EVALUATION OF THE RECOVERY OF THE ELECTRIC SENSIBILITY OF TEETH FOLLOWING ORTHODONTIC TREATMENT

by

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INTRODUCTION

Diagnosis of the state of health of the dental pulpal tissues is a topic of considerable concern to general practitioners, and to dental specialists such as endodontists, oral surgeons, pedodontists, and prosthodontists.

It is fair to state that orthodontists have in the main not been especially concerned with this subject, since the apparent non-damage to orthodontically treated teeth, in which, as Oppenheim (1935)[5] noted, pulps without exception react pathologically, has been patently obvious to generations of experienced clinical observers. Reports in the orthodontic literature discussing pulpal sequelae with respect to multi-banded appliance therapy are consequently sparse.

A general belief still persists that dental pulp vitality can be estimated from the response to stimulation by electric current, despite many and well-documented reports to the contrary, and as such stimulation is in widespread use in dental offices, it is not difficult to see that a negative response to such a test might be interpreted as being indicative of non-vitality.

Endodontic therapy may be instituted on teeth recently debanded following orthodontic treatment, that in fact may be quite vital, as a result of a misunderstanding about the significance of such a diagnosis at that time.

Recent work by Burnside (1972)[39] confirming much earlier studies, indicated a very definite tendency for groups of orthodontically treated teeth to have a raised threshold of sensitivity to electric stimulus, almost as if anaesthetized, and it was for the purpose of examining just how long this level of sensitivity lasted and how severe the effect is, that the present investigation was begun.

Using an instrument with improved reliability, the sensitivity of the same teeth and groups of teeth were compared just prior to debanding following orthodontic treatment, and 60 days later.

REVIEW OF LITERATURE

Classic experimental treatises investigating biologic problems associated with orthodontic treatment were inevitably histologic studies, and the works of Sandstedt (1905)[7] (although not recognized for some years) and Oppenheim (1911)[7] were excellent examples, and in the latter case regarded as law for many years. Damage to the pulp as observed histologically formed part of the basis for Oppenheim (1935)[5] protesting that "no orthodontic therapy can be biologic." Schwarz (1932)[3] pointed out that damage occurred to the pulp as a result of excessive force, and while Orban (1936)[7] proclaimed that "pulpal injuries resulting from orthodontic procedures are exceptional--and associated with special anatomic conditions at the root apex," this was really part of a running feud with Oppenheim concerned with experimental methodology--Should animal tissue experiments be compared with human tissue? Stuteville (1937)[8] noted that the character of the pulp is such that there is not much resistance to injury, but that very few teeth become gangrenous during the course of orthodontic treatment, and in cases where pulp degeneration was demonstrated (histologically) there had been a history of trauma. It is quite apparent that there was a wide range of opinion as to the exact fate of the pulp, since histologic evidence could not be denied, yet clinically there were no alarming symptoms of pulp degeneration. The search for a clinically useful and reliable means of diagnosis was already under way although thermal excitation, percussion, transillumination, and radiographs had all been used in conjunction with thorough history taking and clinical examination. Stimulation of the dental pulp with an electric current has been used for over a century as a diagnostic aid, the Frenchman Magitot (1867)[2] using it to locate dental caries. Marshall (1891),[2] Woodward (1896)[2] also experimented with primitive "pulp testers," and at the turn of the century Fuyt,[4] Frohman,[4] Schroeder,[4] and Hafner[4] and later Machat[1] were busily engaged in research, with Frohman coining the term "threshold of irritability." It was obvious that many people were looking for the electric pulp tester to be the diagnostic panacea, yet repeatedly the sound investigators documented their evidence carefully and refused to make any more than the most cautiously worded conclusions. Reiss and Furedi (1933)[4] noted the important principle of the existence of variation, not only from person to person but also variation within an individual.

Kaletsky and Furedi (1935)[6] commented that "in 30 years there has been no apparent progress in the field of pulp testing," but their study did include teeth undergoing orthodontic treatment, although they stated that Schroder (1907) had used the pulp tester to "determine the condition of the pulp in forced regulation of the teeth."

Further principles relating to the problems of pulp testing were outlined by Ziskin and Wald (1938),[9] who stressed the critical nature of their technique, and that current readings in microamps were a more reliable index of nerve tissue irritability than voltage recordings. Ziskin and Zegaielly (1945)[10] were also made aware of the problems inherent with individual variation.

It was really Markus (1946)[11] who first pointed out that "clinically, pulpal changes resulting from orthodontic treatment had received little attention," and by means of stimulation with electric current he detected that teeth subject to pressure had a lowered threshold of stimulation indicating pulpal irritability. This was an incorrect conclusion based on voltage rather than microamp readings, but he did draw attention to the merits of such stimulation in that it could aid in diagnosis prior to orthodontic treatment, and the subsequent effects on the pulp of such treatment could be examined clinically. Bjorn's (1946)[12] study produced a large amount of material that added to the knowledge gained by previous investigators with specific reference to electrode positioning, type of current, and technique precision, and it is from his stimulator that many others were developed, and adapted for use in a variety of differing research areas. Electric stimulation of teeth to investigate effect of local dental anaesthetic agents was used by Huldt (1953),[19] Berling (1958),[21] Feldman and Nordenram (1959);[22] while Martensson (1950),[13] Bjorlin (1953),[18] and Johnson and Hinds (1969)[32] evaluated tooth sensitivity following oral surgical procedures.

Wide variation in both diameter and number of nerve fibers were found by Graf and Bjorlin (1951)[15] which went a long way to providing a physiological explanation of differing responses of an individual, as commented upon by Harris (1950).[14]

Investigations at this time by Butcher and Taylor (1951)[16] (1952)[17] because "orthodontists seemed uncertain if a tooth pulp could be strangulated--," were carried out with animals to observe the "effects of denervation and ischaemia upon the teeth," and such teeth were not only found to develop a normal structure without a nerve supply, but that force as applied by orthodontists would not be sufficient to "strangle the vascularity of the pulp."

Such histologic observations did not inhibit the use of the electric pulp tester, and in fact Nordh (1955)[20] carried out the first full study with orthodontically treated teeth that had a sound statistical basis, as well as a clearly defined purpose. Nordh used a stimulator almost identical to that developed by Bjorn (1946),[12] and he concluded that (1) placement of an orthodontic band did not change the pain threshold of the tooth, (2) teeth adjacent to an extraction site showed decreased sensitivity to pain temporarily, and (3) sensitivity was temporarily obliterated in some cases where the tooth movement had been unusual.

Nordh advised that a tooth may not respond to electrical stimulation yet still be vital, as did Martensson (1950)[13] and also pointed out the value of stimulation as a diagnostic aid prior to treatment in order to screen out non-vital teeth.

Mumford (1959)[23] began his great contributions to the literature in this area by examining the path of direct current through extracted teeth, concluding that the current density is greatest where the current path is narrowest, at the pulpo-dentinal junction and in the pulp canal, and later in (1959)[24] using two electrodes arrived at the same conclusion.

Mumford (1960)[25] examined the problems inherent in electric pulp testing with respect to reproducibility and discrimination. He found that the incisal edge was the best place to test a tooth, and further that the stimulator that they were using did not produce a square wave at maximum output, an undesirable feature.

Mumford and Bjorn (1962)[27] outlined clearly the requirements for electric pulp testing as (a) an adequate stimulus should be delivered, (b) an adequate technique of application, and (c) a careful interpretation of the results. They gave the reasons for electric stimulation as being for tooth involved conditions, and study of pain perception generally, tooth sensation specifically. They further discussed the physiological basis for such testing, by defining threshold stimulus as a measure of tissue excitability, that current density depended on the size of the electrical conductivity of tissues, and pointed out again that the difficulty in recording voltage is that it was really a measure of resistance rather than tissue excitability. Mumford (1963)[28] tested 180 anterior teeth to determine their pain threshold but although strongly advising the use of rubber dam isolation, his values were too small to be of clinical value. Difficulties measuring and interpreting current were also discussed. Mumford (1965)[29] revised his method of testing by increasing the area of the electrode tip and an increased stimulus, so that a wider range of values were found, indicating that there were no differences in threshold value attributable to either sex or age. Elomaa (1968)[28] also found no difference in threshold values with regard to sex, but that it decreased with advancing age. Mumford noted difficulties in interpretation of results, and that the subject clearly understand at what level of sensation he is expected to respond, i.e., the first sensation is tingling, with pain following. Further, not only will a person's physical or psychological state influence their response to a painful stimulus, but also the intensity of the stimulus is related to excitability and conduction of nerve tissue. Cahn (1930)[29] showed nerve fibers even in totally degenerated areas.

Mumford (1967)[31] examined the resistivity of human enamel and dentine finding values comparable to those of Bjorn (1946),[12] and Mumford (1971)[35] examined the electric sensitivity of retained primary teeth, finding that the zone of excitation was more likely to be at or near the pulpo-dentinal junction, not within the pulp "since in many cases the roots were partly or completely resorbed." .

Reymolds (1966)[30] discussed determination of pulp vitality by means of thermal and electric stimuli concluding that the combination of both stimuli in the same machine was of no value.

Selzer (1971)[36] summarized the state of pulp testing procedures, by saying that in his opinion electric stimulators were not reliable, that a possible future lay with ultrasonics, and noting the work of Howell (1970)[34] with liquid thermographic crystals. Burrill (1962)[26] also described a method of pulp testing by determination of fusion frequency, but found it was not clinically useful.

Chilton (1972)[37] tested the sensitivity of 144 teeth and found no difference in sides tested, and that surface differences on both sides were the same.

Since Nordh (1955),[20] the only study involved with orthodontic treatment has been that of Burnside (1972),[39] who examined 201 anterior teeth for differences in sensitivity to electric stimulus, and found that orthodontically treated teeth did have a higher electrical threshold than non-treated controls.

MATERIALS AND METHODS

This investigation was carried out with the cooperation of patients of the Department of Orthodontics, University of Oregon Dental School, Portland, Oregon. They were selected at random from patients with orthodontic appliances that were due to be removed following treatment, and included 17 persons, 4 males and 13 females ranging in age from 12 to 20 years of age. A total of 165 anterior teeth were tested, 98 maxillary and 67 mandibular teeth, all banded with stainless steel metal bands and .022 conventional Edgewise brackets, yet all differing with respect to the length of treatment and type of tooth movement they had undergone.

Before testing was begun, a specific addition to the medical history included questioning patients regarding the presence of an electrical pacemaker in their hearts was made, since the effects of such electric current as we were providing on a pacemaker are quite unknown.

Determination of the degree of sensitivity to electrical excitation was carried out with the aid of a stimulator designed by Fred M. Sorenson of the University of Oregon Dental School, an improved model of that previously used by Burnside (1972).[39] (Fig. 2)

A single 9-volt battery provided the source of power, and with impulse frequency matintained at approximately 250/sec., short direct impulses with a rectangular wavefront and lasting approximately 2.0 milli/secs., were delivered with an intensity range of 0-180 volts and the current flow monitored with a microampmeter.

Studies of Bjorn (1946),[12] Nordh (1955),[20] Mumford (1965)[29] and Burnside (1972)[39] provided a background for the method used, with further refinements being made as described. The stimulating electrode, wired as a cathode was a metal tip 3 sq. mm. in area and with a shallow groove insulated with a plastic handle, and the passive electrode was a 3" x ¼" copper cylinder clutched firmly in the patient's palm and wrapped in moist gauze, while a potentiometer with scaled divisions regulated the current [voltage] applied, and could be calibrated with the resultant microamperes on a meter (see Fig. 1). Most patients were apprehensive when the testing began, despite time spent explaining the purpose of the study and attempting to allay their fears. Each tooth was carefully isolated with heavy rubber dam, dental floss being used interproximally to ensure even further a saliva-free area; and then carefully dried with an air stream. The electrode tip was dipped in toothpaste sufficient to cover it, and placed on the centre of the incisal edge using the shallow groove in the tip as an aid in contact and the current switched on. Very slowly the current intensity was increased by the potentiometer until patient reaction indicated sensitivity, so that the electrode was promptly removed and potentiometer scale and microampere readings noted out of sight of the patient. Now that the patient knew what to expect for that tooth, the procedure was repeated and readings made again, according to the now much less apprehensive patient who could better describe just what sensation it was that they were feeling. The routine was repeated again with the patient understanding that a prompt signal either by hand or voice would tell the operator that the same sensation had returned, and when after three or four successively similar values of microamps were obtained, the dam was removed and a new tooth tested.

Burnside (1972)[39] described advantages of this technique in that it not only enabled a single operator to perform the test and so established a good rapport, but also that all readings could be seen by the operator out of sight of the patient.

Teeth that gave widely varying responses or responses that indicated either a by-passing of the current through a secondary circuit of band material or saliva were not included in the investigation.

Radiographs had been taken of all the teeth involved in the orthodontic treatment, and further radiographs were taken on those teeth that either elicited no response after 60 days, or indicated a markedly raised threshold of sensitivity to stimulation.

The data were analyzed statistically by means of "t" tests, Poisson distribution and the Chi Square distribution. Reliability of the stimulator has been discussed previously by Burnside,[39] who had a Standard Error of Measure of 0.91 μ amps, and is further reported on by Urban (1973)[40] elsewhere.

RESULTS

Out of 165 anterior maxillary and mandibular teeth tested, 140 gave a response measurable as current in microamps. The results of these responses were analyzed statistically by means of the student "t" test and presented in Tables I-IV.

TABLE I		Before	After	S^2p	sp	t
	N	140	140			
Total Teeth	$\bar{X}$	17.46	13.99	42.01	6.48	4.48*
	S^2	55.46	28.56			
	S	7.45	5.34			

TABLE II						
	N	77	77			
Maxillary Teeth	$\bar{X}$	19.53	15.38	41.33	6.43	4.01 *
	S^2	52.49	30.16			
	S	7.25	5.49			

TABLE III		Before	After	S^2p	sp	t
	N	63	63			
Mandibular Teeth	$\bar{X}$	14.92	12.29	42.85	6.55	2.26*
	S^2	59.11	26.60			
	S	7.69	5.16			
TABLE IV	N	19	19			
Maxillary Cuspids	$\bar{X}$	22.79	17.37	36.71	6.06	2.76*
	S^2	35.84	37.58			
	S	5.99	6.13			
Maxillary Laterals	N	27	27			
	$\bar{X}$	21.63	16.56	43.71	6.61	2.82*
	S^2	66.55	20.87			
	S	8.16	4.57			
Maxillary Centrals	N	31	31			
	$\bar{X}$	15.71	13.13	27.40	5.23	1.94*
	S^2	28.01	26.78			
	S	5.29	5.18			
Mandibular Cuspids	N	16	16			
	$\bar{X}$	23	16.81	36.55	6.05	2.90*
	S^2	61.87	11.23			
	S	7.87	3.35			

TABLE IV (Continued)		Before	After	S^2p	sp	t
	N	24	24			
Mandibular Laterals	$\overline{X}$	14.5	12.46	27.39	5.23	1.35
	S^2	31.04	23.74			
	S	5.57	4.87			
Mandibular Centrals	N	23	23			
	$\overline{X}$	9.74	8.96	16.10	4.01	0.66
	S^2	16.20	15.95			
	S	4.03	3.99			

The "t" tests were one-tailed and * indicated significance at the 0.05% level. Of the remaining 25 teeth, 21 were maxillary and four mandibular teeth, and results of testing were as in Table V.

TABLE V		Before	After	
	(a)	No response	Response	12
		No response	No response	10
		Response	No response	3
	(b)	No response	Before: 22	After: 13

These teeth were analyzed by Poisson distribution by considering each arch in a patient and Chi Square was employed as follows in Tables VI-VII.

TABLE VI — Before

No response	0	1	2	3	4	5
Observed	15	9	4	0	0	1
Expected	17.75	11.53	7.51	4.86	3.16	2.07

$X^2 = 11.2^*$ with 4 df, significant at the .05% level

TABLE VII — After

No response	0	1	2	3	4	5
Observed	19	8	1	1	0	0
Expected	23.26	8.84	1.7	0.44	0.14	0.03

$X^2 = 2.03$ with 4 df, NOT significant at the .05% level

DISCUSSION

As the primary purpose of this study was to evaluate the recovery of electric sensibility of orthodontically treated teeth, it should be stated that the results of the testing indicated a very definite tendency for such a recovery after 60 days.

Of the total 165 teeth tested, 140 gave a response to stimulation both prior to removal of the stainless steel orthodontic bands and 60 days later, and the differences indicated a statistically significant return of electric sensitivity in this group (see Table I).

Both maxillary and mandibular teeth when statistically analyzed arch by arch also showed significant recovery (see Table II and III), and the same was true when each tooth group was analyzed individually with the exception of the mandibular central and lateral incisors (Table IV). Teeth were stimulated just prior to band removal, properly isolated and dried according to the method described, since it was felt on the basis of Nordh's findings, that the presence of the orthodontic band would not affect the prior threshold by drawing off current and influencing the current readings.[20] Results indicated a wide range of responses, as noted by other investigators in this area,[20,27,39] not only due to individual variation, but also because different tooth groups had clearly undergone widely varying movements, e.g., retraction of cuspids as opposed to rotations of lateral incisors, and some teeth had been subject to treatment for a much longer time than others. It was felt that testing the teeth 60 days after band removal procedures would allow sufficient time for tooth spatial positions to stabilize, a situation that is observed clinically, although in all cases a Hawley retainer was worn by the patient in the maxillary arch, and a lower cuspid to cuspid retainer cemented into place in most mandibular arches. The finality of tooth position during retention is debateable, but essentially the amount of current required to stimulate the teeth 60 days after band removal was significantly less, and just how much more recovery in sensitivity would have occurred we are unable to ascertain.

The remaining 25 teeth were analyzed separately out of the total of

165, that gave no response to stimulation, either before debanding or 60 days later. It is the occurence of these non-responsive teeth both at the completion of orthodontic treatment and 60 days later in the retention period that is of prime importance to clinicians. This apparent anaesthetic effect was noted by Nordh,[20] especially in connection with teeth adjacent to extraction sites in the early stages of orthodontic treatment, and Table V (b) shows that 22 out of 165 teeth gave no response just prior to debanding - 13.3%. After 60 days, 13 out of 165 gave no response to stimulation - 7.8%.

As observed by Nordh,[20] and Martensson,[13] the lack of a response to stimulation does not indicate non-vitality and, in fact, Table V (a) shows that 12 teeth exhibiting no response at time of banding altered to show a response. This followed the trend of the 140 teeth that did show responses, toward a recovery of electric sensibility. However, 10 teeth still remained non-responsive to stimulation after 60 days, and it was these teeth that engaged special diagnostic attention. One maxillary lateral incisor, for example, proved to be in the centre of a cleft--apparently quite vital since there was no discernible pathology radiographically--a fact which also applied to the other teeth in this group. It is reasonable to assume that these teeth will recover their sensitivity to electric stimulation, but perhaps a period of time longer than 60 days is needed for this group of teeth to be tested in order to obtain a response.

More difficult to discuss was the fact that three teeth showing a response just prior to debanding became non-responsive after 60 days, although they were all maxillary cuspids and possibly subject to further movement or pressure caused either by natural space closure, the retention appliance, or the "settling in" of a functional occlusion.

The statistical analysis of these 25 teeth was carried out by utilizing a Poisson distribution, and employing the Chi Square Test as in Tables VI-VII, the number of non-responsive teeth was significantly different to that which would be expected to occur by chance alone in the before group of non-responsive teeth. Clearly the presence and persistence of teeth showing no response to stimulation of this kind is well demonstrated, and the trend of a recovery in sensitivity observed.

The reliability of the stimulator is extremely high as reported by Burnside,[39] further discussed by Urban,[40] with a Standard Error of the Measure of approximately one microamp. Modifications from the model used by Burnside[39] were aimed to improve the reliability and these included using a single 9-volt battery, a more precise impulse frequency range of approximately 250-260/ sec., and an improved design of tooth electrode.

Patient reliability is open to question at all times as noted by Harris[14] and Mumford,[27] but a substantial effort was made to eliminate as many variables as possible by standardization and explanations of procedures, and the one to one doctor-patient relationship helped. The technique described was carefully followed, but questions were raised as to the suitability and reliability of the electrolyte. In this investigation it was Crest toothpaste with fluoride. Martin, et al. (1969)[33] suggested that the ideal medium for use in tests of this kind should be a water-based jelly--a material that will not dry out easily (as did the toothpaste), remain where it was placed, and because of the high dielectric constant provide an excellent interface between tooth surfaces and electrode.

The use of direct current with a rectangular wavefront is well-documented by Bjorn,[12] Mumford,[27] Nordh[20] and Burnside,[39] so that nerve tissue excitability is tested and examined more reliably by current readings rather than the voltage required, and continued criticism should be leveled at those machines that do use voltage readings.

Results were not divided according to sex, since Mumford (1963)[28] showed no significant difference between anterior teeth of the sexes, and similarly teeth groups of opposite sides were pooled for the same reasons as Mumford (1963)[28] and Chilton (1972)[37] demonstrated.

SUMMARY

The purpose of this investigation was to evaluate the recovery in electric sensitivity of orthodontically treated teeth at the end of a period 60 days after band removal.

1. A recommendation was made that patients whose teeth are likely to be subjected to electric stimulation should be excluded if their medical history reveals the presence of an electrical pacemaker in their hearts.

2. A statistically significant recovery in sensitivity to electric stimulation for all teeth, and all tooth groups except mandibular central and lateral incisors, was found from the time of orthodontic debanding until 60 days later.

3. Not only did a high percentage (13.3%) of teeth appear completely anaesthetized at the time of debanding, but approximately half of these demonstrated a recovery in electric sensibility after 60 days, while the remainder continued to show no response.

4. The method and technique described will yield reliable and informative data on the basis of current (not voltage) readings.

5. A tooth non-responsive to electric stimulation after completing orthodontic treatment, or 60 days later, should not be considered non-vital, as the trend for recovery of electric sensibility was demonstrated.

CONCLUSIONS

When testing of this nature is carried out, the words of Mumford and Bjorn (1962)[27] hold true that an adequate stimulus should be delivered, an adequate technique should be used, and that a careful interpretation made of the results. Further, electrical stimulation should not be carried out on patients with electrical pacemakers in their hearts.

The mistake should not be made of confusing non-vitality with non-response to electric stimulation of teeth recently treated with orthodontic appliances, and as noted by King (1972),[38] electric stimulation is not a diagnostic aid by itself where pulpal involvement is to be considered. A significant recovery in electric sensitivity following band removal after orthodontic treatment and 60 days later has been denonstrated but it is not known how much longer or to what degree this trend would continue.

BIBLIOGRAPHY

1. Machat, B.: Dental electro-diagnosis. Dental Cosmos 61:123, 1919.

2. Prinz, H.: Diseases of the dental pulp. Dental Cosmos 61:312, 1919.

3. Schwarz, A.M.: Tissue changes incidental to orthodontic tooth movement. Int. Journal Ortho. 18:331, 1932.

4. Reiss, H.C. and Furedi, A.: Significance of the pulp test as revealed in a microscopic study of the pulps of 130 teeth. Dental Cosmos 75:272, 1933.

5. Oppenheim, A.: Biologic orthodontic therapy and reality. Angle Orthodontist 5:159, 1935.

6. Kaletsky, T. and Furedi, A.: Reliability of various types of pulp testers as a diagnostic aid. J.A.D.A. 22:1559, 1935.

7. Orban, B.: Biologic problems in orthodontia. J.A.D.A. 23:1849, 1936.

8. Stuteville, O.H.: Injuries to the teeth and supporting structures caused by various orthodontic appliances and methods of preventing these injuries. J.A.D.A. 24:1494, 1937.

9. Ziskin, D. and Wald, A.: Observation on electrical pulp testing. J.D.R. 17:79, 1938.

10. Ziskin, D. and Zegailly, A.: The pulp testing problem: the stimulus threshold of the dental pulp and the peridental membrane as indicated by electrical means. J.A.D.A. 32:21, 1945.

11. Markus, M.B.: The reaction of pulp to pressure. A.J.O. 32:682, 1946.

12. Bjorn, H.: Electrical excitation of teeth and its application to dentistry. Svensk. Tandlak. Tidskr. 39 Suppl., 1946.

13. Martensson, G.: Dental injuries following radical surgery on the maxillary sinus. Acta. Otolaryng. Suppl. LXXXIV, 1950.

14. Harris, S.C.: The tooth pulp as an algesimetry site. J.D.R. 29:68, 1950.

15. Graf, W. and Bjorlin, G.: Diameters of nerve fibres in human tooth pulp. J.A.D.A. 43:186, 1951.

16. Butcher, E.O. and Taylor, A.C.: The effects of dernervation and ischaemia upon the teeth of the monkey. J.D.R. 30:265, 1951.

17. ______________________________ : The vascularity of the incisor pulp of the monkey and its alteration by tooth retraction. J.D.R. 31:239, 1952.

18. Bjorlin, G. and Persson, P.A.: The effect of surgical intervention on the sensibility of neighbouring teeth. Odont. Revy 4:324, 1953.

19. Huldt, S.: Factors influencing the efficiency of dental local anaesthetics in man. Acta. Odont. Scand. 11, Suppl. 13, 1953.

21. Berling, C.: Carbocaine in local anaesthesia in the oral cavity. Odont. Revy 9:254, 1958.

22. Feldmann, G. and Nordenram, A.: The effect of carbocaine and lidocaine - a comparing experimental investigation. Svensk. Tandlak. Tidskr. 52:531, 1959.

23. Mumford, J.M.: Path of direct current in electric pulp testing using one coronal electrode. B.D.J. 106:26, 1959.

24. ____________ : Path of direct current in electric pulp testing using two coronal electrodes. B.D.J. 106:243, 1959.

25. ____________ : Reproducibility and discrimination in electric pulp testing. J.D.R. 39:1111, 1960.

26. Burrill, D.Y.: Pulp testing by determination of fusion frequency. J.D.R. 41:437, 1962.

27. Mumford, J.M. and Bjorn, H.: Problems in electric pulp testing and dental algesimetry. Int. D.J. 12:161, 1962.

28. Mumford, J.M.: Pain threshold of normal human anterior teeth. Arch. Oral Biol. 8:493, 1963.

29. ____________ : Pain perception threshold and adaptation of normal human teeth. Arch. Oral Biol. 10:957, 1965.

30. Reynolds, R.L.: Determination of pulp vitality by means of thermal and electric stimuli. J. of Oral Surg. Med. & Path. 22:231, 1966.

31. Mumford, J.M.: Resistivity of human enamel and dentine. Arch. Oral Biol. 12:925, 1967.

32. Johnson, J.V. and Hinds, E.C.: Evaluation of tooth vitality after subapical osteotomy. J. Oral Surg. 27:256, 1969.

33. Martin, H., Ferris C., and Mazzella, W.: An evaluation of media used in electric pulp testing. J. of Oral Surg. Med. & Path. 27:374, 1969.

34. Howell, R.M., Duell, R.C., and Mullaney, T.P.: Determination of pulp vitality by thermographic means using cholesteric liquid crystals. J. of Oral Surg. Med. & Path. 29:763, 1970.

35. Mumford, J.M.: Pain perception threshold of retained primary teeth. J.D.R. 35:506, 1971.

36. Seltzer, S.: Advances in biology of the human dental pulp. J. of Oral Surg. Med. & Path. 32:454, 1971.

37. Chilton, N.W. and Fertig, J.W.: Pulpal responses of bilateral intact teeth. J. of Oral Surg. Med. and Path. 33:797, 1972.

38. King, D.R.: Pulp vitality tests. J. Acad. Gen. Dent. 20:35, 1972.

39. Burnside, R.E.: Effects of orthodontic treatment on the electric sensibility of teeth. University of Oregon Certificate Thesis, 1972.

40. Urban, D.E.: The reliability of the electric pulp tester on orthodontically banded teeth. University of Oregon Dental School Certificate Paper, 1973.

Figure 1

STIMULATOR CALIBRATION

Machine No. 1
Battery Test - Voltage 7^+
Current 12-14 a.

Test Path Resistance	Voltage Control Setting 1	2	3	4	5	6	7	8	9	10	10^+
0.5 Meg	1	2	5	9	13.5	16.5	26.5	42	50^+		
1 Meg	.5	2^-	4	8	12	14	22	32	42	48	48
2 Meg	.5	1	3	6	8	10^+	16	22	28	32	32
3 Meg	.5	1	2^+	4^+	6	8	13	17	21	23	23
4 Meg	.5	.5	2	4	5.5	7	11	14	17	18	18
5 Meg	.25	.5	2^-	3	4	6	9	11	13	14	14
6 Meg	+	.5	1	2.5	4^-	5	8	10	11	12	12
7 Meg	+	.5	1	2	4^-	4.5	7	9	10	11	11
8	+	+	1	2^-	3	4	6	8	9	10	10
9	+	+	1^-	2^-	3^-	4^-	6	7	8	9	9
10	+	+	1^-	2^-	2.5	3.5	5	6	7	7^+	7^+

Figure 2. Electric Stimulator