ROOT SURFACE AREA

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A C K N O W L E D G E M E N T

I would like to express my thanks to Dr. Ernesto Hixon, Dr. Fred Sorenson, and my classmates, Dr. Tore Aasen, Dr. Jorge Arango, Dr. Bob Klosterman, Dr. Seymour Miller and Dr. Bob Odom for their assistance in this project.

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INTRODUCTION

In an attempt to gather meaningful information regarding the rate of tooth movement, the 1968 graduate class of Orthodontics at the University of Oregon Dental School initiated a clinical study of this question [1] Their findings tended to contradict the popular concepts of optimal force and differential force. To pursue these findings, a new study was established by the class of 1969.

To better understand the nature of the process which allows a tooth to be moved through bone, it is necessary to determine the amount of applied force; more specifically, the force application per square millimeter of root surface area. At least two investigators have attempted to correlate actual root surface area with measurements obtained from radiographs.[2,3] All of the X-ray determinations, however, were made on extracted teeth, thereby avoiding the many sources of error and frustration inherent in any clinical situation.

It was hoped that a clinically useful technique could be devised to correlate pre-surgical radiographic records with later measurements of root area on the extracted teeth. The purpose of this investigation was to determine whether these techniques could be effectively applied to an in vivo situation, to provide a clinically significant correlation coefficient ($r = 0.80$ or better).

R E V I E W O F T H E L I T E R A T U R E

The orthodontic literature contains a wealth of references to the amount of force that various authors feel should be applied per unit area of root surface,[4,5,6] but is less abundant in the realm of actual root measurements. Much of the present day controversy regarding orthodontic forces can be traced to the work of Sandstedt in 1905.[4] He postulated that heavy forces compress the periodontal ligament and interfere with direct resorption of alveolar bone. Tooth movement could occur, he believed, only after the process of undermining resorption had effectively debrided the necrotic area of compression.

In 1932 Schwarz attempted to quantify orthodontic force with respect to the capillary blood pressure.[7] He theorized that forces in excess of the capillary blood pressure would compress the vessels within the PDL and produce a "strangulated periodontium" which would in turn lead to tissue necrosis.

Schwarz derived a range of 20 to 26 gm/cm^2 for the capillary blood pressure and suggested that continuous orthodontic forces be limited to 15 to 20 $gm/cm.^2$ He felt that forces of this magnitude would allow teeth to move at their biologic optimum and yet provide a margin of safety. Although he was quite explicit in stating the amount of force that should be applied per unit area, he offered no guidelines for the actual determination of root surface area.

This rather arbitrary and somewhat mysterious value of 20 to 26 gm/cm^2

was quickly assimilated into the orthodontic armamentarium and flourished in its new environment. Because it sounded so reasonable and came from such a prestigious authority, it was accepted without a great deal of thought or serious investigation. Wendel Wylie observed that because of the orthodontists' deep-seated desire for orthodoxy, "Conclusions have been arrived at too hastily, and then seized upon as premises to build still more conclusions."[8]

In 1954 MacEwan discussed the question of "anchorage with respect to the use of intermaxillary elastics. He presented a value referred to as the "stability limit" and stated that forces lighter than this limit will not initiate tooth movement: "7 gm. per square centimeter of root surface (or, more precisely, per square centimeter of alveolar lamina dura) if the periodontium is physiologically normal".... "When tooth movement is desired the light forces used exceed the stability limit just mentioned, but do not exceed the capillary blood pressure, which is 20 to 25 gm. per square centimeter."[9] Although he acknowledges the importance of the size of the roots to his equation, he offers neither estimates nor averages as a guide to his determinations.

Halderson in 1957 presented a detailed discussion of orthodontic forces and stressed the importance of not exceeding Schwarz's figures for capillary blood pressure.[10] Precise determinations of force were presented, but the problem of root area was again ignored.

Tylman in 1947 presented a table in which "the root surface areas of periodontal membrane attachments of the average normal teeth have been computed."[11] No further information regarding the sample or the method of determination was given.

In 1950, Brown demonstrated a method of determining root surface area.[12] Liquid latex was painted onto the roots of the teeth. After curing, it was cut, removed from the teeth, and spread flat on a piece of graph paper. The number of squares covered by the irregular outline was used for the determination of area. This procedure was carried out on nine upper central incisors.

Kay studied the anterior teeth in 1954, with particular attention to the relationship between their root length and root volume.[13] Volumetric analysis was accomplished by immersion of the root in mercury and measuring the amount displaced.

Phillips in 1955 attempted to determine the percentage of root surface area lost in apical resorption.[14] Tin foil was adapted around the roots of incisors before and after grinding the apex to simulate resorption. The difference in area of the two pieces of foil represented the amount of area lost.

In 1958, Boyd "measured the periodontal areas" of eighty teeth.[15] No further discussion of technique was included.

Perhaps the most comprehensive study of root surface area was presented by Jepsen in 1963, utilizing 238 extracted teeth.[2] The roots were painted with a polyvinyl chloride solution which, upon polymerization, formed a thin membrane about the roots of the teeth. This was peeled off, placed between glass slides, and exposed on photographic film. The image of the membrane was projected, measured with a planimeter, and corrected for enlargement. Radiographs were taken of the extracted teeth and a positive correlation demonstrated between their area and the true surface area of the roots of the teeth.

Freeman in 1965 followed Brown's latex membrane technique on 330 extracted teeth.[3] After tracing their outlines on graph paper, he measured the areas with a planimeter. Simulated periapical films were taken of the extracted teeth and tracings made of the root outline. The area of the tracing was compared to the actual area and correlation coefficients determined. As in Jepsen's work the correlations were, of course, quite good (average $r = 0.93$).

Moss in 1967 presented his measurements of various parameters of the posterior teeth.[16] While not primarily interested in root surface area, he related his volumetric determinations to Jepsen's results on area, producing an area of possible interest to future investigators.

Emmanuelli in 1969 reported on 120 mandibular teeth.[17] He utilized a Formvar solution to produce a thin root membrane. Photographs of the membrane and a standard of known area were compared by means of a compensating polar planimeter.

M A T E R I A L S   A N D   M E T H O D S

A. Determination of Root Surface Area.

Extracted teeth for this study were obtained from the Department of Oral Surgery, University of Oregon Dental School (Table I). A routine full-mouth radiographic survey was taken on all patients prior to surgery, and whenever possible cephalometric headplates were also obtained.

The extracted teeth were cleaned and dried, and the cemento-enamel junction delineated with a lead pencil. The anatomic crown was then covered with a layer of wax leaving only the root exposed. Rubber base impression material (Permelastic) was mixed and applied to the roots in a manner similar to the latex membrane technique described by Brown.[12] When polymerization was complete, the material was slit with a surgical blade and removed from the root. This thin rubber "impression" was cut so that it could be laid flat and then attached to a microscope slide with rubber adhesive. The glass slide with the irregular rubber form is then ready for area determination on the photogenerative cell.

The photogenerative cell expresses differences in amount of incident light in terms of differences in electrical current. When an opaque form is placed between the cell and the light source, a diminished amount of light strikes the cell resulting in a proportionate drop in current. The electric current is amplified and fluctuations are either read directly from the meter or from the drum recorder. Rubber standards of known areas were constructed, attached to slides, and used to relate the recording scale to known surface areas. This relationship was direct and linear in nature.

Readings were taken on the rubber root forms and related to the known standards. A standard error of the measure was computed by making duplicate impressions of 25 bicuspid roots, resulting in S.E.Meas. = 9 mm^2 which represents an error of roughly 5% of mean area.

B. Roentgenographic Records.

Routine full-mouth periapical radiographic surveys were taken on all patients prior to surgery. They all utilized the standard long-cone technique, but were taken by different operators at different times and on different machines. All surveys were judged to be of good clinical quality.

The radiograph of the tooth to be extracted was projected onto a flat surface at approximately 5X magnification and a tracing of the root outline made on acetate paper. The figure was carefully cut out and later weighed on an electronic balance, giving an expression of the projected radiographic root area in milligrams. The intra-oral radiographs of seven teeth were projected, traced, cut, and weighed a second time, producing a standard error of the measure of 7.2 mgm. or about 3% of the mean tracing weight.

Pre-surgical cephalometric headplates were taken whenever possible, utilizing an adjustable cephalostat that could be rotated 25 degrees to either side. This allowed the patient to be positioned with the right or the left side of the mandible more nearly parallel to the plane of the film, diminishing distortion of the teeth on that side. Tracings of the roots were made directly from the headplates, cut out, and weighed in the same manner as those obtained from the intra-oral films.

The electronic balance used to weigh the root tracings was highly reliable; double determinations agreeing within 1.0 mgm. The frosted acetate paper upon which the tracings were drawn was found to be quite uniform in weight with different samples of the same area varying by no more than the sensitivity of the balance. Since the weight of the paper is a direct function of its area, no conversion to square millimeters was made. The greatest source of error was, of course, in tracing the projected root outline and cutting it out accurately.

FINDINGS

Table II gives the mean, standard deviation, and coefficient of variation of the root surface areas obtained from this sample of extracted teeth as well as the values obtained from the projected root tracings.

Correlation coefficients were calculated between the measured root area and the root tracing from the lateral head film. They were uniformly low, ranging from r = 0.29 to r = 0.54.

The use of projected periapical radiographic tracings gave only slightly higher correlations, ranging from r = 0.40 to r = 0.88. The only correlation exceeding r = 0.80 was for the mandibular cuspid and involved a sample of only 10 teeth. It is likely that an increased sample size would lower this value.

It was originally thought that for any given patient the variables between the right side and the left side should be minimal. The teeth would have a similar configuration and orientation, and the radiographs would have been taken by the same operator, under the same conditions. To treat the pair of teeth as separate samples, therefore, could produce a higher but less valid correlation. It was thought that a more honest approach to dealing with antimeres would be to average them together and treat them as two estimates of the same tooth.

The result of this averaging technique, however, was the opposite of what had been anticipated. When the values for antimeres were averaged, the correlation coefficient increased slightly over that determined by treating each tooth individually. Taking the lower first bicuspid as an example, the ocrrelation coefficient rose from $r = 0.42$ to $r = 0.58$.

DISCUSSION AND CONCLUSIONS

This study demonstrated that there exists a wide range of individual variation in the root surface area of human teeth. Of equal relevance, perhaps, is the observation that there is considerable disagreement among the few investigators of this subject.

Considering these variations, we therefore should look with some skepticism at broad generalizations encountered in dental literature. Until a better clinical technique is developed for root surface area determination, theories concerning the amount of force application per square millimeter of root surface lend themselves more readily to discussion than to practical application.

I have demonstrated that the methods as outlined here failed to satisfy our requirements of clinical usefulness. Perhaps future investigators should return to laboratory radiographs of extracted teeth to confirm the high correlation reported to exist with actual root surface area. It may well be that even under ideal circumstances this correlation is not as great as has previously been reported. If not, there would be little point in pursuing the question from this approach. If, on the other hand, a high degree of correlation is obtained one could proceed with investigations regarding modification and standardization of the radiographic technique.

In the years to come attention may well turn towards the use of stereoscopic radiographs. This would enable the operator to escape the confines of two dimensions as imposed by our present methods. It is not unreasonable to presume that the addition of the third dimension would provide a more accurate index of area. Optimism about the future, however, "...would be better justified were it not for the fact that we have around us too many people inclined to the simple declarative statement. Qualifications and the admission of exceptions are too often taken as signs of indecision."[8]

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Table 1

	Number of teeth	Number of patients
Mandibular Cuspids	11	8
Mandibular First Bicuspid	49	29
Mandibular Second Bicuspid	28	18
Mandibular First Molar	6	6
Maxillary Cuspids	9	7

Table 2

	Measured Root Area				Radiographic Root Area		
Tooth	N	Mean	S.D.	C.V.	Mean	S.D.	C.V.
		$mm.^2$			mgs.		
mandibular cuspids	10	286	64	22.4	214	72	34
mandibular 1st bicuspids	33	202	36	17.8	143	20	13.8
mandibular 2nd bicuspids	28	208	30	14.5	174	23	13
mandibular 1st molars	6	527	82	15.7	288	25	9
maxillary cuspids	11	297	36	11.9	—	—	—

Table 3

Tooth	Freeman	Tylman	Boyd	Jepsen			Atikian		
				Mean	S.D.	C.V.	Mean	S.D.	C.V.
				$mm.^2$			$mm.^2$		
mandibular cuspid	27.0	159	272.2	273	43.9	16.1	321	41.7	12.9
mandibular 1st bicuspid	—	130	196.9	234	33.7	14.4	242	24.6	10.2
mandibular 2nd bicuspid	24.0	135	204.3	220	39.0	17.7	261	21.9	8.4
mandibular 1st molar	47.4	352	450.3	433	40.9	9.4	508	69.5	13.7
maxillary cuspid	28.1	204	266.5	268	42.2	15.7			

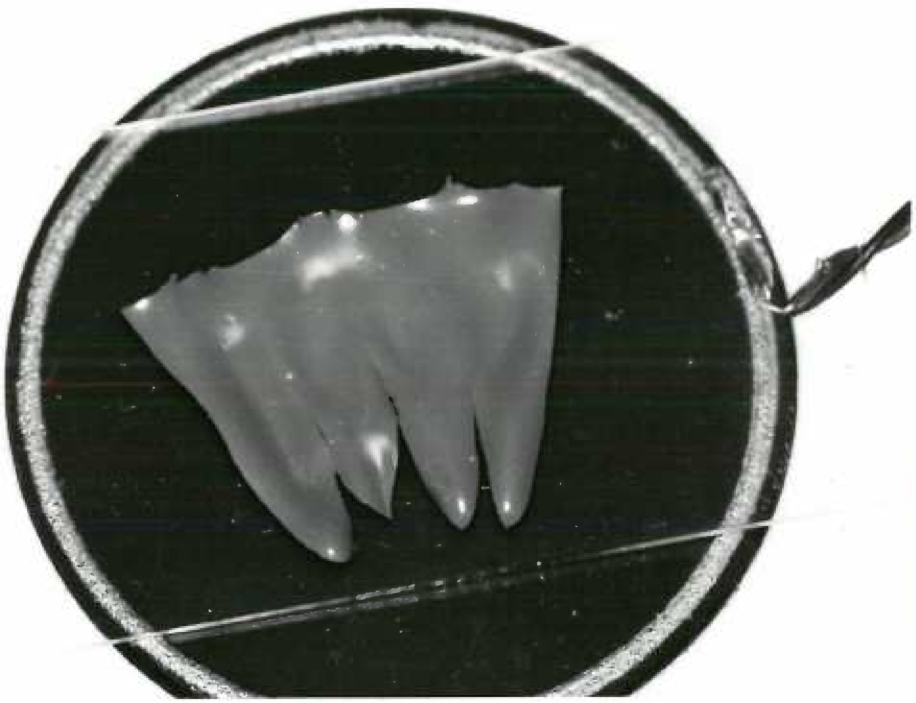


Fig. 1
Rubber "impression" of root placed
on photogenerative cell.

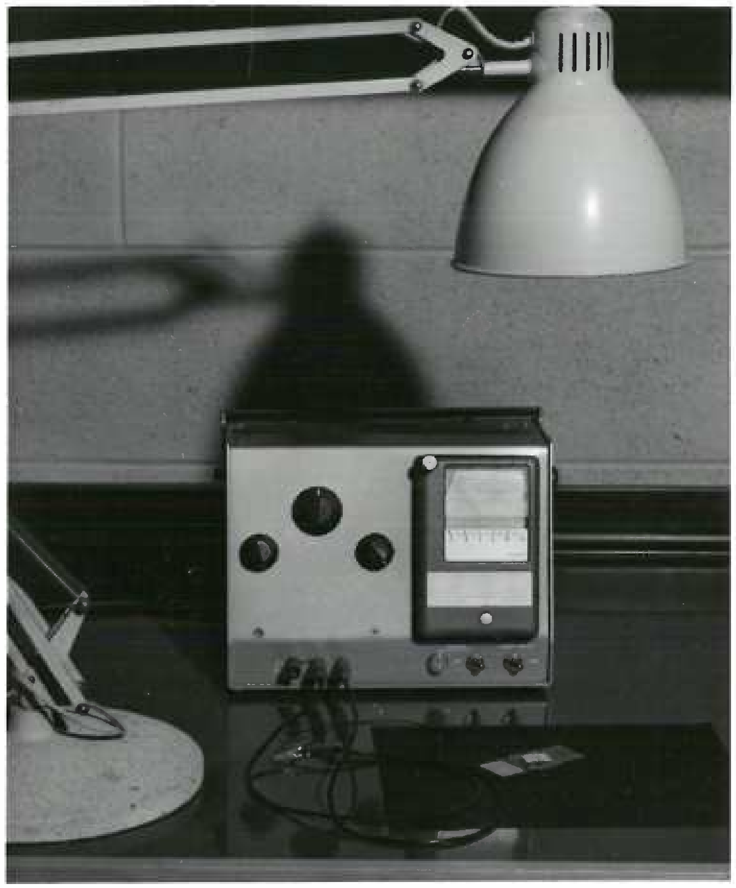
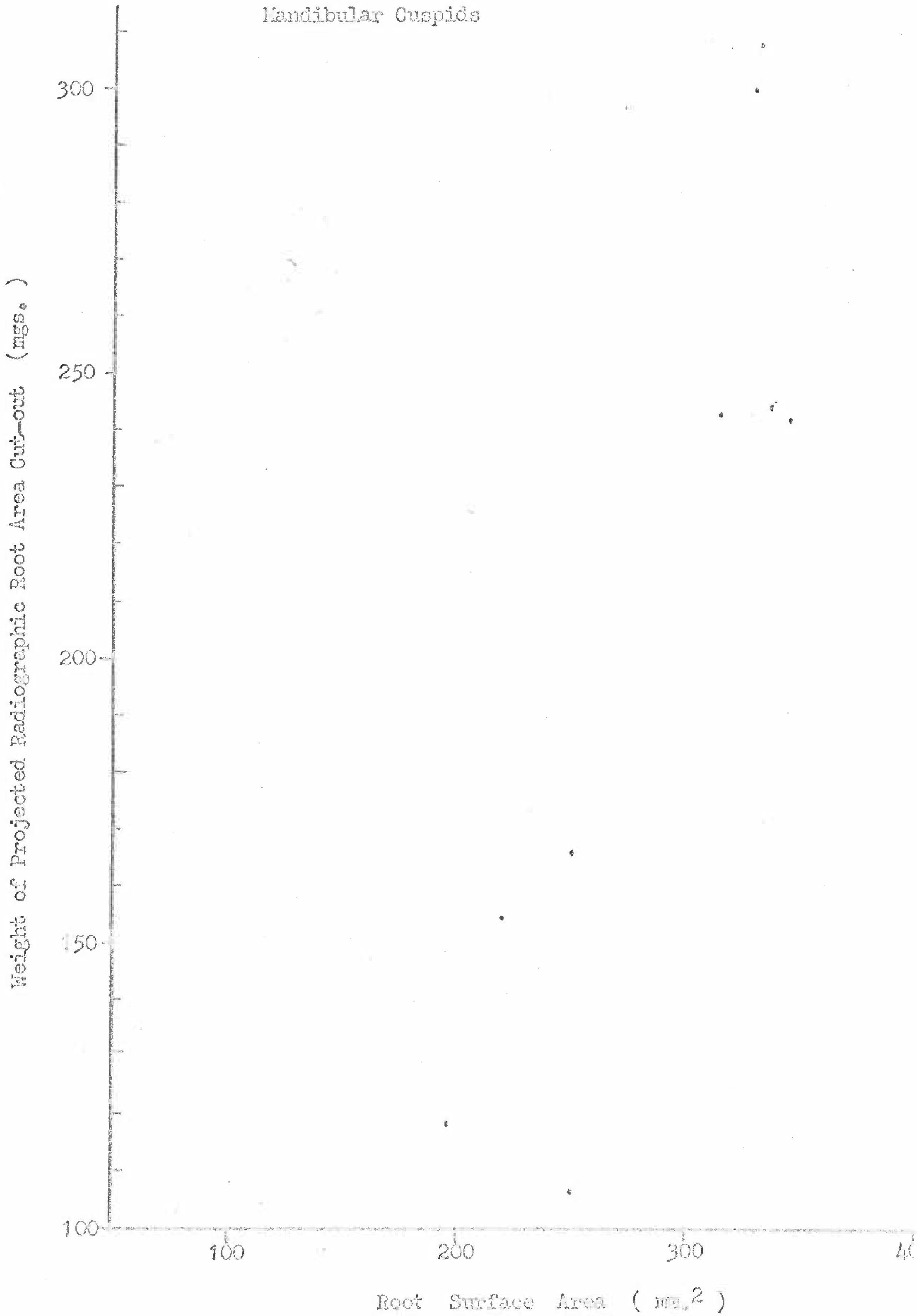


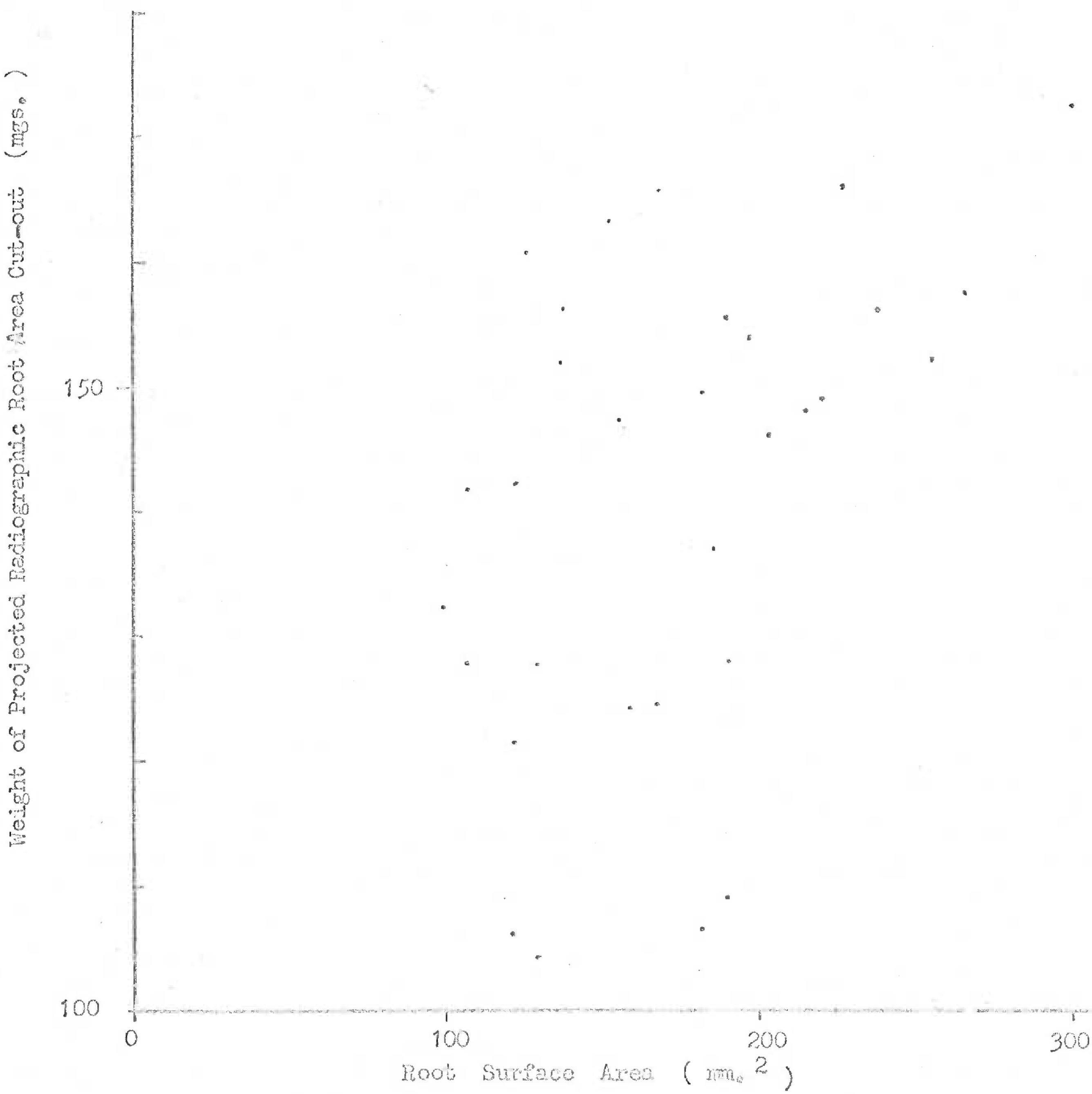
Fig. 2
The photogenerative cell and recorder

THE RELATIONSHIP OF RADIOGRAPHIC ROOT AREA TO MEASURED ROOT AREA



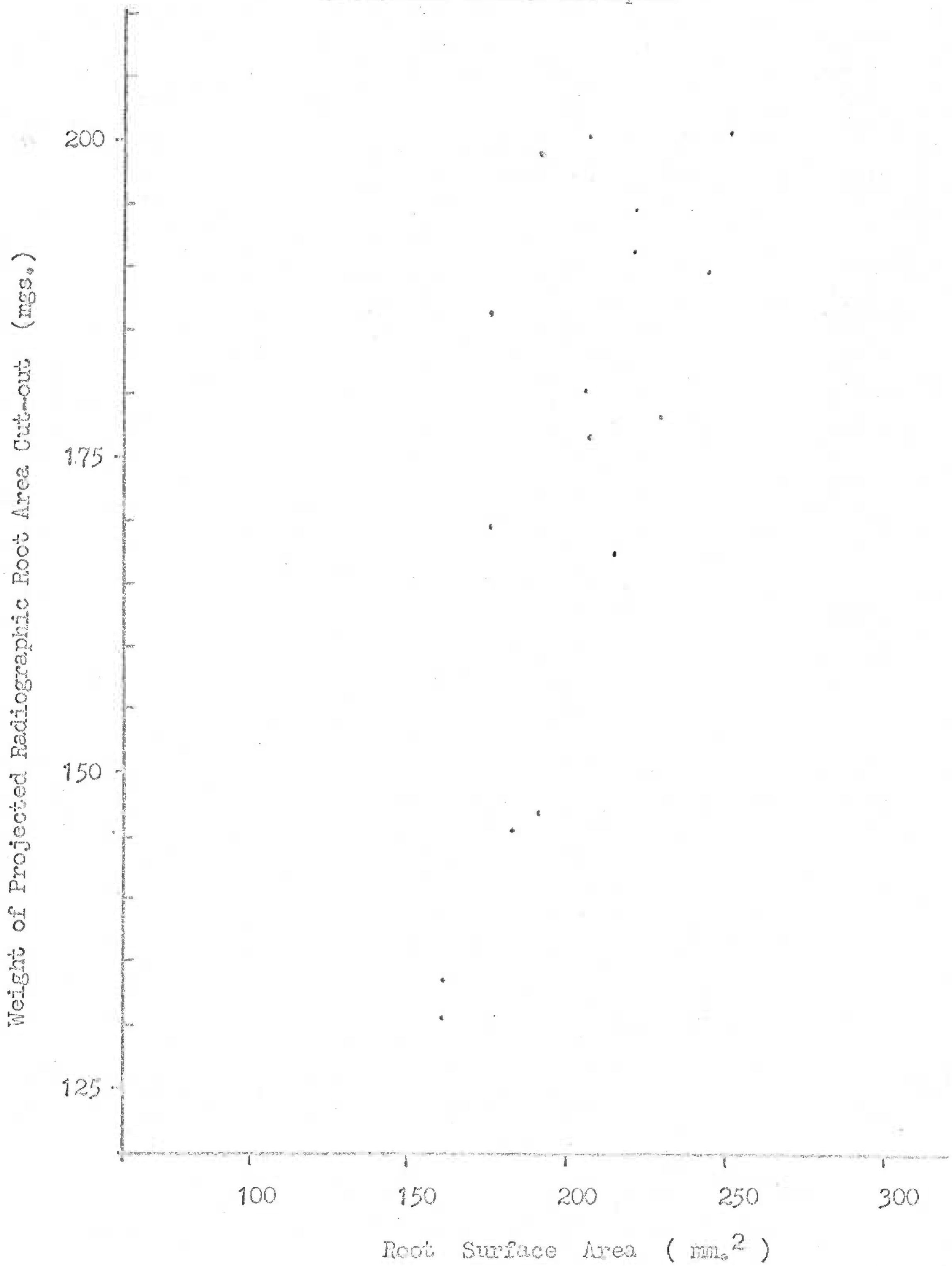
THE RELATIONSHIP OF RADIOGRAPHIC ROOT AREA TO MEASURED ROOT AREA

Mandibular First Bicuspids



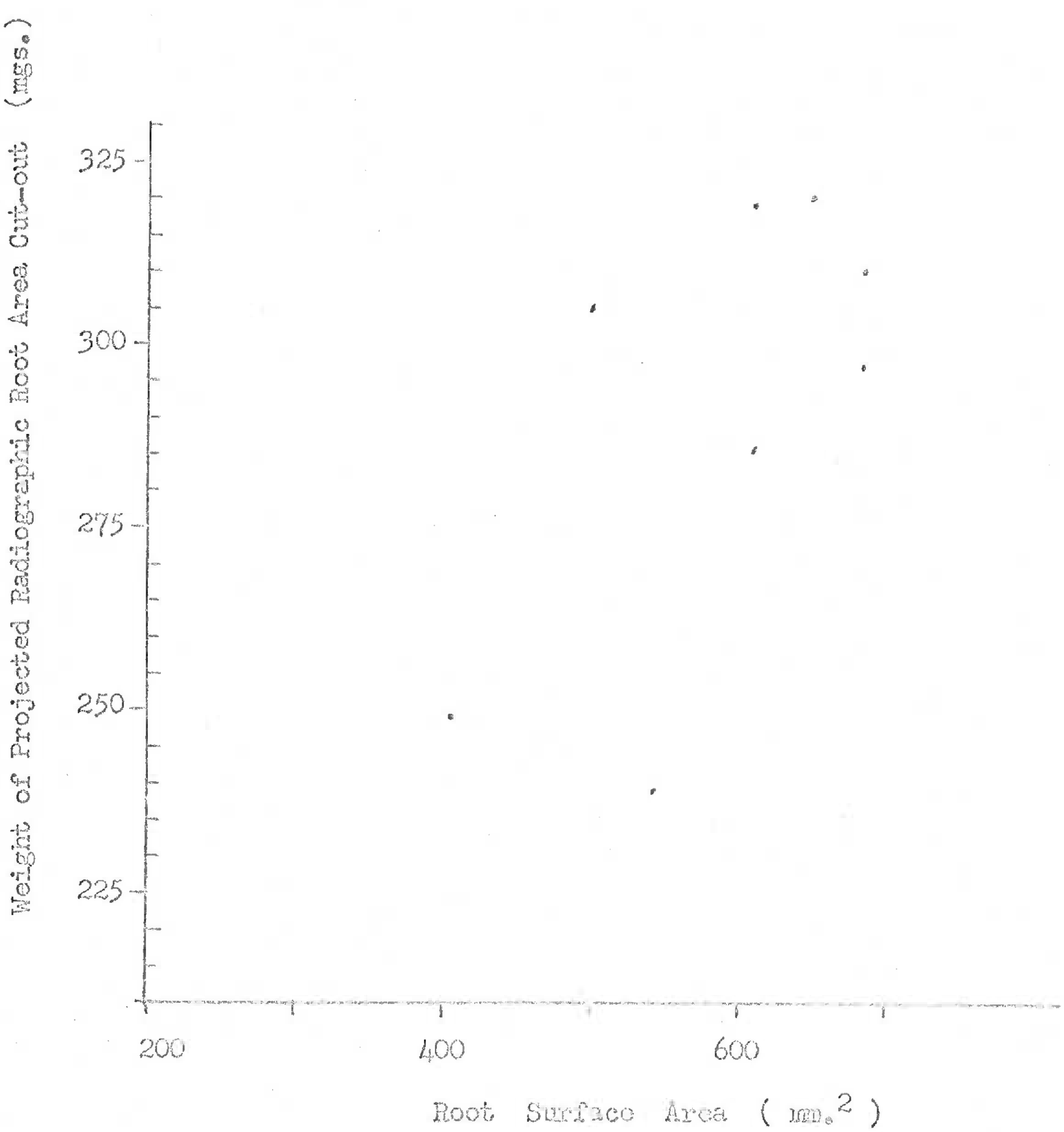
THE RELATIONSHIP OF RADIOGRAPHIC ROOT AREA TO MEASURED ROOT AREA

Mandibular Second Bicuspids



THE RELATIONSHIP OF RADIOGRAPHIC ROOT AREA TO MEASURED ROOT AREA

Mandibular Molars



CALIBRATION OF PHOTOCELL FOR MEASURED ROOT AREA