THE RELIABILITY OF THE ELECTRIC PULP TESTER
ON ORTHODONTICALLY BANDED TEETH

by

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TABLE OF CONTENTS

PAGE

INTRODUCTION

The stimulation of teeth by means of an electrical impulse for the purposes of determining the vitality of the pulp has been part of routine dental diagnostic procedures for many years. Although there are a variety of pulp testing devices available to the dentist for diagnosis of pathology, electrical pulp testing is perhaps the most widely used. Ascertainment of pulpal vitality by means of excavation, probing, thermal changes, etc. are helpful but do not offer a qualitative or quantitative means by which one can clinically evaluate the specific pulp response on different occasions.

The orthodontist is interested in any changes that are brought about in teeth as well as their surrounding structures, not only from the standpoint of the patient, but in regard to the general dentist who may be confronted with a clinical problem of differential diagnosis in an orthodontic patient. Orthodontic literature has suggested that orthodontic treatment may alter the vitality of teeth and interested researchers have been approaching this question with the use of the electrical vitalometer.

The purpose of this paper is to evaluate the accuracy and reliability of the electrical pulp-tester on orthodontically banded teeth and to assess the ability of the operator to obtain repeatable measurements.

REVIEW OF LITERATURE

The dental literature contains many investigations related to tissue changes as a result of forces applied to the teeth. Histological examination of pulpal tissue was a major source of investigation by Orban (1936),[1] Stuteville (1937),[2] and Oppenheim (1942).[3] The methodology of this type of investigation introduced shortcomings in that pulpal changes could not be evaluated at different time intervals. As a result, electrical pulp testing developed over a period to time as one method to evaluate dental pulp tissue. Since the first attempt of electrical excitation of teeth was started in the 18th century by Matigot (1867), many different methods of electric pulp testing evolved and incorporated the various sources of current: faradic current, galvanic current, direct current, and high frequency current.[4]

Reiss and Furedi (1933) and Kaletsky and Furedi (1935) used direct current in their experiments and determined that the electrical pulp tester maintained a method of standardization for normal teeth, but variation was inherent as a result of patient temperament, age, and psychological influence.[5,6] These early investigators attempted to establish a suitable and reliable method for interpretation of clinical findings with the use of the pulp tester. Their technique incorporated a low voltage system using two electrodes, one hand-held by the patient, and the other as the stimulating electrode to the tooth. Kaletsky attempted to categorize ranges for normal teeth, but still found a wide range of variation (1937).[7]

Ziskin and Wald (1935, 1938) decided that the density of current should be expressed in amperage and not in voltage since tooth structure offered such high resistance. The intensity of the current is directly dependent upon voltage, body resistance between hand-held electrode and tooth, resistance between electrode and tooth, and the tooth itself.[8,9]

Ziskin and Zegarelli (1945) further emphasized the necessity for using a current measuring device rather than voltage in order to eliminate the problem of the tooth structure being of such high resistance material.[10] Markus (1946) investigated maxillary centrals of

27 children following orthodontic movement and determined that amperage and voltage readings were altered after pressure was applied to teeth and that there was a tendency toward an increased irritability of the pulp, therefore, a lower threshold of stimulation.[11]

Bjorn (1946), used direct current impulses of specific duration and measured the pulpal threshold value in amperage.[12] He did not find any significant difference between threshold values obtained by using rubber dam and those with the teeth isolated with cotton rolls. He stressed the importance of using current density rather than voltage due to the high resistance of tooth structure.

Nordh (1955) attempted to determine whether the pulpal threshold of sensitivity was changed in connection with orthodontic treatment. Testing was conducted on teeth adjacent to an extraction site and compared to a control. There appeared to be a statistically significant increase in pain threshold values obtained after the extractions, with a tendency to return to the original values with time. There were a few cases where pulpal response to electrical stimulation was reduced entirely and it was indicated that this change was of a temporary nature. The investigator tested 36 teeth on the same day, before and after orthodontic band placement, and found no significant difference between the two readings. This indicated that the stainless steel band and banding procedure did not alter current flow or the pain threshold level. Further testing of 13 teeth before and after orthodontic treatment and comparison with a 10-tooth control showed no statistically significant difference.[13]

Mumford (1959) showed that when direct current passed through an extracted tooth from the crown to the apex, the current density is greatest at the pulpo-dentinal junction and in the pulpal canal.[14] In a later article (Mumford, 1959), through an electrophoresis technique, and using methylene blue to examine the path of current as it traveled through the crown portion of the tooth, supported his earlier finding that current density is greatest at the pulpo-dentinal junction.[15] He also indicated that teeth with incompletely formed roots need greater current to produce nerve stimulation.

Mumford (1963) attempted to establish pain threshold levels for normal human anterior teeth with hopes of offering a useful diagnostic tool.[16] Although he was able to narrow the range of threshold values from those of previous investigators, the range was still too wide to be clinically useful. Mumford described the increase of electrode area which in turn increased the threshold value and considered this to be desireable. With the use of his square wave stimulator, he determined that results were more reproducible when placing the dental electrode on the incisal edge of the tooth rather than on the labial surface. The variation occuring when using the labial surface may have been due to test current leakage to the periodontium.

Mumford and Bjorn (1962) defined various problems in electric pulp testing and suggested that the current registered on an ammeter may not actually reach the pulp due to extreme caries, large restorations, orthodontic bands, and possible surface conduction of the tooth.[17] They suggested that current should be direct current and offer a square wave picture. They found that tissue responds at a lower threshold to cathodal than anodal stimulation with the difference in a ratio of 1:2.5. Consequently, they used the D.C. cathode as the stimulating electrode. The electrode, as found through previous experiments, was placed on the incisal edge to avoid surface conduction. Mumford felt that if the area of contact between the electrode and the tooth was greater, then the area of dentine through which the current passes may also be greater. This would affect the current density in the dentine, but possibly not in the pulp.

Mumford (1965) fabricated an electrical pulp testing device of a square wave nature and using a stimulus of 30 milliseconds in duration at 20 cycles/sec and introduced a high internal impedence so that current strength was almost independent of the subject's resistance. New threshold values for young adults were in a range of 2.2 - 20.5 microamps and within these limits, the pain threshold tended to be higher as teeth were located further from the midline. Difficulty in stimulating newly erupted teeth was experienced with an explanation of incomplete innervation. Adaptation to repeated stimulation was noted and resulted in taking the intial reading as being the most reliable threshold value. There appeared to be no statistical difference due to sex and age on pain perception threshold. This experiment incorporated the use of a rubber dam, for isolation of the teeth, and Mumford felt that there was less variation in readings than those of Bjorn (1946).[18] Mumford (1967) indicated that the electrical resistance of enamel and dentine increased greatly if allowed to dry during in vitro experiments and suggested that dental specimens be imbibed with physiological saline.[19]

Burnside (1972) compared 110 orthodontically treated teeth, having been tested after band removal, and 90 untreated teeth of the same age category.[20] He indicated, through the use of student "t" testing of cross-sectional data, that maxillary/mandibular anterior teeth, which have undergone orthodontic treatment, tend to display a higher threshold to electrical stimulation than do non-treated controls.

MATERIALS AND METHODS

This investigation was divided into three sections. The first involved testing of teeth prior to and following orthodontic banding, the second with testing of subjects in regard to reliability of obtaining repeatable vitalometer recordings, and third, in vitro experimentation on freshly extracted teeth.

The Sorenson Vitalometer (Fig. 1) was used throughout the testing of patients.(20) A more elaborate system incorporating several potentiometers, microampmeters, and a sophisticated variable voltage supply was used in the laboratory. The Sorenson Vitalometer is a small, compact nine-volt battery-operated instrument and offers readings in both voltage and microamps. It produces a rectangular electrical wave with a duration of two milliseconds and frequency of 250 cycles per second. The variable voltage control reads in 10 increments, each increment producing approximately 18 volts for a maximum peak voltage total of 180 volts.

Section I

The indifferent electrode is a copper cylinder measuring 13 mm. in diameter and 8 cm. in length and hand-held by the subject while the stimulating electrode is applied to the incisal edge of the tooth being tested. The stimulating electrode has an insulated handle with a protruding brass tip measuring 2 mm. in diameter. This electrode was tipped with Crest Toothpaste as an electrolyte.

Isolation of each individual tooth was accomplished by placing non-conducting celluloid strips interproximally, displacement of soft tissue by cotton rolls, and drying of tooth structure with an air syringe. Test subjects were instructed to breathe through their noses to control possible surface condensation by moisture in the breath. A thin bead of electrolyte (Crest Toothpaste)* was placed along the entire incisal edge from the mesial incisal angle to the distal incisal angle with the use of a disposable 12 CC Monoject 412 syringe.**

Only maxillary and mandibular anterior teeth which were not moved orthodontically, were tested in this experiment. Teeth were tested prior

* Procter and Gamble, Cincinnati, Ohio 45202.

**Brunswick Laboratories, Post Office Box 880, Deland, Florida.

to banding and approximately one week following band placement. This delay was necessary because it was difficult to introduce the isolation strips between the teeth on the day of banding. The vitalometer was calibrated prior to the testing procedure and three readings were obtained for each tooth. The reading consisted of the voltage and current required to elicit a patient response.

The procedure was explained to the subject with an attempt to maintain a relaxed manner. The patient was seated and given the indifferent electrode which was covered with a wet surgical gauze, to be held firmly in the left hand. All testing apparatus was located out of sight behind the patient. The subjects were asked to respond by uttering a sound when they felt any stimulation. The stimulating electrode was immediately removed after reading the response. All testing was performed by one operator.

Nineteen randomly selected subjects ranging from 11 years and two months to 23 years and four months were tested in this portion of the experiment. A final number of 67 anterior teeth were actually used for statistical analysis. The test subjects (15 females and four males) had been selected as patients by the University of Oregon Dental School, Department of Orthodontics. The number of anterior teeth to be tested varied in each patient as a consequence of the following factors: non-erupted teeth, cuspids involved with retraction prior to banding of crowded anteriors, restorations, endodontic treatment, and adjacent extraction sites. Banded teeth were tested prior to any placement of an arch wire.

Section II

Nine adult subjects, known by the experimentor, were used in this portion of the experiment with an attempt to allay any psychological variable in obtaining successive vitalometer readings. The same testing method was used with these subjects as with the patients in Section I, with the exception of banding, and only maxillary anteriors were tested. The repeat tests were done one week following initial testing.

Section III

Extracted maxillary centrals were used in this portion of the experiment. Requirements for the specimen were that the tooth be freshly extracted, caries and restoration free, completely formed root, and non-obstructed root canal. The teeth were stored in a surgical sponge moistened with physiologic saline.

In preparation for the in vitro experiments, the pulp was extirpated, with endodontic instruments to accept a 15-gauge, $2\frac{1}{2}$-inch length of silver wire. Prior to placement of the wire, alginate impression material, a good electrical conductor, was injected into the pulpal area and the silver wire seated firmly in the canal so that one end was available through the apex of the tooth. A stainless steel orthodontic band was then individualized for the crown and a wire lead soldered to the bracket. The periodontal fibers were scraped from the root surface.

The tooth was mounted by means of alginate in a 3/4-inch diameter by $\frac{1}{2}$-inch length brass ring to which a wire lead was soldered. The tooth was placed so that the alginate covered the root from its apex to the cemento-enamel junction. The brass ring was held by a rubber insulated test tube holder mounted on a ring stand.

The testing apparatus was composed of a Eico voltage regulator (0-400 VDC, 0-150 MA) power source and three microampmeters, each of which had a potentiometer attached. The positive lead of the power source incorporated a copper rod measuring 2 mm. in diameter.

Testing was accomplished so as to determine current readings for a given amount of voltage introduced into any given test circuit. With known voltage and current readings, resistances of each circuit could be calculated. Attempts were made to evaluate the general avenues of current traversing through and possibly down the surface of the crown by affixing leads to different areas of the tooth. One lead went to the root canal, another to the supporting brass ring which represented the periodontal membrane area, another to the incisal edge (positive electrode) and another to the orthodontic band which was cemented to place with Zinc Oxyphosphate cement in the final testing stages.

The freshly extracted tooth was tested as soon as possible following extraction. Upon completion of testing, the specimen was re-tested at intervals of 24 and 48 hours. Between test periods the tooth was kept in a humid atmosphere, but not immersed.

During testing in the laboratory, it was found that use of toothpaste as an electrolyte did not give stable readings and use of a commercial electrode jelly* as the electrolyte resulted in less variation of the tooth-to-electrode contact resistance and then to more stable readings.

The method of statistical analysis for all in vivo experiments was done on matched pairs by means of determination of differences and the use of the student "t" test for final determination of significance at the .05% level of confidence. Correlations between "before" and "after" banding value of current and resistance were also calculated.

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* Cambridge Electrode Jelly, Cambridge Instrument Company, Inc., Grand Central Terminal, New York, New York.

RESULTS

Section 1: The electrical threshold value in terms of voltage and current were determined for 67 maxillary and mandibular anterior teeth; with voltage and current known, the test path resistance could then be calculated. The total number of teeth were divided into eight sub-groups corresponding to anatomical nomenclature. Statistical analysis were performed on before and after banding differences in terms of current and resistance.

Current value results (Table I) indicated that the only group of teeth which offered a statistically significant "t" value at the five percent confidence level was the combined maxillary and mandibular anteriors. The standard deviation of the mean differences varied from 3.99 with the mandibular centrals to 14.94 with mandibular cuspids. The group of maxillary and mandibular anteriors had a standard deviation of 8.08. All "t" test values for each group were of negative sign.

Resistance value results (Table II) show the mean difference for maxillary anteriors to be statistically significant at the five percent level and produced a standard deviation of 2.51. The standard deviation of the mean differences varied from 2.11 with the maxillary centrals to 5.01 with the mandibular laterals. Again, all "t" values were negative in value.

Correlations were run on the before and after banding groups in regard to resistance and amperage (Table V). The current group gave a correlation of .749 and the Null Hypothesis was rejected. The resistance group produced a correlation of .242 and the Null Hypothesis was accepted.

Section 2: Similar statistical testing was accomplished on 49 maxillary anterior teeth of a reliability group of adult subjects. These teeth were further subdivided into three groups according to type of teeth. Matched pairs of data and their differences were calculated in regard to both current and resistance values.

There were no statistical differences between reliability testing of groups in terms of current (Table III). The standard deviation of the differences varied from 1.238 for the maxillary centrals to 3.033 for the maxillary cuspids.

Statistical analysis of the resistance values (Table IV) showed one group, maxillary laterals, to have varied significantly at the five percent confidence level. The standard deviation of the differences varied from 3.63 for the maxillary centrals to 5.61 for the maxillary cuspids, with the standard deviation of the maxillary laterals being 4.53.

Correlations for the reliability group were .86 for current and .271 for resistance (Table V). The current group differed significantly from "0." and the Null Hypothesis was rejected. The resistance group was not significantly different from "0.", therefore the Null Hypothesis was accepted.

Section 3: Although the electrical paths within a tooth are very complex, an attempt was made to extrapolate data from what could be considered major pathways of electrical flow within or on tooth structure. Four basic paths were under consideration in this investigation: (1) a path from the incisal edge, through the enamel and dentin into the pulpal area, and down the root canal (crown-root canal resistance path), (2) the incisal edge and surface of the enamel to the soft tissue (crown-surface resistance path), (3) the pulpal area through dentin to the cementum area of the tooth (pulpal-dentin resistance path), and (4) the crown surface with the influence of an orthodontic band cemented in place.

The crown-pulpal-dentin resistance path as depicted in Figure 1 of Appendix A was 5.0×10^6 ohms as computed through the use of the equation $I = \frac{E}{R}$. The resistance of the crown-root canal was 5.0×10^6 ohms (Fig. 2) and the pulpal-dentin resistance was $.06 \times 10^6$ ohms (Fig. 3).

The electrical configuration in Figure 4 of Appendix A indicates the various resistances when employing all circuits simultaneously. The crown-root canal resistance was 7.14×10^6 ohms, the crown-pulp-dentin resistance was 7.14×10^6 ohms, and the total resistance was 6.25×10^6 ohms. The electrical circuitry involving the orthodontic band is depicted in Figure 5 of Appendix A. The total resistance of the circuit was 5.3×10^6 ohms. The resistance of the crown-root canal path was

5.7×10^6 ohms. When all leads were connected simultaneously with 100 volts, a total of 19 microamps was involved with the circuitry, 17 of which passed through the crown-root canal, and two conducted down the surface of the tooth and through the band material.

A simple test was accomplished in regard to the effect of electrode placement on the crown. Figure 6 of Appendix A shows that resistance increases and current decreases as the electrode was moved from the incisal one-third, to the middle one-third, and then to the gingival one-third of the clinical crown.

DISCUSSION

The primary purpose of this investigation was to determine whether placement of an orthodontic band on a tooth would influence vitalometer readings through alteration of resistance and consequently the current and voltage values. If readings were significantly altered, the reliability of test results would be in question.

Sixty-seven maxillary and mandibular anterior teeth were tested prior to and approximately one week following orthodontic banding. Orthodontic literature suggested that the use of a square wave vitalometer which produced amperage readings would be the instrument of choice in obtaining reliable readings (Mumford, 1963).[16] The Sorenson vitalometer was of a square wave design which incorporated both voltage and current readings and gave a high degree of reliability as demonstrated by Burnside (1972).[20] The stimulating electrode was placed on the incisal edge of the crown as suggested by Mumford (1963)[16] in order to minimize current leakage down the surface of the crown and also to remain free of the orthodontic band. A strip of electrolyte (Crest toothpaste with fluoride) was laid upon the incisal edge to increase the size of the electrode area (Mumford, 1963).[16] In vitro testing demonstrated that toothpaste used as an electrolyte produced variable readings. Electrode jelly such as that used for electrocardiograms was found to be much more reliable. Although the three readings on each tooth tested clinically were relatively constant for any test period, it was felt that there may be the possibility of altered fluid content within the toothpaste over a period of time which in turn would effect the resistance path between the electrode and tooth structure.

A relatively large number of teeth that were tested could not be used for statistical purposes from the standpoint of adjacent extraction influence or the orthodontic band being in contact with gingival tissue. In both situations, a no response reading was obtained on the vitalometer. This supports Nordh's findings regarding the overriding effect of an extraction on adjacent teeth. [13]

The current readings between non-banded and banded teeth had a tendency to increase in values when bands were cemented, as indicated by all negative "t" values in Table VI. During computation of differences, the banded readings, which generally appeared to be higher, were subtracted from the unbanded readings, thus resulting in the negative signed values for mean difference and "t" value results. No statistically significant differences were obtained throughout any of the smaller sub-groups, but the total maxillary and mandibular teeth, consolidated as a single group, did show a statistical difference between banded and unbanded teeth, as would be expected from in vitro testing results. At first glance, the negative "t" values, obtained for the statistical evaluation of resistance values (Table II), might be interpreted as meaning that resistance increases after banding. However, one must consider that the test current, when applied to the tooth, may take at least two pathways: one through the enamel and dentin into the pulp chamber, and the second along the surface of the tooth to the gingival tissue. The patient response is probably dependent only on current flowing through the pulp chamber, and if the presence of the band does reduce the resistance of the surface pathway, as shown in the in vitro studies, a certain amount of current will flow down that pathway, necessitating an increase in amperage to elicit a pulpal response. The result would be that more voltage would be necessary to reach the threshold level within the pulp. Calculation of the resistance from the voltage and current values would then suggest an increased resistance in the test circuit after banding, when, in fact, the opposite is true. By lowering the surface resistance, we increased the relative enamel-dentine-pulp resistance and thus applied more voltage to reach the current values required to obtain pulpal response.

One of the smaller sub-groups offered statistically significant values but this significance was not reflected in the combined maxillary and mandibular anterior group, and its significance remains in doubt at this time.

Correlation values for the before versus after banding groups produced a relatively high correlation for the current testing and allowed rejection of the Null Hypothesis. However, just the opposite was found for the resistance testing. A low correlation was found and the Null Hypothesis was accepted. One would expect a higher correlation in terms of resistance in order to be consistent with the effect of an added constant, the orthodontic band. Theoretically, the resistance of the electrical circuitry of the banded tooth should diminish since the orthodontic band is of much lower resistance material than tooth structure and might be expected to reduce the surface resistance path of the crown surface. One feasible explanation for such a high correlation in the current group and a low correlation of the resistance group would be the much larger variation that is possible in terms of resistance as compared to threshold level current. Response of the dental pulp should be relatively constant with or without the banding of a tooth, with the possibility of slight differences occuring due to the patient's psychological attitude for any particular time and consequent influence upon pain perception. With only a minor portion of the amperage being deflected down the crown surface, as a result of the orthodontic band, total resistance may vary by many hundreds of thousands of ohms in either a negative or positive direction without profound influence upon the ratio of current division through or along the surface of the tooth. The variation in test resistance path may arise from several sources: differences in surface moisture, variation in quality and quantity of the electrolyte used, position of the electrode on the tooth, restorations, length of clinical crown, thickness of enamel and dentin, isolation of the tooth from soft tissue and adjacent teeth, size of electrode area, etc. Recognition of this potential for wide variation in test resistance path emphasizes the advantage of knowing both the amount of voltage applied and the current flow during any electrical vitality test application. If an unusually large (or small) amount of voltage is required to precipitate a pulpal reaction, one may question the validity of that particular test in terms of likelihood that current may be taking different routes throughout the tooth structure rather than the anticipated path directly from the incisal edge to the pulpal area.

The reliability testing of 49 maxillary anterior teeth supported the findings of banded versus non-banded teeth. The statistical computations involving matched pair differences indicated very low "t" values (Table III) and was indicative of reliability when comparing current readings. The resistance findings (Table IV) presented a more varied picture. The total group of maxillary anteriors gave a high but not significant "t" value. The maxillary laterals demonstrated statistically significant differences at the five percent confidence level. The standard deviation for all four groups tended to be higher than those of the current group. This evidence is in support of the clinical variables involved in electric vitality testing.

The correlation coefficient for the current readings, involved with the reliability group, was quite high, yet the resistance correlation was low (Table V). Again, this supports the discussion of range in resistance variation which may be encountered. Considering the testing method to be the same from one week to the next, and the same teeth being re-tested, the most likely variables that would be involved were surface moisture on the crown, patient temperament, ability to obtain repeated measurements on the testing equipment, and amount and quality of electrolyte used. The patient temperament could be ruled out since the current threshold readings were not statistically different. The ability to obtain repeated threshold current measurements is very reliable as demonstrated by Burnside (1972). A strong chance of resistance path variability may stem from the electrolyte (in this case, toothpaste) and how it was applied. It is recommended that another type of electrolyte be considered in future testing.

Several extracted maxillary centrals were used to fabricate the experimental design of the in vitro portion of this investigation. The final test tooth was introduced into the bio-electrical circuitry as outlined in Appendix A. Figure 4 details the two proposed modes by which most of the current passes through the tooth. The total resistance of the entire circuit, when all leads are attached, is 6.25×10^6 ohms, but when either the root canal lead or the brass ring lead is disconnected, the resistance for either circuit is 7.14×10^6 ohms. The only way that total current (both leads connected) can be less than when either one is disconnected, is if the major resistance paths are in parallel (Fig. 4 d). This infers that one major resistance path travels from the incisal edge, through the enamel and dentin to the pulpal tissue, and through the root canal. The second major path would be either down the surface of the clinical crown or perhaps down the dentino-enamel junction. Interconnecting current paths would travel between the two major resistance paths through dentin.

An alternate configuration of current flow could be from the incisal edge, through the enamel and dentin, into the pulpal tissue, and down the root canal. A branching path of current could traverse from the pulpal area and through dentin to the cementum area. But, as Figure 4 (e) indicates, the computed resistance for this configuration is 7.11×10^6 ohms which is greater than the measured total resistance of 6.25×10^6 ohms, or, an impossibility according to electrical physics. We therefore must conclude that the major electrical resistance paths within the tooth structure must be in parallel as depicted in Figure 4 (d).

The influence of the grounded orthodontic band on current flow is outlined in Figure 5, Appendix A. Although the influence of the cemented orthodontic band creates a path of resistance less than that of the enamel surface, the resistance path is still considerably greater than that of the incisal edge to pulpal tissue. The tooth circuit resistance was 5.7×10^6 ohms, where the calculated band circuit resistance was 48.4×10^6 ohms. The crown surface resistance without the presence of the orthodontic band was determined to be 50.14×10^6 ohms (Fig. 4 d). The grounded band therefore decreases the resistance path by approximately two million ohms and bleeds off close to one-fifth of the total current (Fig. 5). This data suggests the possible influence of newly cemented bands on vitalometer readings (i.e., if any portion of the band or connecting arch wire shorts out to soft tissue). Orthodontic bands may draw even more amperage if the cement imbibed fluids or was replaced by saliva or debris.

A simple test which involved placement of the electrode tip on different areas of the tooth (Fig. 6) suggested that as the electrode was placed more gingival, a greater resistance to current flow ensued. For the sake of reliability testing, the electrode tip should be placed on the incisal edge or in the area of the incisal one-third to prevent leakage of current to the supporting tissue.

The extracted tooth was tested 24 and 48 hours after initial testing to determine the possibility of storing dental specimens for future examinations. The tooth was kept in a closed container which maintained a humid stmosphere from enclosed moist gauze. The tooth was not immersed. Testing at both the 24 and 48 hour intervals revealed marked differences from each other as well as from the initial test readings. This potentially important variable should be kept in mind for future in vitro investigation, which may require storage of test specimens.

SUMMARY AND CONCLUSION

The purpose of this investigation was to determine whether the placement of an orthodontic band upon a tooth would significantly affect vitalometer readings and to assess the accuracy and reliability of repeated pulpal threshold measurements.

The study was divided into three sections. The first involved vitalometer testing of 67 maxillary and mandibular incisors of orthodontic patients prior to and following placement of orthodontic bands. The second portion was concerned with reliability; a group of adult subjects in whom 49 maxillary incisors were tested on two different occasions with a week's interval between measurements. The third area under investigation, was an in vitro study using extracted maxillary centrals to determine general avenues of electrical resistance paths within tooth structure and to determine whether current and resistance deviations could be noted under laboratory conditions.

Statistical analysis was performed with the use of student "t" tests and correlations in regard to both amperage readings and resistance computations.

The following conclusions may be drawn from this study:

1) In vitro results indicated that placement of a cemented orthodontic band altered the resistance path of the clinical crown surface enough to cause current leakage to the soft tissue structures.

2) Clinical testing of banded versus non-banded teeth on a matched pair basis indicated (a) statistically significant differences between current readings, and (b) low correlation and generally non-significant statistical results for resistance figures.

3) Reliability testing of maxillary anterior teeth displayed very little statistical variation for current readings from one test period to the next. Resistance figures were much more variable.

4) The overall impression was that minor current leakage does occur as a result of the orthodontic band, but that clinical variables such as electrode placement, type of electrolyte used, moisture condensation, and the general anatomy of the tooth, all of which effect resistance paths

significantly, were a more important consideration.

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TABLE I

MATCHED PAIRED DIFFERENCES FOR MICRO-AMPS BEFORE AND AFTER BANDING

	N	$\bar{D}$	S^2	S	two tail t	5% table	significance
Max. and mand. anteriors	67	-2.226	65.410	8.088	-2.253	2.0	*
Max. anteriors	26	-1.616	44.957	6.705	-1.226	2.06	
Mand. anteriors	41	-2.616	79.428	8.912	-1.879	2.02	
Max. centrals	14	- .836	30.686	5.540	- .565	2.16	
Max. laterals	10	-2.170	77.380	8.797	- .780	2.26	
Max. cuspids	2	-	-	-	-	-	
Mand. centrals	20	- .743	15.909	3.989	- .833	2.09	
Mand. laterals	14	-1.443	79.290	8.905	- .606	2.16	
Mand. cuspids	7	-10.314	223.292	14.943	-1.826	2.45	

TABLE II

MATCHED PAIRED DIFFERENCES FOR RESISTANCE BEFORE AND AFTER BANDING

	N	$\bar{D}$	S^2	S	two tail t	5% table	signif- icance
Max. and mand. anteriors	67	.485	12.403	3.522	-1.127	2.0	
Max. anteriors	26	-1.154	6.30	2.510	-2.343	2.06	*
Mand. anteriors	41	.061	16.052	4.007	- .097	2.02	
Max. centrals	14	- .679	4.437	2.106	-1.205	2.16	
Max. laterals	10	-1.80	9.594	3.097	-1.838	2.26	
Max. cuspids	2	-	-	-	-	-	
Mand. centrals	20	- .163	8.975	2.996	- .243	2.09	
Mand. laterals	14.0	- .304	25.117	5.012	- .227	2.16	
Mand. cuspids	7	.714	23.301	4.83	- .391	2.45	

TABLE III

MATCHED PAIRED DIFFERENCES FOR MICRO-AMPS RELIABILITY GROUP

	N	$\bar{D}$	S^2	S	T	two tail table	Significance
Max. anteriors	49	-.031	4.052	2.013	-.106	1.67	
Max. centrals	17	.205	1.533	1.238	.686	2.12	
Max. laterals	16	-.281	1.999	1.414	-.796	2.13	
Max. cuspids	16	-.031	9.201	3.033	-.041	2.13	

TABLE IV

MATCHED PAIRED DIFFERENCES FOR RESISTANCE RELIABILITY GROUP

	N	$\bar{D}$	S^2	S	T	two tail table	Significance
Max. anteriors	49	1.005	22.285	4.721	1.490	2.0	
Max. centrals	17	.1176	13.149	3.626	-.1336	2.12	
Max. laterals	16	2.813	20.529	4.531	2.483	2.13	*
Max. cuspids	16	.391	31.44	5.607	.2786	2.13	

TABLE V

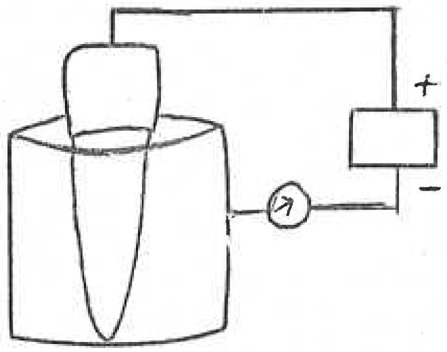
CORRELATION

	MA	Null Hyp.	Resistance	Null Hyp.
Before and after banding	0.749	Reject	.242	Accept
Reliability	0.86	Reject	.2714	Accept

APPENDIX A

Figure 1

CROWN PULPAL DENTIN RESISTANCE PATH

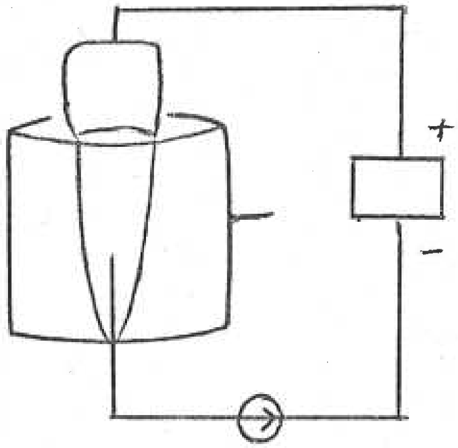


MA = 20

V = 100 $R = 5 \times 10^6$

Figure 2

CROWN-ROOT CANAL RESISTANCE PATH

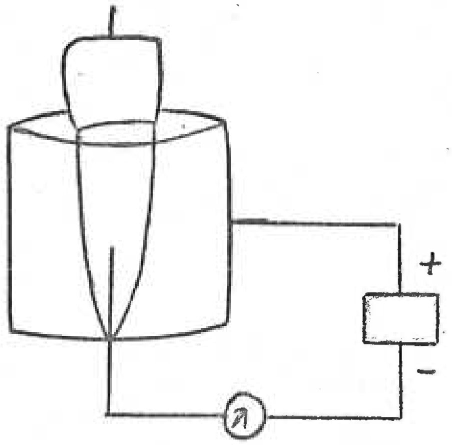


MA = 20

V = 100 $R = 5 \times 10^6$

Figure 3

DENTIN-ROOT CANAL RESISTANCE PATH



MA = Microamps.

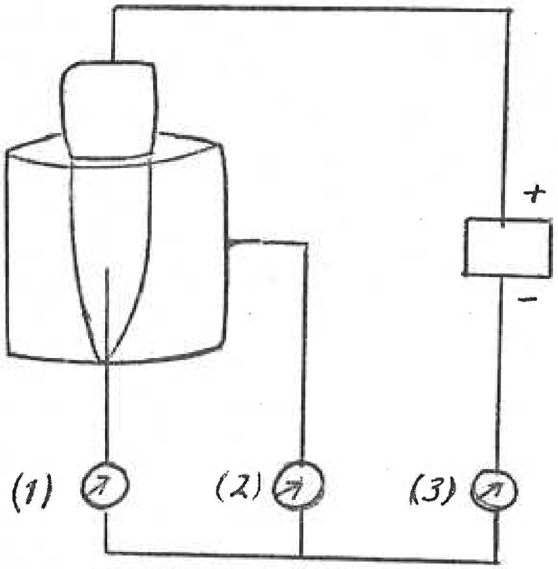
V = Volts

R = Resistance in ohms

MA = 50 V = 3 $R = .06 \times 10^6$

Figure 4

ELECTRICAL CONFIGURATION DEPICTING MAJOR RESISTANCE PATHS WITHIN THE TOOTH



(a) WITH LEAD 2 DISCONNECTED

Meter 1
MA = 14
V = 100
R = 7.14×10^{6}

Meter 3
MA = 14
V = 100
R = 7.14×10^{6}

(b) WITH LEAD 1 DISCONNECTED

Meter 2
MA = 14
V = 100
R = 7.14×10^{6}

Meter 3
MA = 14
V = 100
R = 7.14×10^{6}

(c) WITH ALL LEADS CONNECTED

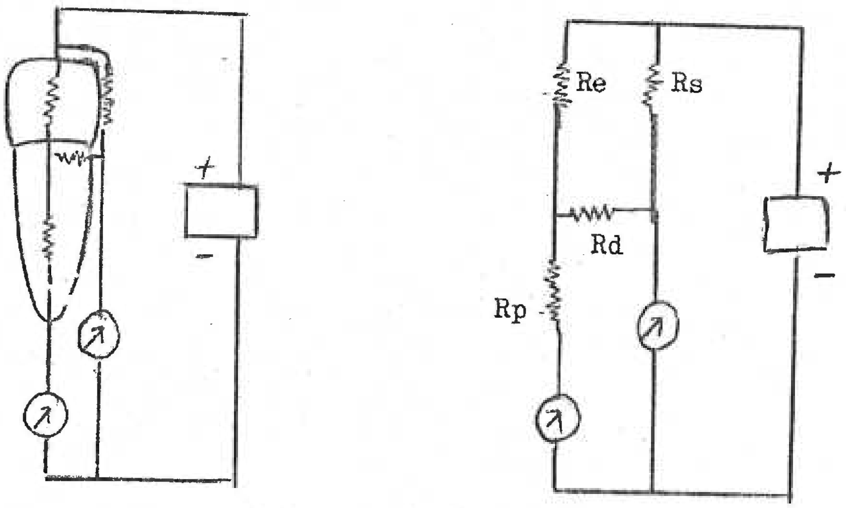
Meter 1
MA = 8
V = 100

Meter 2
MA = 8
V = 100

Meter 3
MA = 16
V = 100
R = 6.25×10^{6} (total resistance)

Figure 4 (Continued)

(d) RESISTANCE PATHS IN PARALLEL



Re = Crown resistance

Rd = Dentin resistance

Rp = Pulpal resistance

Rs = Crown surface resistance

Rp + Rd are small $\therefore$ disregard

$$\frac{1}{R_T} = \frac{1}{R_e} + \frac{1}{R_s}$$

$$R_T = \frac{ReRs}{Re+Rs} = 6.25 \text{ (Meter 3)}$$

Re = 7.14 (Meter 2)

$$\therefore \quad 6.25 = \frac{7.14 \text{ (Rs)}}{7.14+\text{(Rs)}}$$

(7.14 + Rs) 6.25 = 7.14 (Rs)

44.625 + 6.25 Rs = 7.14 Rs

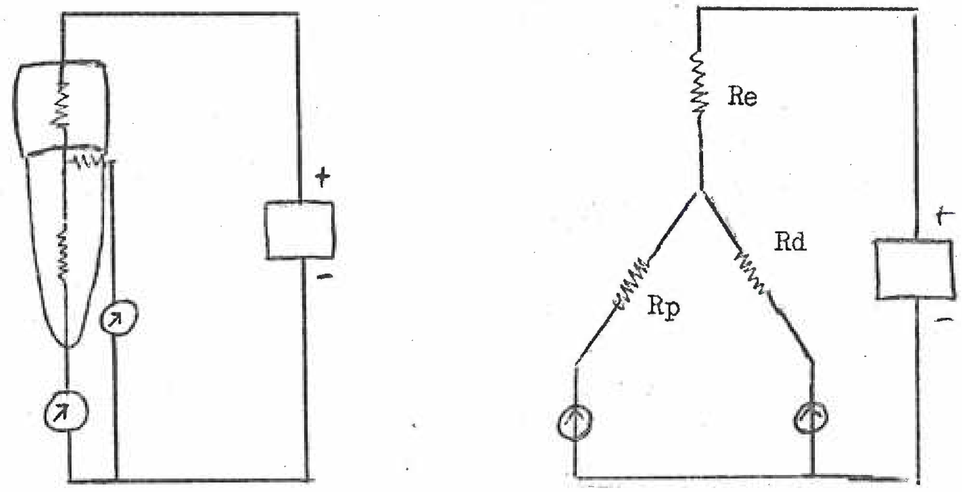
44.625 = .89 Rs

$$Rs = \frac{44.625}{.89}$$

$Rs = 50.14 \times 10^6$
(Crown surface resistance)

Figure 4 (Continued)

(e) ALTERNATE CONFIGURATION WITH
RESISTANCE PATHS IN SERIES



$$\left.\begin{array}{l} Re + Rp = 7.14 \times 10^6 \\ Re + Rd = 7.14 \times 10^6 \end{array}\right) \text{ from Figure 4 (a) and (b)}$$

$$Rp + Rd = .06 \times 10^6 \quad \text{from Figure 2}$$

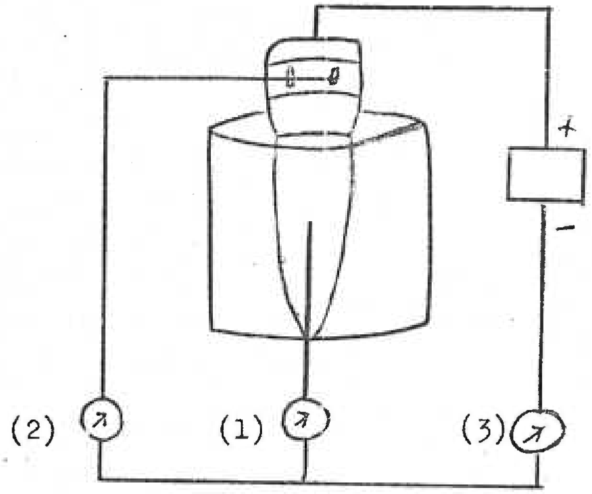
Rp   Rd

$$\therefore\ Rp \simeq .03 \times 10^6 + Rd \simeq .03 \times 10^6 \quad \therefore\ Re = 7.11 \times 10^6$$

$$\text{but } Re + \frac{Rp \cdot Rd}{Rp + Rd} = 6.25 \text{ from 4 (c)}$$

Figure 5

RESISTANCE PATHS WITH ORTHODONTIC BAND CEMENTED



(a) WITH 1 DISCONNECTED; 2 CONNECTED

<u>Meter 2</u>
MA = 17.6
V = 5.6×10^6

<u>Meter 3</u>
MA = 18
V = 100

(b) ALL 3 LEADS CONNECTED

<u>Meter 1</u>
MA = 17
V = 100

<u>Meter 2</u>
MA = 2
V = 100

<u>Meter 3</u>
MA = 19
V = 100
R = 5.3×10^6
(total resistance)

(c) WITH 2 DISCONNECTED; 1 CONNECTED

<u>Meter 1</u>
MA = 17.5
V = 100

<u>Meter 3</u>
MA = 17.5
V = 100
R = 5.7×10^6
(tooth circuit resistance)

Figure 5 (Continued)

WITH ALL 3 LEADS HOOKED UP

Total resistance = $\frac{100}{19}$ = 5.3×10^6

R in tooth circuit = 5.7×10^6 (Meter 3)

$\therefore$ Current is dividing 2 to 17 or a ratio of 1:8.5

Resistance is $\therefore$ 8.5 x's greater than tooth circuit
$8.5 \times (5.7 \times 10^6) = 48.4 \times 10^6$

$\therefore$ tooth circuit resistance = 5.7×10^6

band circuit resistance = 48.4×10^6

When measuring meter differences on #1 during connecting and disconnecting lead #2, the value difference for the band circuit flow was about 4 micro amps.

THUS (1) Current ratio = 4:17.5 or 1:4.4
$4.4 \times 5.7 \times 10^6 = 25.1 \times 10^6$

(2) Tooth circuit resistance = 5.7×10^6
Band circuit resistance = 25.1×10^6

Selecting a mid point value, assume a 3 micro amp value

(mid point between 2:17 and 4:17.5) flowing in band circuit

then current ratio = 3:17.5 or 1:5.8

$5.8 \times (5.7 \times 10^6) = 33.1 \times 10^6$

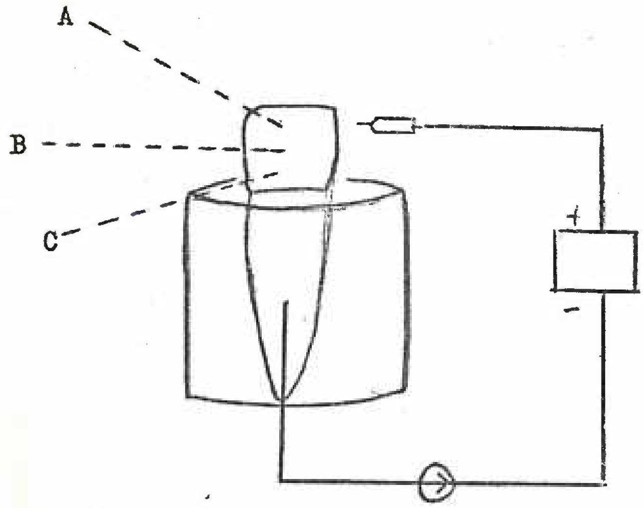
tooth circuit resistance = 5.7×10^6

band circuit resistance = 33.1×10^6

Figure 6

VARIATION IN RESISTANCE WITH

WITH ALTERED ELECTRODE PLACEMENT



"A" incisal 1/3 = MA = 28
V = 100
R = 3.57×10^6

"B" mid 1/3 = MA = 24
V = 100
R = 4.17×10^6

"C" gingival 1/3= MA = 14
V = 100
R = 7.14×10^6

Figure 1
Sorenson Electric Stimulator