EFFECTS OF ORTHODONTIC TREATMENT ON THE ELECTRIC SENSIBILITY OF TEETH

Robert E. Burnside, D.M.D.

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INTRODUCTION

The integrity of the dental pulp during orthodontic treatment is a topic of some interest to the endodontist, oral surgeon, and orthodontist. Growing numbers of the young people in our society are receiving orthodontic care, placing more and more banded teeth in a susceptible position for trauma involvement or carious breakdown.

It is the general belief that the most reliable gauge of tooth vitality is the presence of an adequate blood supply. However, to assess this measure requires histological investigation which is out of the question in a clinical examination. Other methods such as the degree of pain from excavation with explorer or bur, thermal excitation, percussion, or radiograms have also been employed to different degrees. Most practitioners have settled on the electrical pulp tester as the most accurate and practical means of evaluating the condition of the pulp in question.

Though poorly substantiated, it seems to be the feeling of many dental practioners that the sensitivity of teeth may be altered by orthodontic treatment. This impression may have been due to clinical remarks from persons undergoing tooth moving procedures or possibly finds its origin from works of Orban, Stuteville, and Oppenheim. These investigators between 1936, and 1942, noted some devitalization of teeth which were undergoing orthodontic treatment.

It will be the purpose of this study to determine if the pain threshold to electric stimulus differs significantly in orthodontically treated teeth than from those of the control.

REVIEW OF LITERATURE

The dental literature discusses many investigations related to tissue changes about the teeth and jaw structures. However, very few efforts have been directed towards the conditions that exist within the pulp chamber which determine the ultimate fate of the tooth's vitality. Orthodontic treatment may be capable of effecting such pulp changes.

Orban (1936)[4] has mentioned several cases of devitalization of teeth having undergone orthodontic movement. He speaks of "shortening" or "lengthening" procedures which proved to be especially dangerous to the pulp. The shortening resulted in a wedging of the vessels between tooth and bone thereby interrupting circulation. The lengthening caused laceration of vessels ultimately leading to pulp necrosis. He qualified his statement saying that general conclusions cannot be made from occasional observations.

Human pulp tissue changes were observed by Stuteville in 1937.[5] He stated: "The character of the pulp tissue is such that it does not have much resistance to injury. The injuries to the pulp that are caused by orthodontic treatment are the result of shutting off of the blood supply or of hyperemia of the pulp from jiggling of the tooth during mastication, after it has been loosened by the detachment of a large number of the periodental membrane fibers in the course of movement. Jiggling, after the tooth has been loosened, may result in tearing or injury of the vessels entering the apical foramen. Another injury that may be caused is by squeezing of the apex, against the bone, thus shutting off the blood supply to the pulp. There are relatively few pulps that become gangrenous during the course of orthodontic treatment and in most cases showing degeneration of the pulp there is a history of accidental trauma which will account for the death of tissue."

Oppenheim (1942)[8] described "diapedes of the blood corpuscles" in the pulps of teeth undergoing orthodontic treatment. This can be caused by a hyperemia in the pulp and occurs because of the lack of colateral circulation, when pressure is present in the apical region.

In this same period, Strang[9] spoke that orthodontics delivering sudden tension on a tooth, might injure the vessels leaving the pulp and cause serious venous congestion and pulp death. He also felt that strong depressive forces might shut off the arterial supply and thus produce a devitalization of pulpal elements. If restitution of these elements is possible it has not yet been determined.

Histological examination of tissue can give a nearly complete picture of the condition of a pulp. However, as pointed out by Stuteville,[5] in orthodontic treated teeth it is impossible to follow the changes temporally in the pulp. He mentions that in most cases in his study showing degeneration of the pulp, there was a case history of trauma, which accounted for the death of tissue. Since it was impossible to control the condition of the pulp before orthodontic treatment was started, he had to rely on patient information, and, therefore, his scientific information regarding changes in the pulp cannot be considered fully accurate.

With the use of an electrical pulp stimulator, we are able to follow changes in the condition of the pulp over different time intervals. The first to develop an electrical pulp testing method was Magitot in 1867. Since that time many different methods have been used dealing with faradic current, galvanic current, direct current, alternating current and high frequency alternating current. Bjorn (1946)[12] remarked that early tests failed to control variations in the primary circuit which in turn influenced the current in the secondary circuit and made a repeating constant stimulus impossible. There were also difficulties in measuring the intensity of the stimuli, which was estimated by measuring the distance between the two coils.

In 1933, Reiss and Furedi (1933)[1] tested 130 teeth with a direct current stimulation. The strength of their stimulus was measured in voltage which through continued use showed variations in the electrical threshold value of subjects. These variations were dependent upon the temperament and age of the patients and psychological influences such as the nervous state of the patient at the time of the test, all of which could affect the result. However, they did not feel the variations were of such a degree as to "confuse" them. They emphasized the importance of being consistant in the location of electrode placement on both the experimental and control tested teeth. They had some teeth with granulomas and cysts, others impacted and with adjacent soft tissue tumors. They also made histological investigations of these teeth and tried to correlate the two methods.

Some of the teeth with degenerating pulps gave a response to a high stimulus. They explained this phenomenon by the presence of a solitary intact nerve fiber which responded to the stimuli. Nordh (1955)[20] evaluated this as a response most likely from stimulation of the periodontal membrane.

The first study of electrical stimulation of pulps in teeth undergoing orthodontic treatment was carried out by Kaleksky and Furedi in 1935.[2] They also used direct current and measured voltage. The amount of voltage required to elicit a response was called the "threshold value." They reported that the threshold value increased during orthodontic treatment, then had a tendency to return to normal sometime after the completion of treatment. They reported on one such instance: "In the case of a child, 12, a discoloration of the upper right central incisor was noted in the course of orthodontic treatment. The orthodontist referred the case for roentgen-ray and clinical examination in an attempt to ascertain the condition of the pulp. The roentgenogram was negative and the pulp gave a response only to the maximum stimulus. The control tooth and adjacent teeth responded at a normal threshold. In view of these findings, conservative treatment was suggested with periodic observations with the roentgen-ray and the pulp test examinations. Within a period of 3 months, the discoloration is gradually disappearing and, at the present time, this tooth responds within 5 volts of the corresponding control tooth."

Ziskin and Wald in 1935,[3] demonstrated several facts that strengthened electrical pulp testing. They felt that the density of current should be expressed in amperage not in voltage. This opinion is due to the fact that the resistance of the teeth vary with the presence of moisture, denticles, thickness of enamel, amount of attrition and age of patient. They also showed that the duration of the stimulus and the waveform were extremely important. In each instance, the duration of the stimulus and the intensity of the current had to be the same, they were intimately connected and depended upon one another. A short duration requires a higher amperage; a longer duration a smaller amperage. This fact makes a continuous direct current unsuitable because of the difficulties encountered in controlling the duration of the stimulus and the waveform which must be constant and repeatable.

Since that time, Bjorn[12] and others have substantiated these facts.

From Ziskin and Wald[6] 1938 study came information that the intensity of the current is directly dependent upon the voltage, the resistance between the electrode and the tooth, and the resistance of the tooth itself, which varies with the thickness of enamel and dentine. Therefore, to measure the exact strength of the current, you must know the resistance of the tooth to be tested. Mackta[7] emphasized the need to maintain a dry tooth during testing to prevent side currents and possible periodontal response rather than dental response. He also emphasized the importance of good testing procedures involving control teeth before making an opinion of tooth vitality. He stated: "The irritability of the nerves of the pulp is determined electrically by a comparison of its threshold of response with the pulps of other teeth."

In a 1945 study by Ziskin and Zegaielly[10] an attempt was made to determine the resistance of the tooth. Values ran to over one million ohms for the dry tooth to approximately fifty thousand ohms in the wet tooth. The wet-dry difference was also accompanied by a large variation in different teeth. It was noted by them that in addition to a variation of threshold values in different patients that the psychological condition of each patient brought about variations in test values on the same tooth from time to time.

Markus in 1946,[11] stated that electric pulp testing was valuable to the orthodontist for two reasons: (1) to know whether orthodontic treatment has any effect upon the pulp, and (2) to determine the state of health of the pulps of teeth prior to treatment. His investigation involved 53 teeth electrically tested before and after orthodontic pressure had been applied. Measurements were taken in both amperes and volts but no other information was reported as to type of electrical stimulator used. He stated: "It showed a tendency toward an increased irritability of the pulp as denoted by the lowered threshold of stimulation." In 47 of 53 teeth tested there was no change or an increased amperage reading, which indicates a decreased irritability. The author seems to draw his conclusion from the fact that in 37 of the teeth tested the voltage need dropped following orthodontic pressures.

An extensive study on pulp testing was begun by Bjorn in 1946.[12]

His tests were of the electrical stimulation type but did not involve orthodontically treated teeth. He used direct current impulses of a specific duration and measured the threshold value in amperes, due to the inaccuracy of voltage readings (Ziskin and Wald, 1935[3]). Bjorn's stimulator had a maximum reading of 140 microamperes which tested to be insufficient to evoke a periodontal response. A large internal resistance was placed in the stimulator to overshadow the resistance of the teeth. Bjorn showed that threshold values obtained with the anode electrode were approximately 2.5 times the values obtained when the cathode electrode was used. He emphasized the importance of stating what electrode is used in any given study. From his work, he gained several impressions but lacked statistical data to substantiate the effort scientifically. He felt that great variations existed between teeth of different individuals, but that only slight variations were present in an individual when tested from time to time. He found that large variations existed when the electrode was placed on different positions on the crown surface. He found there to be no significant difference between sexes or right and left sides when tested. He placed great importance on the fact that the excitability of the tooth pulp was very much independent of any other tissue. Bjorn's study produced valid information regarding electrical stimulors.

Harris (1950)[15] verified the inaccuracy of threshold values obtained by voltage readings. He spoke of the importance of maintaining the teeth to be tested in a dry condition. A significant variation was found in testing different individuals and a slight variation was found on the same patient from day to day.

Modifications were made in the Bjorn stimulator by Persson and Bjorlin.[18,19] They limited the strength of the current to 70-80 microamperes to eliminate periodontal response. Also the newer stimulators were made capable of direct power connection.

The first complete statistical study on vitality changes in orthodontically treated teeth was done by Nordh in 1955.[20] He approached his study by asking four questions: (1) What is the influence of an orthodontic band on the pain threshold of a tooth? (2) What influence does extraction have on the pain threshold of teeth adjacent to the site of extraction? (3) What influence does tooth movement, as in space closure, have on the pain threshold of teeth? (4) What influence does orthodontic treatment have on the pain threshold of the involved teeth? Nordh felt the Bjorn pulp tester to be the most accurate and used it in the same form as Bjorn had in his 1946 study. Rubber dam isolation was not used in the study, as the teeth were dried and isolated with cotton rolls and the patient asked to breathe through his nose.

Thirty-six teeth were tested on the same day before and after band placement. There was no significant difference between the two readings, showing that the banding procedure and presence of the orthodontic band does not alter current flow or pain threshold level.

Thirty-five teeth were extracted for orthodontic purposes and the 62 adjacent teeth were tested for pain threshold with a control group of 29 teeth from the same individuals. It was found that there was a significant difference at the five percent level of the pain threshold in the experimental teeth. The author felt the higher threshold value obtained could be explained by edema, hyperemia, or haematomata rather than severance of the nerves since none of the teeth showed complete anesthesia. Martensson[14] discussed similar results following the Caldwell-Lue operation. Nordh was able to follow 35 of the 62 teeth tested till space closure was complete. When testing the treated cases against 18 control teeth, no significant difference was found. This seems to substantiate the return to normal of pulp excitability following the removal of orthodontic forces.

In the final group, Nordh tested 13 teeth with a control group of ten teeth before treatment and again after the spaces were orthodontically closed. No significant difference was present between the readings. During this study, the author tested seven teeth which had become completely anesthetized during active tooth movement. At the time the study was completed, one of these teeth had returned to a normal threshold value. Nordh feels that this apparent damage of nerve tissue may be due to improper band placement, too fast tooth movement, poor root torque, or excessive depressive or erupting forces. This tends to confirm Martensson's statement that a tooth may show total anaesthesia without being non-vital.

Work of Butcher and Taylor (1949)[13] showed that in the rat retraction of a tooth into the alveolus caused necrosis of the pulp tissue. When the forces were removed, tissue regeneration into the pulp cavity took place, but was devoid of odontoblasts and dentin-forming potentiality. The odontoblasts seem to be very specialized cells which cannot differentiate from all connective tissue cells. When working with monkeys, the authors[16] found that the pulp of teeth with large apical foramina are more easily injured by retraction than the pulp of teeth with small foramina. In the large foramina teeth, the odontoblasts and most of the pulp degenerate upon retraction; and upon release these are replaced from compressed tissue at the apex.

In 1952, Butcher and Taylor[17] discussed the possibility of the orthodontist strangulating the pulpal vessels with his appliance: "The orthodontist uses small forces compared with those used in these experiments. Second, his force is not exerted on the long axis of the tooth but is usually constructed for tipping the tooth. While tipping the tooth labially would interfere with most vessels, enough communicating vessels would probably still exist lingually for necessary vascularization. It, therefore, is possible, yet not very probable that any appliance of the orthodontist would have such a force or direction as to strangulate the vessels to the extent of causing a necrosis of the pulp. In many instances, as shown by our previous experiments, the necrotic pulp would be invaded and repopulated by growth of tissue from the apical region... Although there is more danger of altering the blood vessels by tipping the tooth labially, there is little evidence that the retractive force applied by orthodontists would be sufficient to strangulate the vascularity of the pulp."

Mumford and Bjorn (1962)[22] in an article on electric pulp-testing, spoke of basic requirements in obtaining accurate results. They feel an adequate stimulus, an adequate technique of applying the stimulus to the teeth, and a careful interpretation of the results are essential. Mumford[23] found in a threshold study of normal anterior teeth that no significant difference existed between tested male or female subjects, between maxillary canines, laterals, or centrals, or between mandibular canines, laterals or centrals if rubber dam was used and an electrode of sufficient size was used to overcome the variation due to the subjects impedance.

Other studies of Mumford[22,24,25] have added such information as effects of age, adaptation, current direction, changes in stimulator frequency and electrode area. His study on the resistivity of human enamel and dentine have also added to the knowledge of dental physiology.

Many of the properties of the stimulation used by Bjorn and Mumford have been incorporated into the apparatus developed at the University of Oregon Dental School and used in this experiment.

MATERIALS AND METHODS

Patients were selected at random from the Department of Orthodontics, University of Oregon Dental School, Portland, Oregon, and included 15 persons; five males and ten females ranging in age from 11-3 to 17-4 years of age who were undergoing orthodontic treatment. Control subjects were drawn from examined patients prior to placement of orthodontic appliances and included 11 persons, five males and six females ranging in age from 11-8 to 16-1 years of age. A total of 201 maxillary and mandibular anterior teeth were tested, 111 orthodontically treated and 90 untreated. The experimental teeth were treated with an .022 bracket conventional appliance.

The method used to determine and measure the pain threshold of the teeth tested in this study was similar to that employed by Bjorn (1946)[12] and Nordh (1955).[20] The stimulator (Fig. 1) used in this study was operated by two 9-volt batteries and had a current intensity range of 0 to 190 microamps working into a load of 1.0 million ohms. The current produced by the machine consisted of short direct impulses with a rectangular wavefront (Fig. 2) and a duration of approximately 0.2 milliseconds. The frequency of the current impulses could be varied. During this investigation the frequency of the impulse was maintained at approximately 120 per second. To eliminate the variations of the external resistance, the stimulator was supplied with an internal resistance of approximately 100,000 ohms.*

The patient held a hand electrode, copper cylinder wrapped in wet gauze which conducted the stimulating current. A metal tipped electrode of approximately three square millimeters in transverse section with a plastic insulated handle acted as the stimulating electrode and was held against the tooth to be tested. The tooth electrode was wired so as to always become the cathode. The intensity of the stimulating current was regulated by a potentiometer, on which the value of outgoing impulses was read in scale divisions. The threshold value obtained was then read in microamperes on a microammeter. The correlation between scale divisions and microamperes was obtained by constructing a calibration curve for the

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* Stimulator designed and constructed by Fred M. Sorenson, University of Oregon Dental School, Portland, Oregon.

stimulator (Figs. 3,4).

The patient was placed in the dental chair and the details of the experiment explained. The stimulator was placed out of the direct sight of the patient yet close enough for the tester to read the microammeter. The patient was asked to hold the hand electrode firmly in his left hand. The tooth to be tested was isolated with a two-inch square piece of rubber dam material and dried with a stream of air. The tip of the electrode was dipped in tooth paste and then placed on the mid-incisal edge of the tooth to be tested.

The patient was told to "grunt" or raise his right hand at the instant he felt the first sensation within the tested tooth. The intensity of the current was then slowly increased by the potentiometer until the patient responded. The scale divisions were then read for the first time and the potentiometer was turned back to zero. The current was again slowly increased until the patient indicated a second sensation. This procedure was repeated until approximately the same threshold value was observed three times in succession.

The instrument used in this experiment allowed a single operator to conduct the test. The operator stood behind the patient, dried the tooth, held the potentiometer in the left hand and with his right hand contacted the tooth and electrode.

Radiographic records were taken on all subjects prior to the treatment procedures. Further radiographs were taken on those teeth showing abnormally high threshold values.

The data was statistically analyzed by employing T tests, pre-selecting an alpha level of .05 for significance. A sample of 35 representative teeth were tested by the double determination method to obtain an estimate of reliability (SEMeas $= \sqrt{\frac{\Sigma d^2}{2N}}$).

RESULTS

The electrical threshold value of each of 201 maxillary and mandibular teeth was determined. The control and 110 orthodontically treated teeth were divided into eight groups for statistical analysis.

The total grouped maxillary and mandibular anterior teeth were analyzed (Fig. 5) and the range of response varied from 1-25 ua. The mean level of response for the orthodontically treated teeth was 8.8 with a standard deviation of 4.7. The control mean was 7.1 with a standard deviation of 4.4. Analysis by the "t" test showed t = 2.50 for infinite degrees of freedom, which is significant at the five percent level.

The maxillary anterior teeth consisting of 56 test teeth and 45 control teeth were tested (Fig. 6). The mean response for the experimental teeth was 11.0 with a standard deviation of 4.9. The maxillary control teeth had a mean value of 7.9, and a standard deviation of 4.2. The "t" test value of 7.56 was significant at the five percent level with 99 degrees of freedom.

Maxillary central incisors included 22 orthodontically treated teeth and 12 control teeth (Fig. 7). The orthodontically treated teeth had a mean of 9.8 and a standard deviation of 3.7. The controls in this group had a mean of 5.2 and a standard deviation of 1.9. Results of the "t" test were significant at the five percent level with a value of 4.81 using 32 degrees of freedom.

Maxillary lateral incisors showed a similar trend to the three previous groups (Fig. 8). Eighteen experimental teeth had a mean response of 11.4 and a standard deviation of 5.1. The 14 control teeth in this group had a mean of 6.9 and a standard deviation of 4.4. The "t" test value of 2.69 with 30 degrees of freedom was significant at the five percent level.

The maxillary cuspid teeth when analyzed showed no significance, however the 16 orthodontically treated teeth, when compared with the 19 control teeth, followed the same trend as shown in the previous groups (Fig. 9). The test teeth had a mean of 12.2 and a standard deviation of 5.9. The control cuspids had a mean of 11.2 with a standard deviation of 3.7. The "t" test value of .065 was not significant at the five percent level with 33 degrees of freedom.

Mandibular anterior teeth, 45 control and 55 experimental, were compared (Fig. 10). The experimental teeth had a mean of 6.5 and a standard deviation of 2.9. The control teeth had a mean of 6.4 with a standard deviation of 4.6. The "t" value of 1.25 with 98 degrees of freedom was not significant at the five percent level. However, 60 percent of the orthodontically treated teeth did indicate a raised threshold response to the electrical stimulus.

The mandibular central and lateral incisor teeth were analyzed as one group (Fig. 11). The 36 orthodontically treated teeth had a mean response of 5.9 and a standard deviation of 2.7. The 31 control incisors had a mean of 4.7 with a standard deviation of 3.4. The "t" test value of 1.66 with 64 degrees of freedom was not significant at the five percent level. Approximately 88 percent of the treated teeth indicated an increased threshold to the electric stimulus.

When the 19 experimental mandibular cuspids were compared to the 14 control mandibular cuspids no statistical significance was shown (Fig. 12). The experimental cuspids had a mean of 7.5 with a standard deviation of 3.1. The control teeth had a mean of 10.0 and a standard deviation of 5.0. The "t" test value of 1.67 with 31 degrees of freedom was not significant at the five percent level.

To determine an estimate of reliability, 35 anterior teeth were tested by the double determination method. A value of .91 was found for the Standard Error of the Measure using the experimental procedures outlined in the Methods' section of this paper.

DISCUSSION

The instrument used in this study showed a relatively high level of reliability as demonstrated by the SEMeas of .91 μamps and ease of operation by one person. Furthermore, it appeared that the patients were less apprehensive during the testing procedure than when tested with instruments requiring two operators. In all likelihood the familiarity of the one doctor to patient relationship was responsible for this observation. The current type testing of the instrument by-passes the weakness of voltage testing as stated by Bjorn (1946).[12] Since it is the current which produces excitation, any values given for the voltage may therefore be a gauge of the electrical resistance actually occurring at the time of measurement rather than of the excitability of the dental tissues.

The study was limited to maxillary and mandibular anterior teeth. It was felt these teeth would be more easily isolated and would experience the movements common to orthodontic treatment: retraction, rotation, tipping, intrusion, and extrusion. Rubber dam isolation was placed on each tooth prior to testing. Mumford, Bjorn (1962)[22] spoke of the possible loss of current by-passing the dentine and pulp over the tooth surface to the gingiva. They further advocated rubber dam isolation, stating: "Generally the loss tends to increase as moisture from the gingival or expired air collects on the tooth. This explains why the threshold value apparently rises in some teeth when not adequately isolated."

The tooth electrode was slightly grooved so as to cradle the incisal edges of the tested teeth. This location seemed to be the most convenient, furthest removed from banding material, easiest to repeat and found to be more consistent in tests by Mumford (1960).[21]

Data obtained in this study was not separated as to male or female subjects. Mumford's study of 1963,[23] showed no significant difference at the five percent level when comparing anterior teeth of the two sexes.

When maxillary and mandibular teeth combined were tested, the experimental and control differed significantly at the five percent level. This elevation in the stimulus threshold of orthodontically treated teeth is further suggested in Figure 5, which shows approximately 90 percent of the treated teeth required more current to respond than did the controls.

Further division of the data shows a significant raise in the threshold of the total maxillary anterior teeth, the maxillary central incisors, and the maxillary lateral incisors when grouped and compared as control to experimental teeth. This raising of the threshold value was also suggested by the lower percentage of treated teeth responding at a given microamp level when compared with the controls.

The maxillary and mandibular cuspids, the mandibular incisors, and the mandibular anterior teeth, show no statistical significance between control and experimental teeth. However, each of these groups demonstrated a trend towards higher current readings for experimental against control teeth excepting the mandibular cuspids. This tendency for a raised threshold to electrical stimulus for experimental teeth seemed to prevail in all cases except the mandibular cuspids (Fig. 12). The size and position of both the maxillary and mandibular cuspids may be responsible for the failure of these teeth to show significant threshold changes. The cuspid is supported and protected in the dentition so as to withstand strong insults and maintain its status quo. Effects of orthodontic forces may possibly be seen much earlier and more frequently in those teeth not as well protected as the cuspid.

SUMMARY AND CONCLUSION

The purpose of this study was to assess if orthodontic treatment has an effect on the electrical sensibility of human anterior teeth.

The electrical threshold for 111 orthodontically treated anterior teeth and 90 control anterior teeth was determined. The tested and control teeth were divided into eight groups and "t" tested for significance. The eight groups were also plotted on graphs to demonstrate trends.

Comparisons of the findings were made and the following conclusions may be drawn from the study:

1. Maxillary and mandibular anterior teeth while undergoing orthodontic treatment display a higher electrical threshold than do non-treated controls (cross-sectional data, "t" tested for significance at five percent level).

2. Maxillary cuspid, mandibular cuspid, and mandibular incisor threshold levels for electrical stimulation between orthodontically treated and control groups show no significant difference at the five percent level.

3. Although only two groups show statistically significant differences, all groups except the mandibular cuspids show increased average current required to stimulate the treated teeth.

BIBLIOGRAPHY

1. 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.

2. Kaletsky, T. and Furedi, A.: Reliability of Various Types of Pulp Testers as a Diagnostic Aid. J.A.D.A. 22:1559, 1935.

3. Ziskin, D. and Wald, A.: The Physiology of Pulp Testing. Dental Review 7:4, 1935.

4. Orban, B.: Biologic Problems in Orthodontia. J.A.D.A. 23:1836, 1936.

5. 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.

6. Ziskin, D. and Wald, A.: Observation on Electrical Pulp Testing. J.D.R. 17:79, 1938.

7. Mackta, L.: Electrical Nerve Stimulation as Applied to Dental Nerves. Col. D. Rev. 9:74, 1938.

8. Oppenheim, A.: Human Tissue Response to Orthodontic Intervention of Short and Long Duration. A.J.O. 28:263, 1942.

9. Strang, R.H.W.: A Textbook of Orthodontia. Lea and Febiger, 1943.

10. Ziskin, D. and Zegaielly, 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 the 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. Taylor, A.C. and Butcher, E.O.: Regulation of the Eruption Rate of Rat Incisors. Anat. Rec. 103:95, 1949.

14. Martensson, G.: Dental Injuries Following Radical Surgery on the Maxillary Sinus. Acta Otolaryng. Suppl. LXXXIV. 1950.

15. Harris, S.C. and Brandel, N.E.: The Tooth Pulp as an Algesimetry Site. J.D. Res. 29:68, 1950.

16. Butcher, E.O. and Taylor, A.C.: The Effects of Denervation and Ischemia Upon the Teeth of the Monkey. J.D. Res. 30:265, 1951.

17. ______________________________: The Vascularity of the Incisor Pulp of the Monkey and Its Alteration by Tooth Retraction. J.D. Res. 31:239, 1952.

18. Persson, P.A.: Nitrons Oxide Hypalgesia in Man. Acta Odont. Scand. 9, Suppl. 7, 1951.

19. Bjorlin, G. and Persson, P.A.: The Effect of Surgical Intervention on the Sensibility of Neighboring Teeth. Odont. Revy 4: 324, 1953.

20. Nordh, N.A.: Study to Determine the Degree of Vitality of the Permanent Teeth in Connection with Orthodontic Treatment. Northwest. Univ. Bull. 56:16, 1955.

21. Mumford, J.M.: Reproducibility and Discrimination in Electric Pulp-testing. J. D. Res. 39:1111, 1960.

22. Mumford, J.M. and Bjorn, H.: Problems in Electric Pulp-testing and Dental Algesimetry. Int. Dent. J., Lond. 12:161, 1962.

23. Mumford, J.M.: Pain Threshold of Normal Human Anterior Teeth. Arch. Oral Biol. 8:493, 1963.

24. ____________: Pain Perception Threshold and Adaptation of Normal Human Teeth. Arch. Oral Biol. 10:957, 1965.

25. ____________: Resistivity of Human Enamel and Dentine. Arch. Oral Biol. 12:925, 1967.

Fig. 1 Electric Stimulator

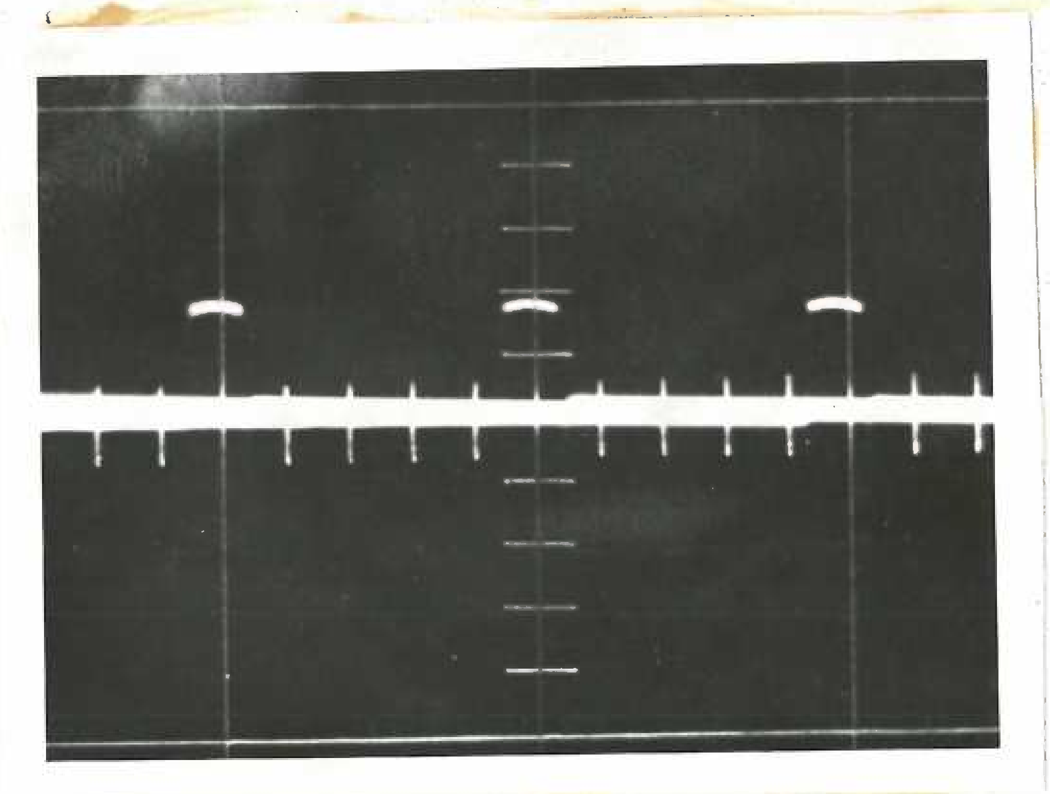
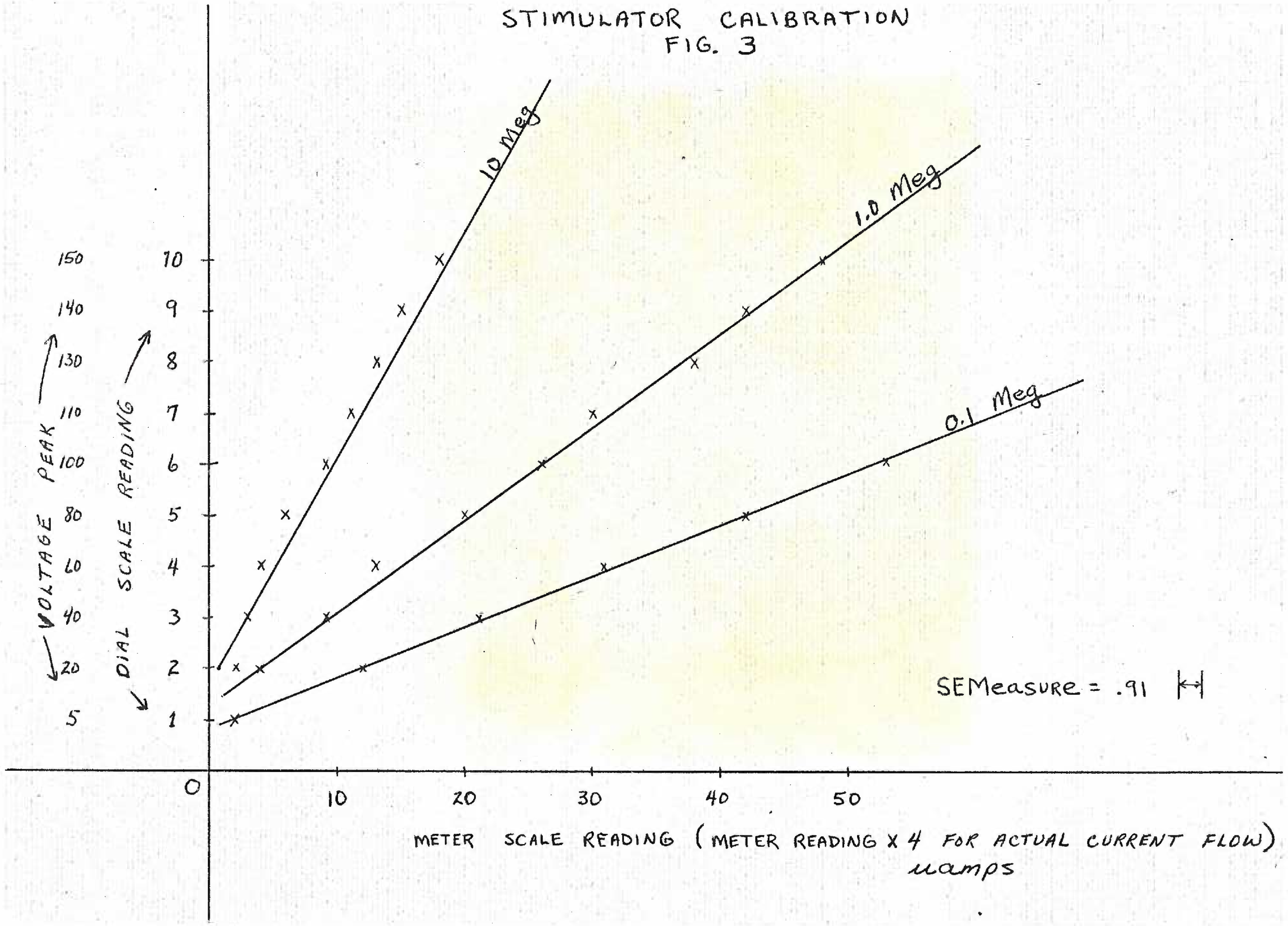


Fig. 2 Electric Stimulator Rectangular Wavefront.

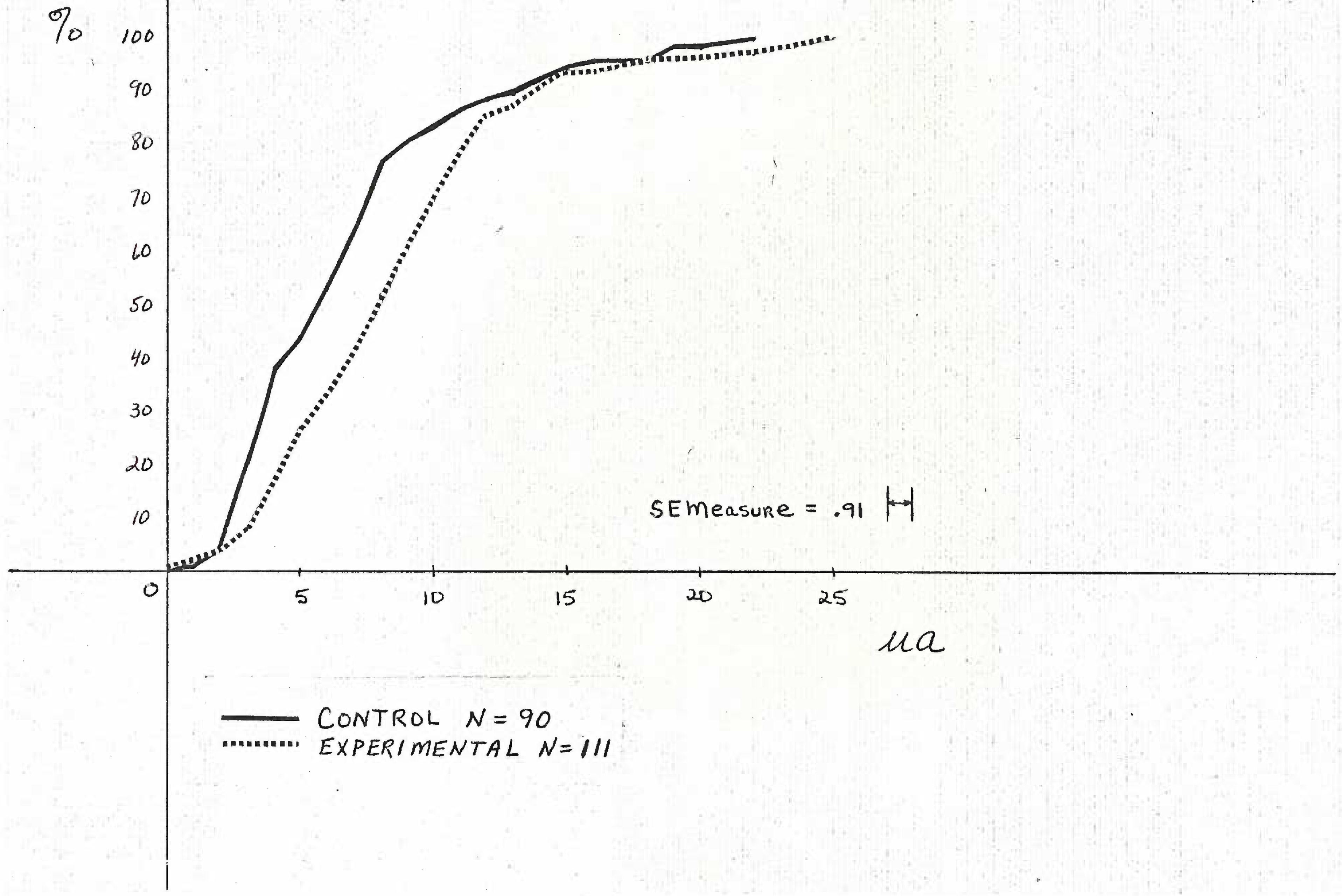
STIMULATOR CALIBRATION
FIG. 3



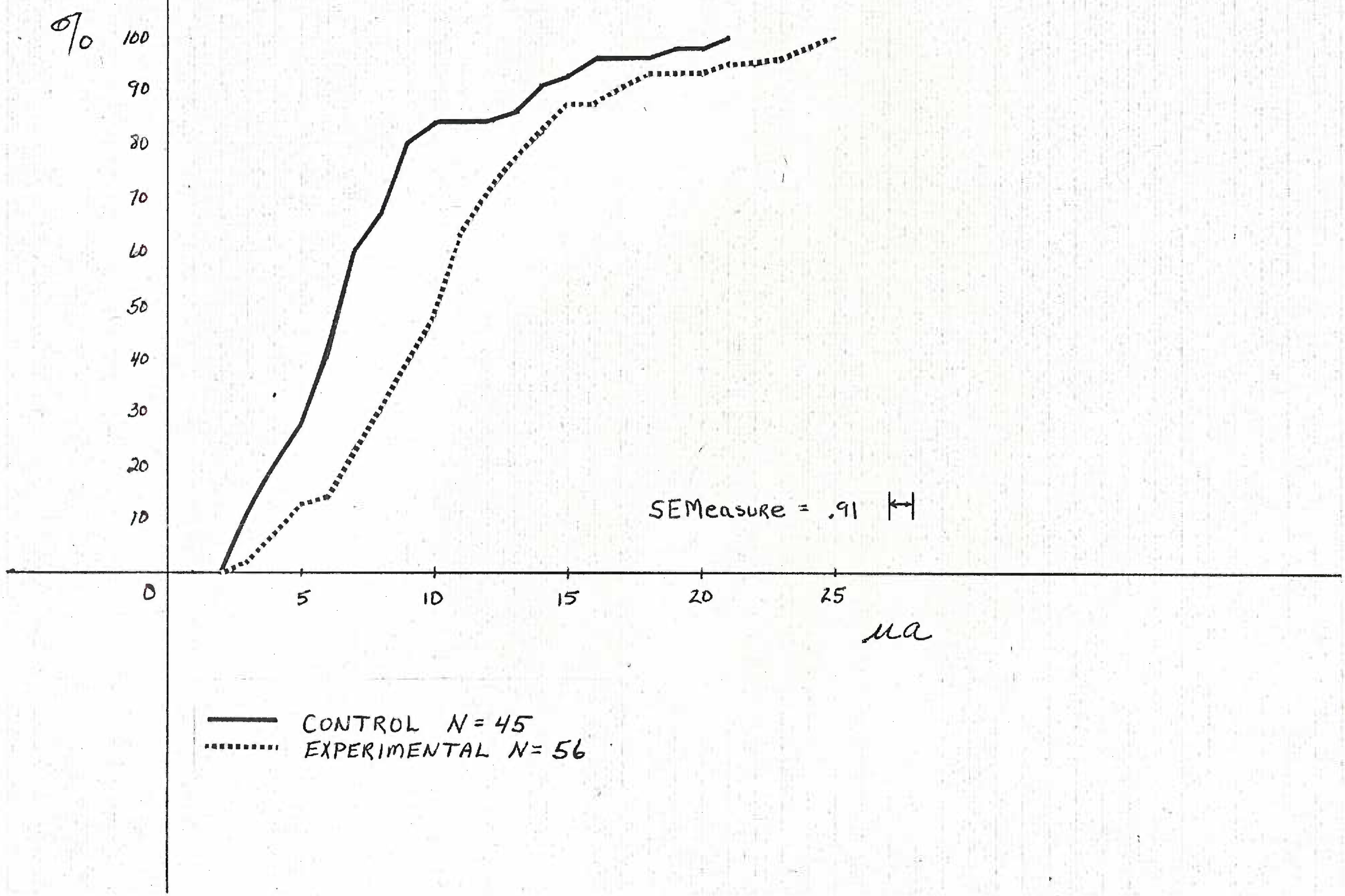
STIMULATOR CALIBRATION Fig. 4

SCALE DIVISIONS	ACTUAL CURRENT FLOW		
		μamps	
	10 Meg	1.0 Meg	0.1 Meg
1.0	-	-	8.0
2.0	3.2	16.0	48.0
3.0	12.0	36.0	88.0
4.0	20.0	60.0	128.0
5.0	28.0	80.0	168.0
6.0	40.0	104.0	208.0
7.0	48.0	124.0	-
8.0	56.0	148.0	-
9.0	64.0	-	-
10.0	76.0	-	-

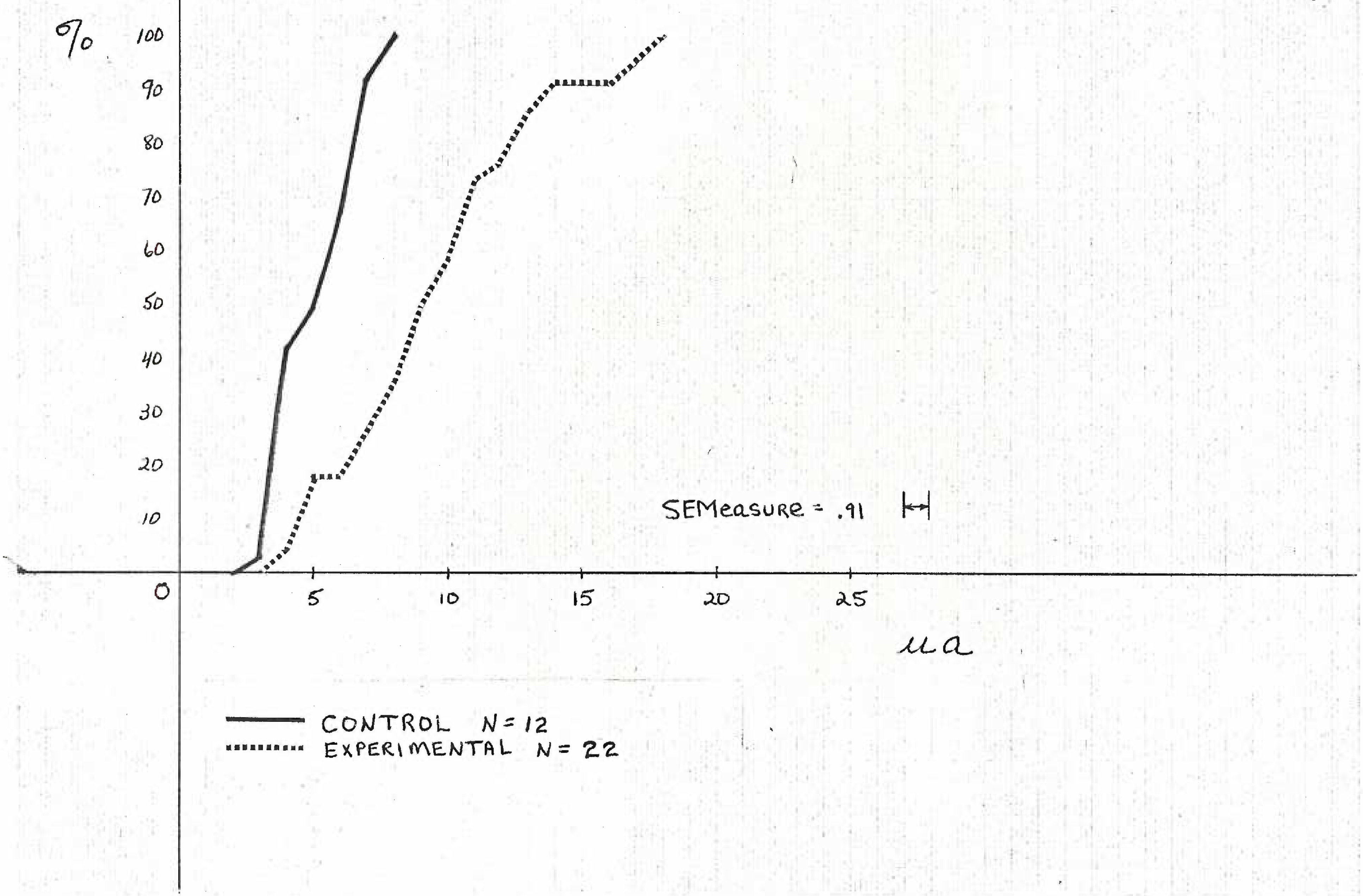
MAX. AND MAND. ANT. TEETH Fig. 5



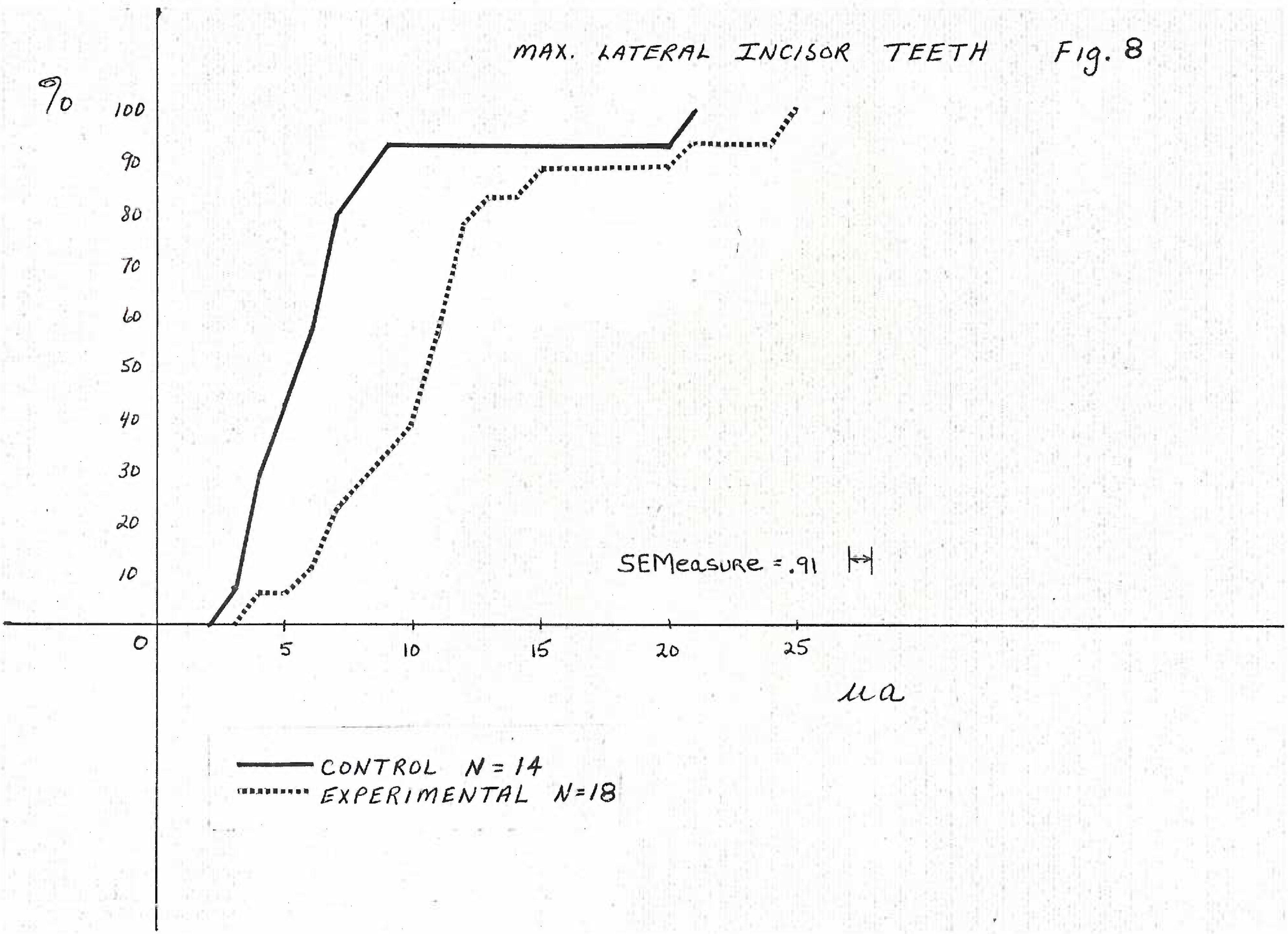
MAX. ANT. TEETH ONLY Fig. 6



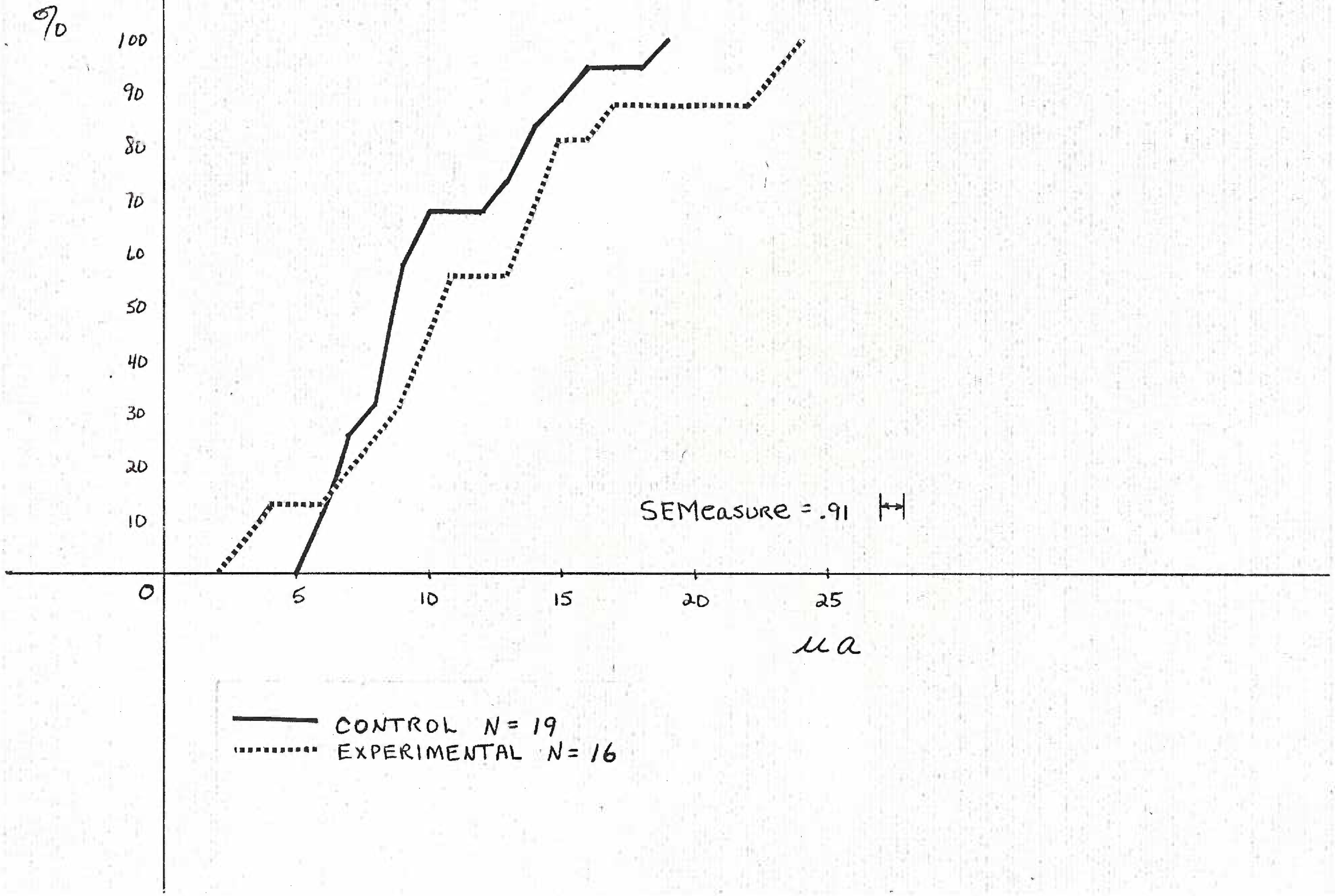
MAX. CENTRAL INCISOR TEETH Fig. 7



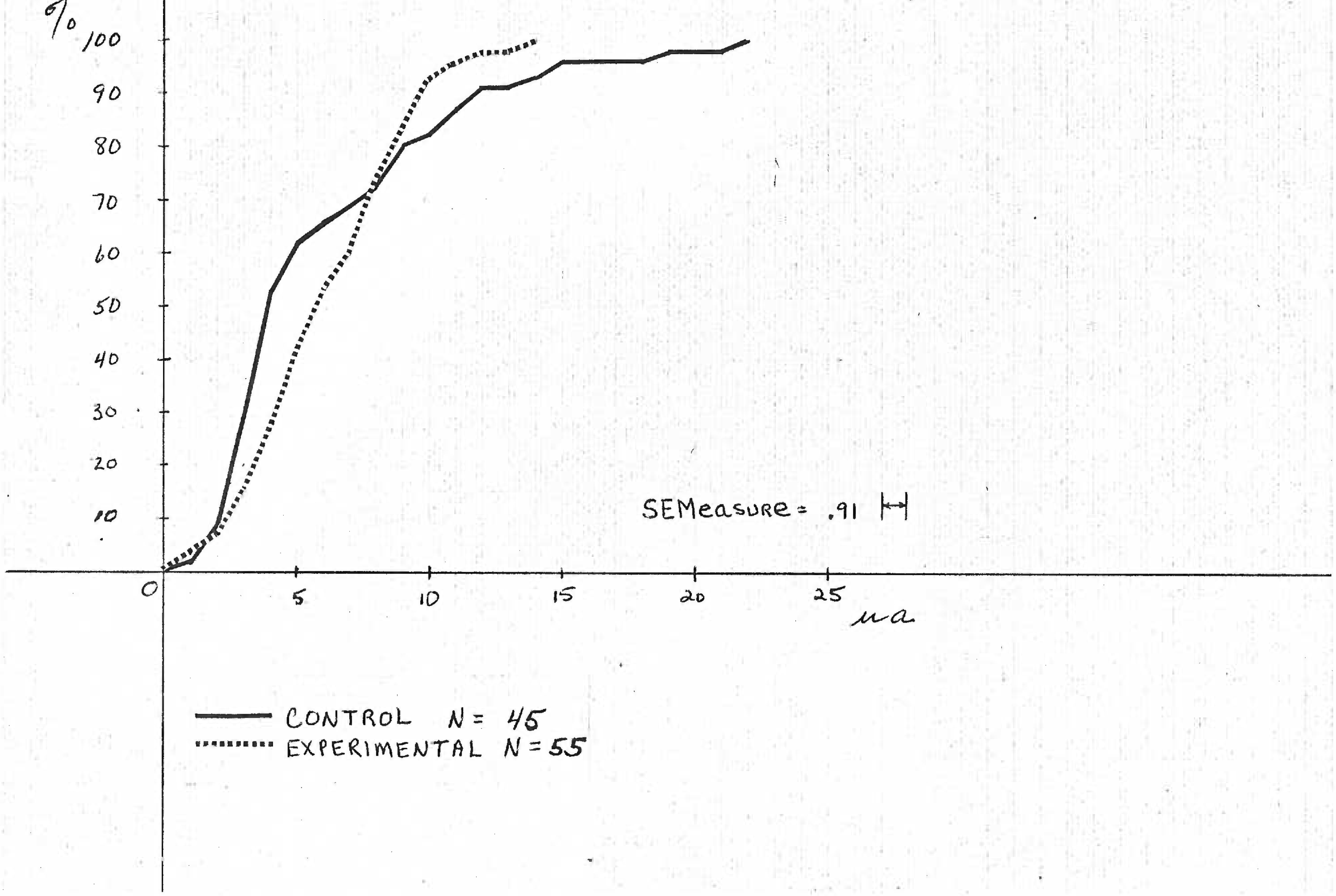
MAX. LATERAL INCISOR TEETH Fig. 8

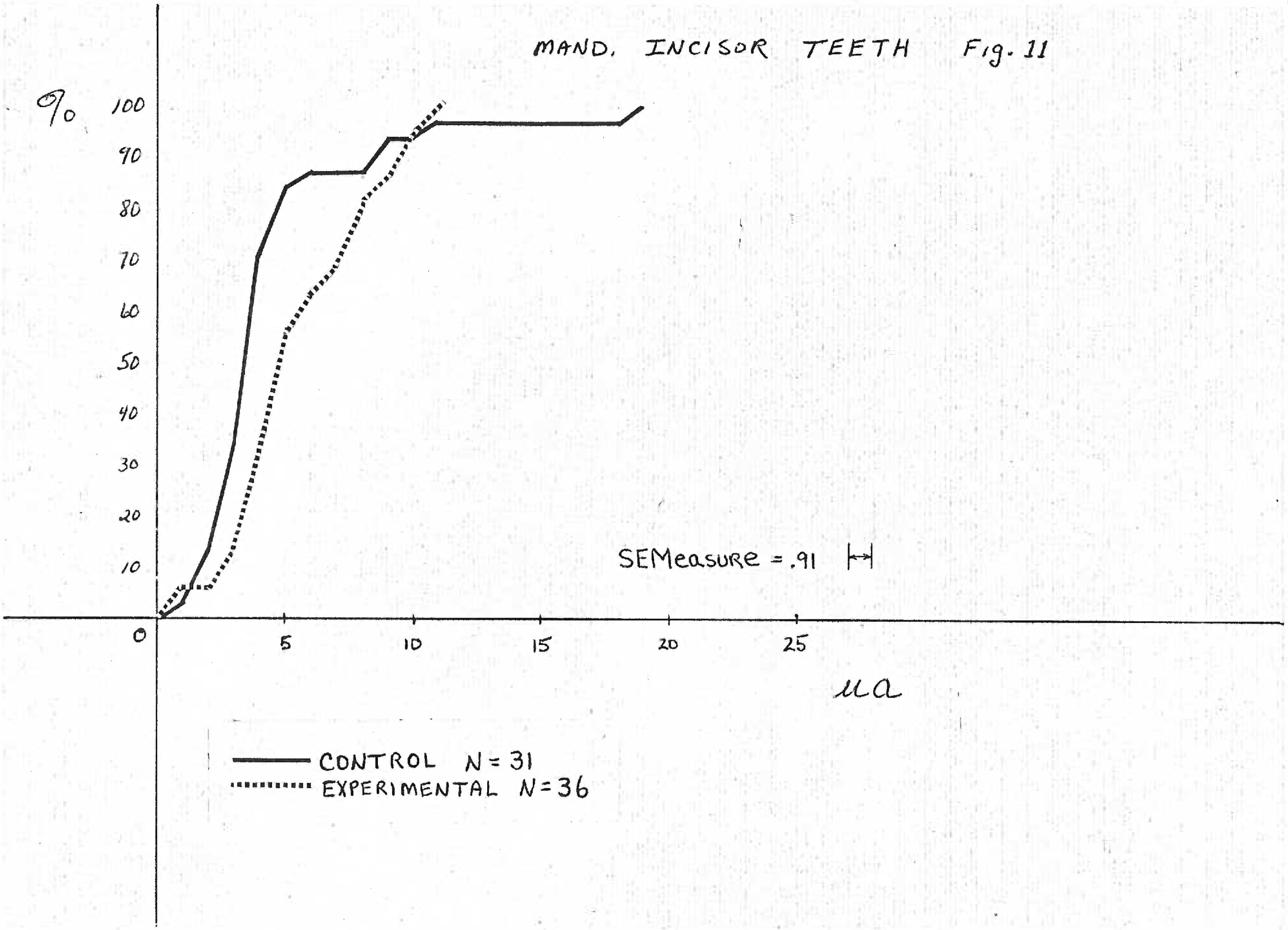


MAX. CUSPID TEETH Fig. 9



MAND. ANT. TEETH ONLY Fig. 10





MAND. INCISOR TEETH Fig. 11

MAND. CUSPID TEETH Fig. 12