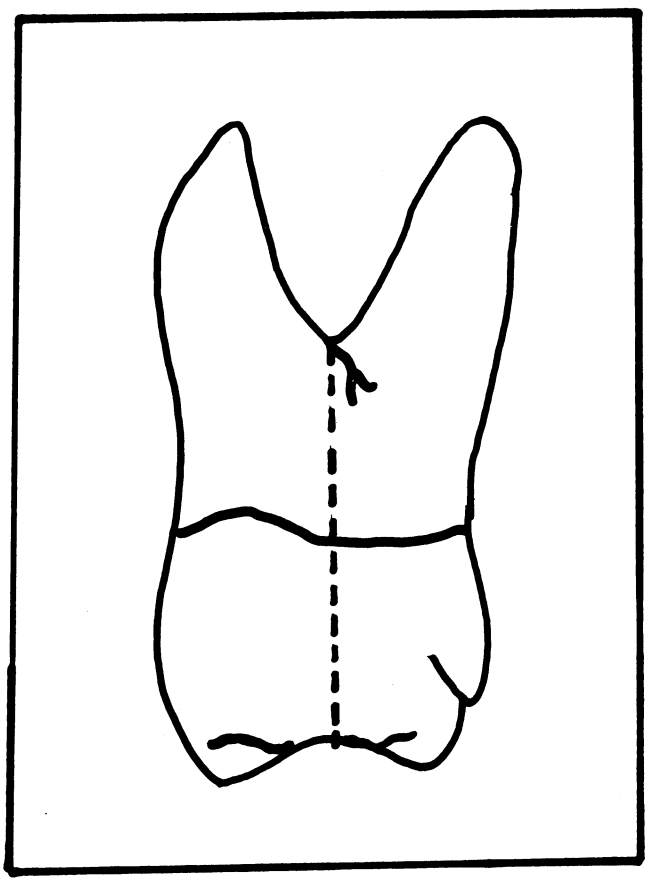


FIGURE 16.

MESIAL VIEW

SECTIONING OF LINGUAL ROOT

er's saw. (Figure 15,16). The mesial view of the disto-buccal root and the buccal view of the lingual root were photographed through their long axis from the trifurcation to the apices. The roots were always photographed with their long axis parallel to the camera.

All the measuring of pictures was done on a drafting board. The picture was laid flat under a glass cover 4" x 6" as the outline of the membranes and roots were being traced with the planimeter. Each square, membrane, and projected root area was measured three times and recorded. The average of the three readings was used in the calculations to avoid errors in measurements.

CHAPTER IV

FINDINGS

The process of condensing the data was begun after the measuring of the projected root surface area and total root surface area of the maxillary teeth was completed. The square, membranes, and projected areas of the teeth were each measured three times with the compensating polar planimeter as described in Chapter III. This totaled a minimum of 3000 measurements with the planimeter involving more than 500 pictures.

The true projected and total root surface areas were calculated by the following ratio:

$$\frac{a}{b} = \frac{c}{d} \quad .$$

Where a) is the true area of square (mathematical),

b) is the measured area of membrane,

c) is the true area of membrane (mathematical),

and d) is the measured area of membrane.

Solving for c, $c = \frac{a}{b} d$.

Substituting numerical values, we have:

$$c = \frac{25 \text{ mm}^2}{26 \text{ mm}^2} \times 250 \text{ mm}^2 = 240.4 \text{ mm}^2.$$

The above formula was used in every measurement. All the photography was done in the same manner with a constant object to film distance. Yet, the magnification of the pictures was not constant. This is an important factor to consider because the precision of the method would have been affected if this procedure was not rigidly adhered to.

The accuracy of the method was checked using a cylinder with measurements accurate to 0.002 mm. The surface area of the cylinder was calculated mathematically to be 157 mm^2 by using the formula:

$$\text{Area} = \pi \, d \times h$$
$$= 3.14 \times 5 \times 10$$
$$= 157 \text{ mm}^2$$

The projected area of the cylinder was determined mathematically by the formula:

$$\text{Area} = b \times h$$
$$= 10 \times 5$$
$$= 50 \text{ mm}^2$$

The total surface area of the cylinder using the membrane technique was found to be 153.8 mm^2. This was 3.2 mm^2 less than the known value or a 2% error from the true value. The projected area was measured to be 50.7 mm^2 or an error of 1.4%. (Table I).

The precision of the method was determined by measuring the total root surface area of two molar teeth. Tooth no. 14 was measured to be 420.8 mm^2 the first time and 410.3 mm^2 the second time. The deviation was 1.3%. Tooth no. 17 measured 476.0 the first time and 470.1 on the second measurement for a deviation of 0.6%.

The average root surface area of the central incisor was 209.4 mm^2. (Table II). The high value in the sample was 179.1 mm^2. Tooth no. 2 which had the smallest total root surface area also had the smallest bucco-lingual projected area. This bucco-lingual projected area as mentioned before is the mesial view of that tooth. The mesio-distal projected area of tooth no. 2, however, was not the smallest. Tooth no. 5 had the highest bucco-lingual and mesio-distal projected root surface area which were 87.0 mm^2 and 81.0 mm^2, respectively. The arithmetic average of the bucco-lingual projected area was 77.1 mm^2 and the

Table I

Control Measurement of Cylinder

Total Surface Area (mm^2)

Known	Measured	Deviation
157.0	153.8	2%

Projected Area

50.0	50.7	1.4%

Control Measurements of Teeth

Measurements

	I (mm^2)	II (mm^2)	Deviation
Tooth 14	420.8	410.3	1.3%
Tooth 17	476.0	470.1	0.6%

Table II

Maxillary Central Incisor

Tooth No.	Total Root Surface Area mm^2	Projected Root Surface Area BL mm^2	Projected Root Surface Area MD mm^2
1	209.0	82.0	69.0
2	179.1	61.3	58.7
3	196.0	72.0	62.0
4	210.0	74.0	69.0
5	222.2	87.0	81.0
6	218.7	83.3	65.2
7	221.4	80.6	75.0
8	182.8	66.3	56.7
9	222.2	75.9	80.1
10	216.7	80.4	73.2
11	213.5	91.0	62.5
12	214.8	83.0	70.0
13	217.0	83.3	65.2
14	193.3	76.0	52.1
15	227.2	80.8	72.0
16	220.2	72.1	68.3
17	181.7	67.3	51.0
18	225.0	82.4	72.2
19	211.6	75.9	62.2
20	204.5	67.6	63.9
Total	4186.9	1542.2	1329.3
Mean	209.4	77.1	66.5
Standard Deviation	14.9	7.6	8.1

BL = Bucco-lingual Projected Area (mm^2)

MD = Mesio-distal Projected Area (mm^2)

mesio-distal was 66.5 mm^2. The ratio of the bucco-lingual projected area over the mesio-distal value was 1.17 with a standard deviation of 0.11. (Table III). The total area over the mesio-distal projected area ranged from a low of 2.74 to a high of 3.57 with a mean of 3.16 and a standard deviation of 0.23.

The maxillary lateral incisor, as would be expected, had the smallest root surface area. (Table IV). The mean value was 179.0 mm^2 with a standard deviation of 11.7 mm^2. The bucco-lingual projected area had a low of 60.0 mm^2 to a high of 84.9 mm^2. The average size was 69.0 mm^2 with a standard deviation of 6.2 mm^2. The average mesio-distal surface area for the same teeth was 49.0 mm^2. The bucco-lingual value over the mesio-distal area had a mean ratio of 1.41 with a standard deviation identical to that of the central incisor. The average ratios of the total surface area over the bucco-lingual and mesio-distal were found to be 2.60 and 3.67, respectively. (Table V). The standard deviation for the former was 0.13 and the latter, 0.19.

The maxillary canine had the second largest surface area with an average of 263.4 mm^2, and a standard deviation of 20.9 mm^2. (Table VI). The smallest

Table III

Maxillary Central Incisor Ratios

Tooth No.	Bl/MD	Total/BL	Total/MD
1	1.19	2.55	3.03
2	1.04	2.92	3.05
3	1.16	2.72	3.16
4	1.07	2.84	3.04
5	1.07	2.55	2.74
6	1.28	2.62	3.36
7	1.07	2.75	2.95
8	1.17	2.26	3.22
9	1.06	2.77	2.93
10	1.10	2.68	2.95
11	1.46	2.35	3.42
12	1.19	2.59	3.07
13	1.27	2.60	3.31
14	1.46	2.54	3.71
15	1.12	2.81	3.16
16	1.06	3.05	3.23
17	1.32	2.70	3.57
18	1.14	2.73	3.12
19	1.10	2.79	3.06
20	1.06	3.02	3.20
Total	23.36	53.54	63.18
Mean	1.17	2.68	3.16
Standard Deviation	0.11	0.18	0.23

$$\frac{BL}{MD} = \frac{\text{Bucco-lingual Projected Area}}{\text{Mesio-distal Projected Area}}$$

$$\frac{Total}{BL} = \frac{\text{Total Root Surface Area}}{\text{Bucco-lingual Projected Area}}$$

$$\frac{Total}{MD} = \frac{\text{Total Root Surface Area}}{\text{Mesio-distal Projected Area}}$$

Table IV

Maxillary Lateral Incisor

Tooth No.	Total Root Surface Area (mm^2)	Projected Root Surface Area BL mm^2	MD mm^2
1	165.8	60.6	46.3
2	169.3	60.0	49.0
3	217.4	84.9	64.7
4	170.4	70.6	43.2
5	187.5	72.6	50.3
6	188.3	70.9	52.3
7	185.0	66.7	49.3
8	176.3	66.8	45.7
9	189.6	77.2	53.3
10	174.0	61.5	49.3
11	170.7	66.6	52.1
12	178.6	67.7	49.3
13	194.8	77.7	53.8
14	169.4	67.9	44.1
15	194.2	72.3	54.7
16	180.3	72.9	46.2
17	164.8	68.9	45.7
18	164.6	64.7	43.4
19	179.7	67.7	45.7
20	160.0	62.0	41.7
Total	3580.0	1380.2	980.1
Mean	179.0	69.0	49.0
Standard Deviation	11.7	6.2	5.3

BL = Bucco-lingual Projected Area (mm^2)

MD = Mesio-distal Projected Area (mm^2)

Table V

Maxillary Lateral Incisor Ratios

Tooth No.	BL/MD	Total/BL	Total/MD
1	1.31	2.74	3.58
2	1.22	2.82	3.46
3	1.31	2.56	3.36
4	1.63	2.41	3.94
5	1.44	2.58	3.73
6	1.36	2.66	3.60
7	1.35	2.77	3.75
8	1.46	2.64	3.86
9	1.45	2.46	3.56
10	1.25	2.83	3.53
11	1.28	2.56	3.28
12	1.37	2.64	3.62
13	1.44	2.51	3.62
14	1.54	2.50	3.84
15	1.32	2.69	3.55
16	1.58	2.47	3.90
17	1.51	2.39	3.61
18	1.49	2.54	3.79
19	1.48	2.65	3.93
20	1.49	2.58	3.84
Total	28.28	52.00	73.35
Mean	1.41	2.60	3.67
Standard Deviation	0.11	0.13	0.19

$$\frac{BL}{MD} = \frac{\text{Bucco-lingual Projected Area}}{\text{Mesio-distal Projected Area}}$$

$$\frac{Total}{BL} = \frac{\text{Total Root Surface Area}}{\text{Bucco-lingual Projected Area}}$$

$$\frac{Total}{MD} = \frac{\text{Total Root Surface Area}}{\text{Mesio-distal Projected Area}}$$

Table VI

Maxillary Canine

Tooth No.	Total Root Surface Area mm^2	Projected Root Surface Area BL mm^2	MD mm^2
1	252.1	106.2	63.5
2	226.0	94.6	66.5
3	260.0	114.1	79.0
4	248.9	101.0	79.0
5	263.8	104.2	72.5
6	275.0	108.0	82.0
7	236.0	106.2	65.0
8	267.8	122.8	77.2
9	249.0	98.0	62.0
10	244.2	96.3	67.3
11	293.4	133.3	92.7
12	271.9	112.5	66.7
13	267.7	94.2	80.2
14	278.0	118.0	81.0
15	258.3	102.0	65.7
16	293.2	110.5	72.0
17	310.0	133.3	84.4
18	278.0	112.0	78.0
19	241.7	98.7	59.2
20	252.2	95.8	71.5
Total	5267.3	2161.7	1468.1
Mean	263.4	108.1	73.4
Standard Deviation	20.9	11.7	8.7

BL = Bucco-lingual Projected Area (mm^2)

MD = Mesio-distal Projected Area (mm^2)

canine root was 226.0 mm^2 and the largest was 310.0 mm^2. The projected root surface area from a mesial view ranged from a low of 94.2 mm^2 to a high of 133.3 mm^2. The average was 108.1 mm^2 with a standard deviation of 11.7 mm^2. The mesio-distal projected area had an average of 73.4 mm^2 with a standard deviation of 8.7 mm^2. The highest ratios of bucco-lingual projected area over the mesio-distal area was 1.69 and the lowest was 1.18. (Table VII). The mean value was 1.49 and the standard deviation was 0.13. The total root surface area divided by the bucco-lingual projected area ranged from a low of 2.18 to a high of 2.84 for an average of 2.45 and a standard deviation of 0.16. The total root surface area over the mesio-distal projected area had a higher difference of ratios. The high was 4.08 and the low was 3.17 for a mean ratio of 3.64 and high standard deviation of 0.29.

The first premolar is slightly smaller than the canine, although, all the teeth selected in this research had two roots. The average was 255.0 mm^2 and the standard deviation was 22.7 mm^2. (Table VIII). Tooth no. 15 with a surface area of 299.8 mm^2 had the largest value while tooth no.18 had the smallest area with 211.5 mm^2. The mesial view of the projected area had an average size of

Table VII

Maxillary Canine Ratios

Tooth No.	BL/MD	Total/BL	Total/MD
1	1.67	2.37	3.97
2	1.43	2.39	3.41
3	1.45	2.28	3.29
4	1.41	2.46	3.46
5	1.44	2.53	3.64
6	1.32	2.55	3.35
7	1.63	2.22	3.63
8	1.59	2.18	3.47
9	1.58	2.54	4.02
10	1.43	2.54	3.63
11	1.44	2.70	3.17
12	1.69	2.42	4.08
13	1.18	2.84	3.34
14	1.46	2.36	3.43
15	1.55	2.53	3.93
16	1.54	2.65	4.07
17	1.58	2.33	3.67
18	1.44	2.48	3.56
19	1.67	2.45	4.08
20	1.34	2.63	3.53
Total	29.84	48.95	72.73
Mean	1.49	2.45	3.64
Standard Deviation	0.13	0.16	0.29

$$\frac{BL}{MD} = \frac{\text{Bucco-lingual Projected Area}}{\text{Mesio-distal Projected Area}}$$

$$\frac{Total}{BL} = \frac{\text{Total Root Surface Area}}{\text{Bucco-lingual Projected Area}}$$

$$\frac{Total}{MD} = \frac{\text{Total Root Surface Area}}{\text{Mesio-distal Projected Area}}$$

Table VIII

Maxillary First Premolar

Tooth No.	Total Root Surface Area mm^2	Projected Root Surface Area BL mm^2	Projected Root Surface Area MD mm^2
1	252.3	85.4	48.0
2	228.7	89.3	54.0
3	284.3	94.8	72.6
4	292.4	98.0	83.4
5	264.8	96.0	79.0
6	251.5	86.9	42.7
7	288.0	108.7	64.5
8	243.5	93.3	64.5
9	259.6	89.1	74.3
10	250.9	91.3	76.3
11	229.3	87.5	64.4
12	271.3	95.2	77.8
13	262.7	104.6	59.5
14	230.6	89.3	61.2
15	299.8	105.5	83.3
16	238.1	81.8	72.7
17	236.2	95.2	76.0
18	211.5	78.0	76.6
19	264.0	92.8	77.0
20	240.7	81.3	71.8
Total	5100.2	1844.0	1241.9
Mean	255.0	92.2	62.1
Standard Deviation	22.7	8.0	13.4

BL = Bucco-lingual Projected Area (mm^2)

MD = Mesio-distal Projected Area (mm^2)

92.2 mm^2 and the buccal view was 62.1 mm^2. The projected area of the first premolar from a buccal view, as mentioned earlier in the previous chapter, was added to the projected area of the lingual root which was sectioned at the bifurcation. The mesio-distal projected surface area of the lingual root was taken to be through the long axis of the bifurcation to the apex of the root. The sum of these values is given in Table VIII.

The ratio of the bucco-lingual area over the mesio-distal area was 1.31 with a standard deviation of 0.20. (Table IX). The total surface area divided by the bucco-lingual area ranged from a high of 3.00 to a low of 2.19. The mean was 2.73. The mesio-distal area divided into the total surface area had a mean ratio of 3.58.

The second premolar had an average total root surface area of 215.1 mm^2 which is only 5.7 mm^2 larger than that of the central incisor. (Table X). The mesial view of the projected area of the premolar is 87.1 mm^2 while the buccal view is 46.6 mm^2 which is even smaller than that of the lateral incisor. The ratio of bucco-lingual area to the mesio-distal area of 1.88 is high. (Table XI). In addition, the total root surface area to mesio-distal area also has a high ratio of 4.62 with a standard devia-

Table IX

Maxillary First Premolar Ratios

Tooth No.	BL/MD	Total/BL	Total/MD
1	1.15	2.95	3.41
2	1.65	2.56	4.24
3	1.30	3.00	3.91
4	1.18	2.98	3.51
5	1.22	2.76	3.35
6	1.26	2.90	3.64
7	1.69	2.65	4.47
8	1.45	2.61	3.78
9	1.20	2.19	3.49
10	1.20	2.75	3.29
11	1.36	2.62	3.36
12	1.22	2.85	3.49
13	1.76	2.51	4.42
14	1.46	2.58	3.77
15	1.27	2.84	3.60
16	1.13	2.91	3.28
17	1.25	2.48	3.11
18	1.02	2.71	2.76
19	1.21	2.85	3.43
20	1.13	2.96	3.35
Total	26.11	54.66	71.66
Mean	1.31	2.73	3.58
Standard Deviation	0.20	0.21	0.26

$$\frac{BL}{MD} = \frac{\text{Bucco-lingual Projected Area}}{\text{Mesio-distal Projected Area}}$$

$$\frac{Total}{BL} = \frac{\text{Total Root Surface Area}}{\text{Bucco-lingual Projected Area}}$$

$$\frac{Total}{MD} = \frac{\text{Total Root Surface Area}}{\text{Mesio-distal Projected Area}}$$

Table X

Maxillary Second Premolar

Tooth No.	Total Root Surface Area mm^2	Projected Root Surface Area BL mm^2	Projected Root Surface Area MD mm^2
1	223.7	86.7	44.3
2	227.0	86.7	51.7
3	219.3	88.9	45.5
4	244.5	91.6	52.6
5	251.7	98.0	53.0
6	219.3	93.5	47.0
7	238.7	88.1	51.6
8	200.4	77.0	43.9
9	196.7	85.7	48.7
10	212.6	88.7	45.3
11	210.4	85.2	45.5
12	227.0	94.7	46.7
13	196.1	72.8	42.3
14	208.2	88.4	51.8
15	220.2	88.0	47.3
16	206.0	85.9	41.2
17	198.4	82.8	45.8
18	204.3	85.7	44.1
19	197.8	86.6	40.5
20	199.4	86.7	43.8
Total	4301.7	1741.7	932.6
Mean	215.1	87.1	46.6
Standard Deviation	12.5	5.5	3.7

BL = Bucco-lingual Projected Area (mm^2)

MD = Mesio-distal Projected Area (mm^2)

Table XI

Maxillary Second Premolar Ratios

Tooth No.	BL/MD	Total/BL	Total/MD
1	1.96	2.58	5.05
2	1.68	2.62	4.39
3	1.95	2.47	4.82
4	1.74	2.67	4.65
5	1.85	2.57	4.75
6	1.99	2.35	4.67
7	1.71	2.71	4.63
8	1.75	2.60	4.57
9	1.76	2.30	4.04
10	1.96	2.40	4.69
11	1.87	2.47	4.62
12	2.03	2.40	4.86
13	1.72	2.69	4.64
14	1.71	2.36	4.02
15	1.86	2.50	4.66
16	2.09	2.40	5.00
17	1.81	2.40	4.33
18	1.94	2.38	4.63
19	2.14	2.28	4.89
20	1.98	2.30	4.55
Total	37.50	49.15	42.46
Mean	1.88	2.46	4.62
Standard Deviation	0.14	0.14	0.27

$$\frac{BL}{MD} = \frac{\text{Bucco-lingual Projected Area}}{\text{Mesio-distal Projected Area}}$$

$$\frac{Total}{BL} = \frac{\text{Total Root Surface Area}}{\text{Bucco-lingual Projected Area}}$$

$$\frac{Total}{MD} = \frac{\text{Total Root Surface Area}}{\text{Mesio-distal Projected Area}}$$

tion of 0.27. The ratio of the total area to the bucco-lingual projected area was 2.46 with a standard deviation of 0.14.

The first molar with an average total surface area of 438.3 mm^2 had a high of 501.0 mm^2 and a low of 362.8 mm^2. (Table XII). The standard deviation was 35.8 mm^2. The mesio-distal projected root surface area of the lingual root was measured from the trifurcation of the three roots apically through the long axis of the root. This measurement was added to the mesio-distal projected area of the two buccal roots. The sum of the values was averaged to be 125.7 mm^2 with a standard deviation of 17.2 mm^2. The mesial view or bucco-lingual projected root surface area of the molar was added to the bucco-lingual projected root surface area of the disto-buccal root. The projected area of the disto-buccal root was determined to be through the long axis of the root from the trifurcation to the apex. The mesial views of the three roots were added and the high was 188.0 mm^2 and the low was 123.4 mm^2. The average was 154.0 mm^2 with a standard deviation of 18.5 mm^2. The ratio of the bucco-lingual area to the mesio-distal projected area was 1.23 with a standard deviation of 0.24. The mean ratio of the total

Table XII

Maxillary First Molar

Tooth No.	Total Root Surface Area mm^2	Projected Root Surface Area BL mm^2	Projected Root Surface Area MD mm^2
1	408.0	124.7	125.0
2	501.0	173.5	162.2
3	431.9	149.4	138.3
4	413.8	137.0	133.0
5	467.6	163.1	131.6
6	362.8	125.0	95.4
7	415.1	151.9	120.4
8	410.2	159.6	117.3
9	404.0	138.9	97.7
10	477.0	180.8	146.2
11	462.2	147.4	130.6
12	453.3	168.7	143.0
13	465.2	188.0	137.0
14	420.4	135.9	115.2
15	438.9	169.0	116.3
16	472.3	123.4	93.5
17	476.0	160.0	126.8
18	390.9	171.6	138.0
19	423.4	141.1	125.6
20	475.4	171.4	121.5
Total	8766.4	3030.4	2514.6
Mean	438.3	154.0	125.7
Standard Deviation	35.8	18.5	17.2

BL = Bucco-lingual Projected Area (mm^2)

MD = Mesio-distal Projected Area (mm^2)

area to the mesio-distal area was the lowest of all the teeth with a value of 3.54. (Table XIII).

A comparison of the ratio between the different types of teeth revealed that the highest variation occurred between the total root surface area over the mesio-distal projected area of the roots. It would be difficult, therefore, to predict the total root surface area of all the different teeth on the basis of the mesio-distal projected root surface areas. (Table XV). This is the buccal view of the teeth. The highest figure was 4.62 and the lowest was 3.16. There was an intermediate range of ratios between the bucco-lingual projected area divided by the mesio-distal area. The ratios varied from 1.17 to 1.88. The least variation of ratios was found to be for the total surface area to the bucco-lingual projected area. The low was 2.45 and the high was 2.88 with a mean of 2.63 and a standard deviation of 0.17. It was this group of ratios that had the smallest difference.

The second premolar had the highest ratio among the teeth when the bucco-lingual and total root surface areas were divided by the mesio-distal projected areas. The figures in both instances were the highest in their

Table XIII

Maxillary First Molar Ratios

Tooth No.	Bl/MD	Total/BL	Total/MD
1	1.00	3.27	3.26
2	1.06	2.89	3.09
3	1.08	2.89	3.12
4	1.03	3.02	3.11
5	1.24	2.87	3.55
6	1.31	2.90	3.80
7	1.26	2.73	3.45
8	1.36	2.57	3.50
9	1.42	2.91	4.14
10	1.24	2.64	3.26
11	1.13	3.14	3.54
12	1.18	2.69	3.17
13	1.37	2.48	3.40
14	1.18	3.10	3.65
15	1.45	2.60	3.77
16	1.32	3.83	5.05
17	1.26	2.97	3.75
18	1.24	2.28	2.83
19	1.12	3.00	3.37
20	1.41	2.77	3.91
Total	24.66	57.52	70.72
Mean	1.23	2.88	3.54
Standard Deviation	0.13	0.24	0.46

$$\frac{BL}{MD} = \frac{\text{Bucco-lingual Projected Area}}{\text{Mesio-distal Projected Area}}$$

$$\frac{\text{Total}}{BL} = \frac{\text{Total Root Surface Area}}{\text{Bucco-lingual Projected Area}}$$

$$\frac{\text{Total}}{MD} = \frac{\text{Total Root Surface Area}}{\text{Mesio-distal Projected Area}}$$

Table XIV

Mean Results of Maxillary Teeth

Type of Tooth	Total Area mm^2	Projected Area BL mm^2	Projected Area MD mm^2
Central Incisor	209.4	77.1	66.5
	sd 14.9	sd 7.6	sd 8.1
Lateral Incisor	179.0	69.0	49.0
	sd 11.7	sd 6.2	sd 5.3
Canine	263.4	108.1	73.0
	sd 20.9	sd 11.7	sd 8.7
First Premolar	255.0	92.2	62.1
	sd 22.7	sd 13.4	sd 13.4
Second Premolar	215.1	87.1	46.6
	sd 12.5	sd 5.5	sd 3.7
Molar	438.3	154.0	125.7
	sd 35.8	sd 18.5	sd 17.2

sd = standard deviation

BL = Bucco-lingual Projected Area

MD = Mesio-distal Projected Area

Table XV

Mean Ratios of Maxillary Teeth

Type of Tooth	BL/MD	Total/BL	Total/MD
Central Incisor	1.17	2.68	3.16
Lateral Incisor	1.41	2.60	3.67
Canine	1.49	2.45	3.64
First Premolar	1.31	2.73	3.58
Second Premolar	1.88	2.46	4.62
Molar	1.23	2.88	3.54
Total	8.49	15.80	22.21
Mean	1.42	2.63	3.70
Standard Deviation	0.25	0.17	0.15

$$\frac{BL}{MD} = \frac{\text{Bucco-lingual Projected Area}}{\text{Mesio-distal Projected Area}}$$

$$\frac{Total}{BL} = \frac{\text{Total Root Surface Area}}{\text{Bucco-lingual Projected Area}}$$

$$\frac{Total}{MD} = \frac{\text{Total Root Surface Area}}{\text{Mesio-distal Projected Area}}$$

respective groups with a value of 1.88 for the former and 4.62 for the latter.

The differences of ratios among the remaining teeth are small. The canine would have the high ratio of bucco-lingual area divided by the mesial-distal projected area if the second premolar is excluded. The difference in range is small if one considers the low in the same group is 1.17. The total/MD ratio, again, excluding the second premolar had a high figure of 3.67 and a low of 3.16.

CHAPTER V

DISCUSSION

The purpose of this project was to develop a method of measuring total and projected root surface area of maxillary human teeth and to correlate the findings. One writer, (Freeman, 1965) apparently confused projected root surface area with total root surface area. The projected area of a root as defined by Geigel (1965) is:

> The area of the projection of the root of a tooth that is made on a screen that is in a plane parallel to the long axis of the tooth when rays of a light are parallel. For pure translation in the distal direction, the projection that is considered is the one that occurs when the screen is in a buccal-lingual plane and the light source is in a mesial position directed distally.

The importance of measuring the areas and noting the correlation between the total and projected areas in orthodontics is exemplified by the focus of attention upon root pressure as the important factor in determining tooth movement. Storey and Smith (1952) concluded that there was an optimal force per unit area of root surface that would yield desirable physiologic

tooth movement. Jarabak and Fizzell (1963) have combined and introduced the disciplines of analytical mechanics, applied physics, and biology into orthodontics. They estimate from a study of available figures that the most effective pressure at the root surface is in the range of 2 - 2.5 gm/mm^2 of projected area.

Review of the literature indicated that the precise measurement of projected root surface area has received limited attention. Numerous pieces of research have been done to correlate periodontal ligament area with masticatory pressure, e.g., Boyd (1958) and Jepsen (1962).

The membrane technique to measure total root surface area was utilized in this research. A photographic method was used to measure projected root surface areas of the maxillary teeth. The accuracy and precision of this method are given in Table I. Formvar which is a material normally used in electron microscopy work can be used to measure total root surface area of teeth. A comparison of the figures as presented by this author corroborates the findings of Jepsen and Boyd. The measurements given by Tylman and Tylman (1960) and Freeman (1965) are significantly lower than those presented here. (Table XVI). It would be well to note,

Table XVI

Comparison of Measurements of Root Surface Areas

Type of Tooth	Average Area (mm^2)	Stand. Dev.	Jepsen (1962)	Stand. Dev.	Tylman and Tylman (1960)	Boyd (1958)	Freeman (1965)
Central Incisor	209.4	14.9	204	31.4	139	204.5	23.0
Lateral Incisor	179.0	11.7	179	24.9	112	177.3	19.4
Canine	263.4	20.9	273	43.9	204	266.5	28.2
First Premolar	255.0	22.7	234	33.7	149	219.7	---
Second Premolar	215.1	12.5	220	39.0	140	216.7	25.4
First Molar	438.3	35.8	433	40.9	335	454.8	53.3

however, that those measurements given by Tylman and Tylman, as they mention, are simply a basis for comparison. It might then be assumed that those values are not an expression of the true size of the root surface area and they cannot be used where an exact knowledge of the root surface area of a tooth or teeth is required. Freeman presented "actual root surface area" that is apparently in gross error and it would be beyond the realm of this writing to discuss the reason for such an apparent error. He found, for example, the root surface area to be 53.3 mm^2 for the maxillary molar and 25.4 mm^2 for the second premolar. It would suffice to mention that the root surface areas as given by Freeman in his study are far too low.

The values arrived at by Boyd and Jepsen, except for the first premolar, are nearly identical with those of this investigator. The difference could be due to the selection of first premolar teeth. All the first premolars selected in this work were birooted and this could account for the slightly higher figure given here. The value given for the first molar by Boyd is slightly high but this may be due to the number of samples taken. Boyd measured only five teeth of each type, whereas,

twenty were sampled in this study. One extreme value could affect the average considerably in a small sample.

Brown (1950) had an average of 192 mm^2 for the central incisor. This value is somewhat low. He utilized the membrane technique but he used grid paper to determine the area of the membrane. This method of using grid paper introduces a certain degree of uncertainty since fractions of a square would have to be estimated.

The Phillips method of using tin foil to measure the root surface area of anterior teeth would be difficult to utilize on multirooted teeth.

The work of Jepsen is essentially confirmed by this study. The standard deviations reported by Jepsen are high, however, probably caused by a larger amount of experimental error.

There are several steps described by Jepsen that could logically introduce a degree of error. The first is the use of an oven to polymerize the membrane. It took 30 minutes at 130° C. for polymerization to occur. He found these values to be critical because he states, "a longer time made it too weak." It would not be unreasonable to suspect that tooth size would change when subjected to such a high temperature for thirty

minutes.

A second variable that may have influenced his finding was his method of measuring the membrane. He placed the membrane on a photographic film in a darkroom which was then exposed. The film, after development, was printed in an enlarger set to five times linear enlargement. It has been the experience of this investigator that where the pictures used in this research were enlarged three times the original size, it was always necessary to utilize the square in the picture to obtain the exact linear enlargement. That is, the linear enlargement was determined precisely by measuring the square first.

The precision of this method can be attributed to several factors. Formvar can be air cured in half the time that it takes to cure polyvinyl chloride in an oven at 130° C. The pictures taken of the membrane and projected root surface areas were always taken with a fixed object to film distance. The square was used as reference in every picture to obtain exact magnification. Finally, the compensating polar planimeter is the most accurate means now known by which the membranes and projected areas could be measured.

Realizing that the biophysics of orthodontic forces is a relatively new science, it is not difficult to understand that a method of determing projected root surface areas has not been clearly established. The accuracy of the method used in this research in measuring projected area has been discussed.

The total bucco-lingual projected area of the molars includes the mesial view of the disto-buccal root through the long axis of that root from the trifurcation to the apex. The mesio-distal projected area of both the molar and first premolar include the buccal view of the lingual roots through the long axis from the junctions of the roots to the apices. This discipline was rigidly adhered to throughout the experiment.

The results indicate that the ratio of total root surface area to bucco-lingual projected area is rather constant between the different types of teeth. That is, the average ratio among the types of teeth is 2.63 with a standard deviation of 0.17. The coefficient of variation is 6.4%. The bucco-lingual to mesio-distal ratio is classified here as having the intermediate difference. The high is 1.87 and the low is 1.17. The largest difference occurred in column three of Table XV which is

the ratio for total root surface area over mesio-distal projected area. The high values in column one and three are those of the second premolars. The bucco-lingual projected area of that tooth is nearly twice the mesio-distal area.

The above findings suggest that one can estimate with a reasonable amount of certainty the total root surface area of any tooth in the maxillary arch, from the central incisor to the first molar, if the bucco-lingual projected area is known. One can predict, to a lesser degree, the total root surface area of the teeth if given the mesio-distal projected root surface areas.

The projected areas of each type of teeth are given in Table XIV. These are values which can be useful in determining root pressure in grams per square millimeter of projected area for physiologic tooth movement.

The projected root surface area as a method of calculating the theoretical stresses in the periodontal ligament was verified by Evans (1966) and Nakfoor (1966). This method was described by Jarabak and Fizzell. Now, the researcher has a tool to calculate stresses that de-

velop in the periodontal ligament in different situations and this provides a basis for comparison.

Ballard (1958), who utilizes removable orthodontic appliances, remarked in a symposium, "that if you apply 25 grams from a plate to both canines there is no difficulty in moving these canines back. If you apply more than 30 grams, you produce stasis."

Reitan's reply to this statement was that: "It is more practical to use a heavier strain. I have been using a force recently of between 100 and 150 grams..."

The above discussion is an example of the controversy that exists in orthodontics. Jarabak and Fizzell (1963) have pointed out in their concept of biophysics of orthodontic forces that root pressure is a more important factor in determining tooth movement than the force applied to the crown.

The technique that one uses in orthodontics to move teeth or the magnitude of force that one uses to move teeth is important only to the extent that one recognizes the existance of a biologic condition, referred to by Jarabak and Fizzell, as critical root pressure. The acceptance of this principle will clarify many of the phenomenons occurring in clinical orthodontics.

It must be remembered that force and pressure are clearly and precisely defined by the physicist and those two terms are not symonymous.

The use of those terms interchangeably would only lead to further confusion. An example of how orthodontists tend to use the terms force and pressure loosely and inaccurately is the comment made by Ballard (1958). He stated: "We started measuring the pressure and it was when we found that these pressures were over 30 grams (up to 60, in fact, and these are light pressures by Dr. Rickett's standards) the arch was moving forward and the canines were not moving back." This is just one of the examples that typifies the inconsistent use of terminology in orthodontics.

Reitan (1957) found that by tying a sectional arch back one mm., for space closure after extraction, a force of 500 grams was exerted on the canine. This caused the molar and premolar to move mesially, whereas the canine did not move for a while. He observed a favorable reaction with a full arch tied back for final space closure because of the increased number of teeth included in both sides of the arch.

It should be interesting to evaluate his observa-

tions on the basis of root pressure described by Jarabak and Fizzell. The sum of the projected root surface area of molar and premolar, as given in Table XIV, is 241.1 mm^2 and the projected root area of the canine is 108.1 mm^2. The pressure exerted on the posterior teeth would be:

$$\text{Pressure} = \frac{F}{A}$$

where F = translating force

and A = projected area of the root,

Substituting numerical values, we have:

$$\text{Pressure} = \frac{500 \text{ gm.}}{241.1 \text{ mm}^2} = \frac{2.1 \text{ gm.}}{\text{mm}^2}$$

The pressure exerted on the canine root will be:

$$\text{Pressure} = \frac{F}{A \text{ (projected)}} = \frac{500}{101.1} = \frac{4.7 \text{ gm.}}{\text{mm}^2}$$

This is an example of supramaximal pressure at which undermining resorption occurs. The pressure on the root of the canine would be far less if a full arch wire was tied back because this would include the central and lateral incisors. The pressure exerted on the central and lateral incisors would be on the lingual surface. Therefore, the sum of the mesio-distal projected areas

of the incisors as determined in this research is 115.5 mm^2. (Table XIV). The canine would be moved distally and the pressure would be on the distal surface. The sum of the bucco-lingual projected area of the canine and the mesio-distal projected area of the incisors on one side of the arch would be 223.6 mm^2.

The pressure on the roots of the anterior teeth would be:

$$\text{Pressure} = \frac{F}{A \text{ (projected area)}}$$

$$= \frac{500}{223.6} = 2.3 \text{ gm/mm}^2$$

The pressure now exerted on the incisors and canine is 2.3 gm/mm^2. The pressure on the roots of the posterior teeth is 2.1 gm/mm^2. The pressure distributed between the root surfaces of the anterior and posterior teeth are nearly identical. It is for this reason that Reitan observed favorable reaction when the whole maxillary arch was tied back. This confirms what Jarabak and Fizzell have asserted: "The most effective pressures at the root surface are likely between 2 gm. and 2.5 gm/mm^2 of projected area."

Reitan (1957), conjectured that 150 to 250 grams of

force is needed to move the maxillary canine during the final stage of closure. Jarabak and Fizzell (1963), found that a force of 180 grams applied to the maxillary canine did not result in any root resorption. The pressure on the canine root, subjected to a 200 gram force, would be 1.9 gm/mm^2 of projected area. The pressure for a force value used by Jarabak and Fizzell for physiologic tooth movement would be 1.7 gm/mm^2 of projected area. This value is slightly higher than 1.5 gm/mm^2 which they feel is ineffective in maintaining motion. This is referred to as subliminal pressure.

The foregoing discussion is evidence of the clinical significance of total and projected root surface area. The clinician would then be able to use one group of teeth as an anchor unit to move a tooth or several teeth by designing his force systems in terms of root pressure rather than force.

CHAPTER VI

SUMMARY AND CONCLUSION

A. Summary:

A sample of 120 maxillary teeth were measured in this study. The membrane technique was used to measure the total root surface area. Formvar was the choice of material used because of its ease in handling and accuracy in measuring root surface area.

The projected root surface areas were measured by photographing teeth from the buccal and mesial views of the roots. The roots of multirooted teeth were sectioned and the values of the bucco-lingual and mesio-distal projected areas were added together accordingly.

The findings given here essentially confirm the work of Jepsen and Boyd. These results, however, do not agree with previous reports as presented by Tylman and Tylman (1960) and Freeman (1965). Tylman and Tylman mentioned that the figures are to be used only as comparison, thus indicating that they are not accurate root surface areas of the teeth. Freeman (1965) utilized the membrane technique to measure root surface areas. He also used

the compensating polar planimeter to measure the membrane. His values were less than one-eighth the total root surface that this investigator as well as Jepsen and Boyd have found. A total root surface area of 53.3 mm^2 for the maxillary molar and 25.4 mm^2 for the second premolar are extremely low figures.

The slightly higher value of this study for the first premolar in comparison to the study of Jepsen and Boyd can be attributed to the selection of teeth. The samples used in this study were all birooted, whereas, no mention is made of this by the other researchers.

The standard deviations as reported by Jepsen are somewhat higher than those presented here. This could be attributed to several factors. The first is the high temperature used by Jepsen in polymerizing the membrane. The time and temperature of polymerization to occur were found to be critical in order to obtain membranes that were measurable. Secondly, the enlarger was set to exactly five times linear enlargement but it was found by this worker that this does not produce exact magnification.

The precision of this work can be accounted for by several factors. Formvar is relatively easier to handle

and it can be air cured in a few minutes without subjecting the tooth to a high temperature in an oven. The pictures of the membranes were always taken with a fixed object to film distance and the square in every picture was an excellent reference for exact magnification.

The determination of projected root surface area of the teeth has not been documented previous to this study. The accuracy in measuring the projected area of the cylinder is given in Table I. The ratio of total root surface area to the bucco-lingual projected area had the smallest difference while the largest variation occurred between the total root surface area to the mesial-distal projected area and to a lesser degree between bucco-lingual projected area to the mesio-distal projected area.

The projected root surface area as a method of calculating the theoretical stresses in the periodontal ligament have been verified in an earlier study.

Reitan reported that tying back a sectional arch one mm. caused hyalinized areas to form distal to the canine while the anchor teeth moved mesially. Favorable reaction occurred when the whole arch was tied back. This phenomenon was logically explained on the basis of root pressure as described by Jarabak and Fizzell. Their

assertion that the effective pressures at the root surface are likely between 2 and 2.5 gm/mm^2 of projected root area was substantiated on the basis of the translatory force magnitude described by Reitan and the projected root surface areas of the maxillary teeth given in Table XIV. The pressure on the anterior teeth of 2.3 gm/mm^2 and the pressure on the posterior teeth of 2.1 gm/mm^2 induced favorable tooth movement.

The maxillary canine was retracted with an average force of 200 gm. by Reitan and 180 grams of force as described by Jarabak and Fizzell with no root resorption. The average projected area of the maxillary canine from a distal view was measured to be 108.1 mm^2. The pressure exerted on the root of the canine would then be 1.9 gm/mm^2 for the former and 1.7 gm/mm^2 for the latter researchers. These values are higher than the subliminal pressure of 1.5 gm/mm^2 which Jarabak and Fizzell feel is ineffective in maintaining motion.

B. Conclusion:

1. This research presented a method of measuring total root surface area of teeth using formvar as the coating material. The technique was demonstrated to be

accurate, precise, and practical.

2. A reliable photographic technique was devised to measure projected root surface areas of the same teeth.

3. One can predict with reasonable accuracy the total root surface area of any teeth in the maxillary arch from the central incisor to the first molar if the bucco-lingual projected area is known. That is, the ratio of total root surface area to bucco-lingual projected root surface area was essentially constant from one type of tooth to another.

4. The total root surface area can be predicted to a lesser degree of accuracy if the mesio-distal projected root surface area is known.

5. The data collected in this research revealed that a force of 500 grams developed in the final closure of spaces will exert a pressure of 2.1 gm/mm^2 of projected area on the molar and second premolar. The pressure on the anterior teeth will be 2.3 gm/mm^2 of projected area. These figures substantiate values of effective root pressure as presented by Jarabak and Fizzell.

6. The projected root surface areas will be useful in calculating root pressures in the clinical application of the biophysical concepts of tooth movement.

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APPROVAL SHEET

The thesis submitted by Dr. Clifton Y. Moromisato has been read and approved by members of the Departments of Anatomy and Oral Biology.

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 with reference to content, form, and mechanical accuracy.

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

May 11, 1967
DATE

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