A CEPHALOMETRIC EVALUATION OF VARIOUS TOOTH MARKING TECHNIQUES FOR RELIABILITY

by

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Introduction

The use of cephalometrics in research studies and orthodontic diagnosis has increased steadily since the first publication by Pacini in 1922.[1] It has grown from an isolated laboratory experiment to a valuable clinical and research tool. Numerous landmarks, having been designated by many investigators, are used to evaluate the relationship of the jaws to cranial structures and each other. Many clinicians, knowing the intimate relationship existing between the patient's growth pattern and their treatment prognosis, recognized cephalometrics as an adjunct to their diagnostic tools. Some, however, have accepted it as a panacea and diagnose the course of treatment by the numbers. Others, more concerned with measuring the annual rates of the individual growth pattern questioned the reliability of measurements obtained by these methods. Reliability of cephalometric measurements is dependent upon being cognizant of all sources of error and their reduction to the smallest possible amount.

The various sources which contribute to the total error have been studied[3,4,5,6] and can be separated into the within film, between films and technique components. The within film factor can be due to any or all of the following: enlargement, distortion, and/or blurring.

Enlargement is defined as the percentage of size increase of the image above its actual size. It is a direct function of the tube-subject distance to the subject-film distance.[2] It can be corrected for but the simplest solution is to make it constant when comparing ratios of linear measurements. Enlargement correction is necessary only for obtaining absolute linear values.[4]

Differential enlargement, distortion, is related to bilateral structures not lying in the same sagittal plane. It is the result of projecting the image of a three dimensional object onto the two dimensional film. The point on the side farthest from the film is affected more by enlargement than its mate, giving us a distorted view. This error is minimized by using the mid-point between the bilateral points instead of the left or right point alone.[4]

The factors causing blurring are listed by Thurow[4] as (1) motion of the machine or subject, (2) optical blurring or penumbra which is dependent on the size of the x-ray anode focal spot and tube to subject distance, and (3) grain caused by intensifying screens and films. Another factor, especially in older subjects, is secondary radiation from the facial structures. Between film sources of error may originate from variation in exposure time, patient positioning and/or developing procedures.

It is standard practice in orthodontic diagnosis to trace various cranial and facial structures on acetate paper for case evaluation. This also introduces additional sources of error because of (1) the operator's increased difficulty visualizing the landmark, (2) movement of tracing paper, (3) width of the pencil line, and (4) the validity of the reproduction to the original structure.[3]

Review of the Literature

The amount of error which can be tolerated depends upon the purpose for which the measurement is taken. In studies involving cross-sectional data, the individual differences are much larger than the measurement errors incorporated. Hatton and Grainger[5] determined their error variance using duplicate tracings on fifteen three year old children. They concluded the technical process needed no practical improvement. For example, the tracing errors were 2.0, 1.5, 14.6 percent and the radiographic errors were 1.7, 0.5, 11.5 percent of the distribution variance for Bolton Point to nasion, mesiodistal mandibular measurement, and molar height respectively. Savara[6] in a similar type study found the total variability of his cephalometric measurement system was less than the variability existing among ten normal children, the range of measurement error being 15 percent to 37 percent for the among children variation. Others [3] concur by stating the differences between individuals are so much larger than measurement errors that the clinician is ill-advised to interpret variation and errors of two or three degrees as meaningful differences. In this prespective, the commonly employed, commercially available installation adequately meet requirements for either clinical use or cross-sectional research purpose where group statistics are being compared.

However, in studies concerned with very small dimensions, such as the annual rates of facial growth, the amount of error included will be extremely important to the interpretation of longitudinal data. Hixon[3] has shown the invalid conclusions which could be drawn if the magnitude of measurement error was not considered in studying facial growth patterns.

Bjork[8] has studied the reliability of craniometric and constructed points on twenty subjects using double determinations. Duplicate cephalograms were obtained on each individual within a few days interval and analyzed independently by different investigators. All measurements were made directly on the film between the previously pin-pointed reference points. The sources of error due to the method employed were divided into three catagories. First were the errors arising out of differences in the method of photography, this causes projected images to vary from case to case. The second type were caused by variation in marking of the reference points. Variation occurs here because some are located by sharply defined contrasting lines, some must be identified by less distinct contours of bone and some are more accurately located in one direction than another.

Finally, there are the minor errors of reading, which are negligible in the case of measurements made from marked points and are always of the same order.

Bjork[8] emphasizes that all angular and linear dimensions measured from lateral cephalograms are only projections of the actual structures onto the medial plane.

Broadway,[7] studying the accuracy of certain angles on cephalometric tracings, states the standard deviations are usually increased when the findings of two different observers are compared.

Several investigators have used some type of metallic tooth markers to increase the reliability of reference point location on the cephalogram. Bjork[8] in the previously mentioned study used wire loops in the interdental space mesial to the right maxillary permanent molars. Nevakari[10] marked both the right permanent second molar and canine temporarily with lead pellets in his study of the mandibular movement from rest to occlusal position.

Possselt,[11] in order to reduce the measurement error sufficiently so significant differences could be detected, in his study on mandibular movement, marked infradentale with a small metallic ball.

Broadway,[7] states the use of tin foil over the crowns of the centrals did not reduce the measurement error.

Purpose

The purpose of this study is to determine the reliability of cephalometric measurements involving tooth markers in preparation for future studies concerned with evaluating different orthodontic treatment techniques. Three different clinical techniques will be used in an attempt to reduce the measurement error sufficiently to permit the accurate following of the individual movements of one tooth or teeth during or throughout orthodontic treatment and retention. These techniques will attempt to detect differences in reduction of the Standard Error of the Measurement* from cephalometric tracings and those using different types of tooth markers. Bjork[9] has shown that part of the error existing in cephalometric tracings is due to the inability to locate reliably the skeletal landmarks used for reference points. His mandibular implant study established fixed reference points. This, when used in conjunction with some type of tooth marking technique could reduce the S.E.M. sufficiently so that movement of small magnitude could be detected.

This project will not be concerned with the metallic implants as reference points, but will examine the reliability of measurements between tooth markers and various cephalometric points.

*Hereafter to be refered to as S.E.M.

Materials and Methods

The initial sample of 27 was randomly chosen from those accepted to receive orthodontic treatment at the University of Oregon Dental School. The only prerequisite was the patient's availability and need for immediate treatment. Ten patients were lost for various reasons leaving a final sample of 17.

From the initial models taken, gold tooth markers (Figure I) were cast in accordance with an accepted inlay technique for the right central incisors and first permanent molars. On the centrals, the castings covered the entire incisal edge and extended gingivally on both the labial and lingual surfaces until a definite seat was established, but did not extend into the area to be covered by the band. The molar castings were approximately one millimeter in thickness and covered the entire occlusal surface including the cusp tips.

Labial extensions to establish definite measuring points were incorporated into the anterior castings. The maxillary projected horizontally and the mandibular, after projecting horizontally beyond the bracket space was curved gingivally to insure its placement in a visible position with a minimum of open bite. Lingual extensions were placed on the molar bands. The length needed to extend beyond the bands gingival edge produced casting difficulties so the cast extension was replaced with a .020 gold wire attached to the wax pattern prior to investing. In one case where a lower lingual arch was to be placed, the molar's gingival extension was designed accordingly.

All the cephalograms were taken with the unit located in the orthodontic clinic at the Dental School. A standardized tube-subject and subject-film distance was established and maintained throughout. The Bucky-

Figure 1. Patient J.H. Models and gold castings.

Potter diaphragm used in the first series was replaced with a high resolution grid before the second series was initiated, thus necessitating an increase from the previous 5 to 12 milliamp seconds. The Kilovoltage remained constant at 120.

Two series of three lateral cephalograms (Figure II) were taken. The first prior to any banding and the second with at least partial banding completed. After being positioned in the head holder, the patient was instructed to bring the teeth together. The films were exposed in the following manner: the first without any added tooth marking material, the second with lead foil over the incisal edge of the centrals and band material between the right first permanent molars and their adjoining bicuspids, the third with the cast tooth markers temporarily cemented with Dycal or ZOE. Upon completion of at least partial banding, including the previously designated teeth by the student treating the case, the second series of lateral cephalograms was completed in a similar manner.

The reference points were selected in both vertical and horizontal positions relative to the involved teeth as depicted in Figure III. All landmarks selected except the constructed gonion and pogonion have been studied and found to be relatively reliable.[8] Wherever two images were discernible, the mid-point was always used.[4] Using the two images of articular as base points, our constructed gonion was located in the following manner. On each side of the ramus, a straight edge connected the respective articulare with the most porterior point on the ramus. This latter point was marked and the procedure repeated for the opposite side. The mid-point, betweenthe two located points, was used for horizontal measurements to the mandibular central and molar. Pogonion, the most anterior point on the chin, was located using a right angle from the mandibular plane.

Figure 2. Patient P.L., Unmarked teeth before and after banding.

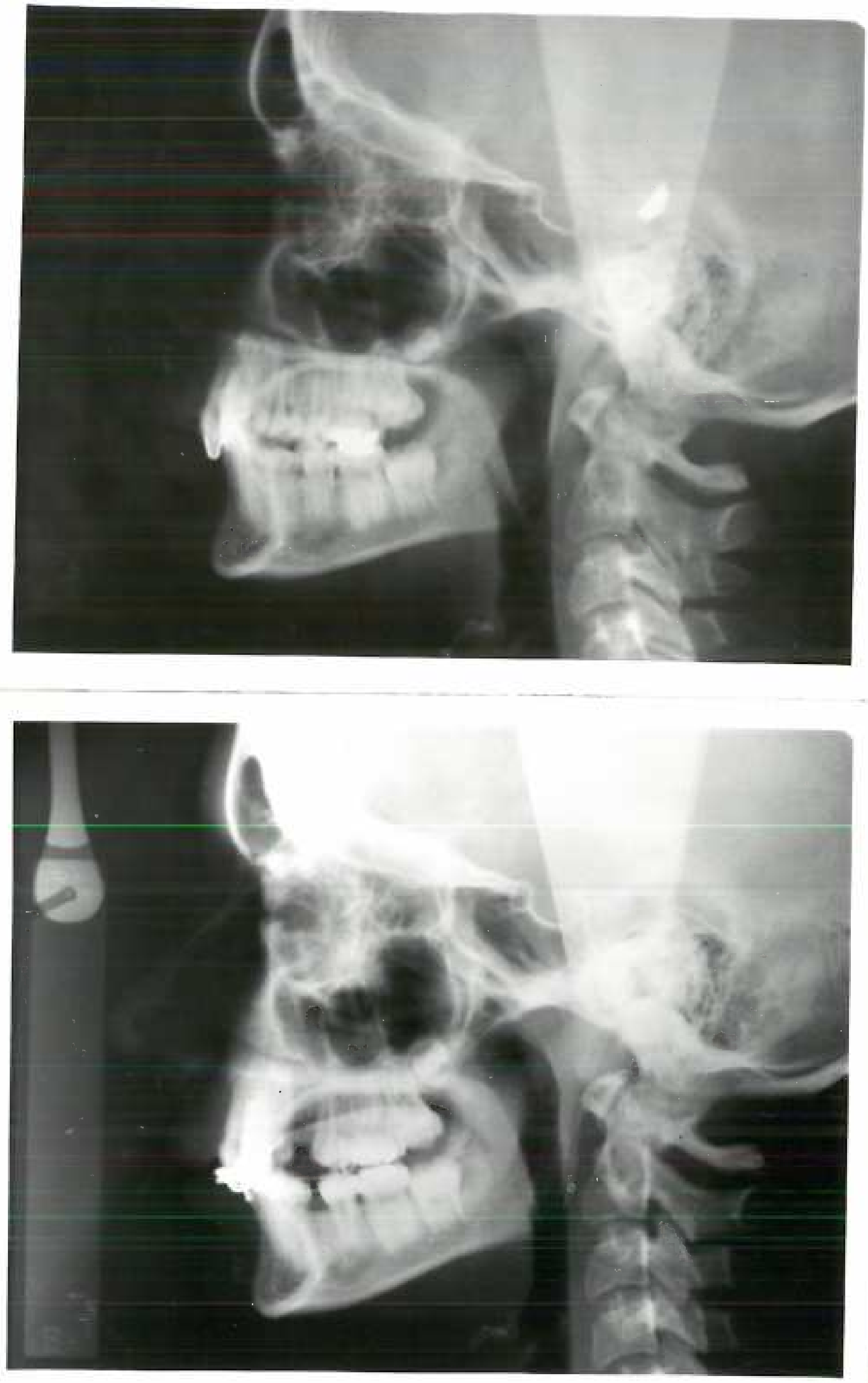

Figure 2. Patient P.L., Unmarked and marked with lead foil and banding material.

Figure 2. Patient P.L., with castings, before and after banding.

Figure III

Reference points from which measurements were made.
1. Nasion
2. Articulare
3. Gonion
4. Posterior point used to construct the mandibular plane, anterior one being the symphysis
5. Gnathion
6. Pogonion

Mid-points were used to locate 2,3, & 6.

A cephalometric tracing was made from the first film in each series before the reference points were marked directly on the films. Prior to marking the reference points, each was observed on the entire set of six films and punched before another one was considered.

The maxillary measurements were made between the two involved teeth and from each tooth to nasion and articulare respectively. The mandibular measurements were also made between the two involved teeth and from each tooth to articulare, gonion, and pogonion. The measurement from gnathion was made only to the incisial edge of the lower central. On the tracings and films without the cast tooth markers, the measurements were made from the reference points to the incisial edge of the centrals and the most mesial aspect of the molars.

Measurements were completed on at least three individuals at one time. The same tracing or film for each individual in the series was completed in rotation before proceeding to the next. The linear dimensions were approximated to the nearest .1 from a metal millimeter scale and reported to a recorder. The recorder ask for a verification of any measurement in the second series, which differed from its homologue in the first series by more than 2.4 mm. It was also rechecked on the corresponding film in the first series. If a .2 millimeter difference for any measurement was detected, another measurement was taken at a later time and the average of the three from the same film was used.

Two methods were used to analyze the data. The first, "F" test,[12] to determine if a significant difference in variation occurred between the different techniques for any of the measurements studied; the second, the S.E.M. to elucidate in absolute values the differences in amount of error existing between the four techniques.

Discussion

In Table I are listed the S.E.M. between films for each of the four techniques within each linear dimension measured. If the error between the different techniques is randomized, the mean difference for each technique will be zero. The variance for each, however, will be inversely related to the reliability of the technique involved. This variation has been tested for significance at the 5 percent level with the statistic "F". All those which are significantly different from the variation existing in the technique using cast tooth markers are labeled with an asterisk. The variances as such are not listed. It should be borne in mind that these figures represent the total error. The portion contributed by tooth movement will be examined later for certain measurements.

The S.E.M. denotes in absolute values the range of variation existing in each technique for each dimension studied. For example, 66 percent of the measurements between the cast tooth marker for the dimension A - $\underline{6|}$ will be within .620 mm. of the mean difference, zero for the entire sample. In comparison to the technique using lead foil and band material, an equal percentage of the measurements will be distributed over approximately 37 percent more area.

In further examination of Table I, it will be noted in the technique using cast gold tooth markers, the S.E.M. is equal to or less than the variation existing in nearly all the other techniques. Variation of this magnitude, however, is to large for our purpose in analyzing orthodontic treatment techniques.

The linear dimensions $\underline{6|}$ - $\underline{1|}$ and $\overline{6|}$ - $\overline{1|}$ were subjected to further statistical analysis and the error contributed by tooth movement was separated from the total error. This is based on the assumption that the

Table I

The Standard Error of the Measurement Between Techniques for Each Linear Dimension

Maxillary Arch

Measurement	Technique Used: Tracing	Unmarked Teeth	Pb Foil & Gold Foil	Cast Tooth Markers
A - 6⌋	0.853	6.07	0.987	0.620
A - 1⌋	.685	0.675	1.12*	0.634
N - 6⌋	1.249*	0.989*	0.550	0.401
N - 1⌋	0.627	0.495	0.593	0.477
6⌋ - 1⌋	1.000*	1.469*	0.915*	0.404

Mandibular Arch

Measurement	Technique Used: Tracing	Unmarked Teeth	Pb Foil & Gold Foil	Cast Tooth Markers
A - 6⌉	1.389	1.562	1.533	0.998
A - 1⌉	0.980	1.240*	.970	0.599
G - 6⌉	1.20	0.809	1.382*	0.705
G - 1⌉	1.118	0.950	.920	0.941
P - 6⌉	1.42*	1.109	.768	0.589
P - 1⌉	0.957*	0.630	0.411	0.393
6⌉ - 1⌉	1.44*	1.253	0.990	0.741
Gn - 1⌉	0.662	0.633	0.421	0.531

*Denotes a significant difference exists between the variation within this measurement and the cast tooth marker measurement as detected by the "F" test at the 95% confidence level.

mean difference for the sample is equal to the amount of tooth movement which has taken place. By substracting this mean difference from each individual difference and applying the formula, S.E.M. = $\sqrt{\frac{\sum d^2}{2N}}$, a new standard error, minus the portion due to tooth movement, is calculated. They are listed in Table II.

Table II *

	Technique Used			
Measurement	Tracing	Unmarked Teeth	Pb Foil & Band Mat.	Cast Tooth Markers
$\underline{6|} - \underline{1|}$	±0.927	±0.874	±0.675	±0.259
$\overline{6|} - \overline{1|}$	±0.509	±0.819	±0.475	±0.253

*Refer to Table III for additional information.

Our S.E.M. in the technique using cast tooth markers is comparable to analagous measurements made by Bjork.[8] His are 0.21 mm. and 0.18 mm. for the dimensions $\underline{6|} - \underline{1|}$ and $\overline{6|} - \overline{1|}$ respectively.

The considerably larger error present in the other three techniques requires some explanation. In these, especially the one using lead foil and band material, the incisial edge of $\underline{1|}$ or $\overline{1|}$ and the mesial aspect of $\underline{6|}$ or $\overline{6|}$ may present vague measuring points. If the incisial edge of $\underline{1|}$ or $\overline{1|}$ is not at right angles to the x-ray beam, the foil appears twisted resulting in a radio-opaque area completely obscuring the incisial edge. A similar result may occur in the unmarked teeth because of a large overbite.

The metal filling material, limited to the posterior teeth in this study, superimposed upon each other in some patients expanded the right permanent molar's mesial aspects into an area instead of a point.

A slight open bite was produced by placement of the cast gold tooth markers, how much variation this produced in articulare relation to the other techniques is questionable.

The tracings have all the error inherent to the films plus additional portions contributed by the reasons previously listed.

In three patients, two surface restorations were placed in the lower permanent first molars after completion of the first series of films. This introduced some discrepancy of fit between the previously prepared casting and the modified occlusal surface. However, it was found only a very slight modification of the casting was necessary to restore the fit.

Summary and Conclusions

Using cephalometrics, the reliability of various tooth marking techniques has been examined. Two series of three films each were employed, the first before the teeth were banded and the second after at least partial banding was completed. From the first film in each series a customary tracing was made to simulate normal case evolution procedure.

The right central incisor and first permanent molars were marked on the second and third films in each series, the former with lead foil over its incisal edge and the latter with a strip of band material between it and the adjoining bicuspid. In the third film, the same teeth were marked with individualized gold castings.

Measurements were taken in each arch between the marked teeth and from each tooth to designated reference points on the tracings and films in both series. The differences in the measurements, between the unbanded and banded series, for the four techniques, were analyzed for variation and absolute differences.

Assuming the measuring error is randomly distributed, the mean difference between the techniques will be zero. However, the variation will be a direct function of the accuracy of the measuring procedure. Using the cast gold tooth markers variation as a base line, the variation in each of the other three techniques were examined for significance using the "F" statistic. Those found to be significantly different are marked with an asterisk in Table I.

The portion of total error introduced by the movement of teeth occuring in the time interval between the two series of films, was removed for the linear dimensions $\underline{6\rfloor} - \underline{1\rfloor}$ and $\overline{6\rceil} - \overline{1\rceil}$. This residual error, due to measuring procedures for the cast tooth markers is comparable to

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Various factors which contribute to the residual error within each technique have been mentioned.

The cast gold tooth marking technique is apparently reliable enough for longitudinal studies evaluating orthodontic treatment technique.

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Table III

The Standard Error of the Measurement Between Techniques for Each Linear Dimension Minus the Portion Due to Tooth Movement

	Technique Used			
Measurement	Tracing	Unmarked Teeth	Pb Foil & Band Mat.	Cast Tooth Markers
6⌋ - 1⌋	0.927	0.874	0.675	0.259
6⌉ - 1⌉	0.509	0.819	0.475	0.253
A - 6⌋	.506	.593	.602	.379
A - 1⌋	.337	.440	.589	.313
N - 6⌋	.824	.675	.373	.243
N - 1⌋	.429	.356	.430	.321
A - 6⌉	.792	.953	.790	.627
A - 1⌉	.577	.770	.597	.370
G - 6⌉	.736	.560	.889	.387
G - 1⌉	.710	.622	.530	.553
P - 6⌉	1.04	.634	.511	.743
P - 1⌉	.550	.327	.210	.264
Gn - 1⌉	.436	.400	.268	.336