

**THE REPRODUCIBILITY OF JOHNSTON'S
CEPHALOMETRIC SUPERIMPOSITION METHOD IN ANALYZING
ACTIVATOR TREATMENT CHANGES.**



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ABSTRACT

A method of cephalometric superimposition, described by Johnston (1986), was evaluated to determine its reliability. Fifteen pairs of before- and after-treatment cephalograms, were measured five times, and an analysis of variance (ANOVA) was carried out on the measurements to check for any significant differences between the repeated measures.

The results of the analysis found Johnston's method of cephalometric superimposition to be reliable and consistent, with lower standard deviations in the measurements found, compared to other commonly used methods. This method was then used to analyze the treatment changes in activator patients.

A sample of thirty-six Class II division 1 patients treated with activators were analyzed, and it was found that the treatment changes were mainly dentoalveolar. There was a slight orthopedic restraining effect on the maxilla, but no significant mandibular growth was observed in the patients, above that which could be expected from normal growth.

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DEDICATION

This thesis is dedicated to my husband, Kamel,
for his patience and understanding, without which,
this thesis would not have become a reality.

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A. INTRODUCTION

Since the introduction of standardized cephalometrics in 1931 by Broadbent, orthodontists have made cephalometric roentgenograms a very important part of their diagnostic armamentarium. Their treatment decisions have become geared towards the achievement of certain perceived cephalometric norms, and they measure the success of their treatment based on their findings of the changes seen on subsequent radiographs.

To compare changes from one cephalometric roentgenogram to another, the radiographs or their tracings are superimposed on certain cephalometric landmarks or planes which are considered to be stable. The change in positions of the other landmarks are then measured either relative to one another or to the reference plane in order to determine the changes.

Many different methods of cephalometric superimposition have been described by various authors (Broadbent, 1931; De Coster, 1952, 1953; Steiner, 1953; Bjork, 1969; Bjork and Skieller, 1983; etc.), using different anatomic planes or constructed lines as the references. Other authors (Kerr, 1978; Lee, 1980; McWilliam, 1982, 1983a, b) have described methods of superimposing directly from radiographs, thus removing tracing error. No plane or line of superimposition, nor any method of superimposition, has yet been found to be ideal.

The errors associated with cephalometric superimposition can be attributed to growth and remodelling at the reference plane (Bjork, 1969; Bjork and Skieller, 1977), as well as the reproducibility of the act of superimposition on that plane itself

(Baumrind et al, 1976; Houston and Lee, 1985). Other factors include landmark identification and tracing error, as well as errors inherent in the cephalometric technique itself (Hixon, 1956; Baumrind and Frantz, 1971a, b; Gravely and Benzies, 1974; Cohen, 1984). Several authors (Baumrind et al, 1976; Houston, 1983; Pancherz and Hansen, 1984; Houston and Lee, 1985; Ghafari et al, 1987) have discussed the relative inaccuracy of the different methods. The errors were found to be related to the reproducibility of the identification and superimposition of the reference plane, and they were magnified the further the landmark is from the plane of reference. Thus, the choice of the plane of superimposition may affect findings, leading to possibly false impressions of the effect of growth or the effectiveness of the treatment.

Ghafari and Efstratiadis (1989) reported that superimposition on the maxilla gave a different interpretation of the changes, compared to superimposition on the cranial base. Maxillary superimposition would take into account the change in the position of the maxilla in relation to cranial base, and provide an assessment of both the skeletal and dentoalveolar mandibular movements and their contribution to the occlusal change.

Johnston (1986) described a method in which he accounts for the treatment changes by breaking it down into: tooth movement relative to basal bone; and the translatory growth of the jaws, both with respect to the cranial base and to each other. His main plane of reference is the palatal plane, which is considered by Baumrind et al to be the least reliable compared to other commonly used reference planes. The relative proximity of the palatal plane to the structures studied, however, makes it easier to identify the areas in which changes have actually occurred and may minimize the errors (Baumrind et al, 1976).

This method, if proven to be reproducible, could be very useful in determining treatment changes, especially, in cases treated with functional appliances, where there is some controversy as to whether the changes seen were due to mainly tooth movement or an actual apical base change.

The aim of this thesis is to evaluate the reproducibility of this method of superimposition, and to use it to analyze the treatment effect in thirty-six cases of activator treatment.

Firstly, however, the distinction between 'validity' and 'reliability' must be clearly defined. Measurement validity refers to the degree of approximation to true physical values, while reliability of measurements refers to repeatability. Thus in cephalometry, validity must be ascertained by comparison of measurements from cephalograms of a skull with actual measurements on that skull; while reliability is determined by making repeated measurements on the same film (Savara et al, 1966). Houston (1983), however, stated that 'reliability' may be used in a broader sense to encompass both 'validity' and 'reproducibility'. He defined reproducibility (or precision) as the closeness of successive measurements of the same object. In this thesis, the term 'reliability' is used as defined by Savara et al, and is interchangeable with the term 'reproducibility'. The validity of Johnston's method of superimposition is beyond the scope of this thesis and will not be discussed.

B. REVIEW OF LITERATURE

1. THE CEPHALOMETRIC TECHNIQUE (Manson-Hing,1985)

Cephalometric radiography is the production of skull radiographs, which are useful in making measurements of the cranium and orofacial complex. The radiograph is called a cephalogram. The lateral or profile view of the skull is the most common projection used in orthodontics; however, the posteroanterior and oblique views are also utilized.

In this chapter, the technique and the factors affecting the quality of the radiographic image of the lateral cephalogram will be discussed.

1.1 EQUIPMENT AND SET-UP (Manson-Hing,1985)

The basic equipment needed to produce a cephalometric radiograph is a source of x-rays, a patient head holder (cephalostat), and an image recording system (usually films, screens, and film processing).

Cephalometric radiographs can be made with the conventional dental x-ray machine used for making intra-oral radiographs. These machines usually have a self-rectified x-ray tube with a stationary anode, 10-15 milliamperes, and 70 kVp (peak kilovoltage) or a kilovoltage range around 70 kVp. For cephalometric purposes, the tubehead of this type of machine is fixed to a stationary device to direct the x-ray beam in a fixed position relative to the patient and film.

The patient is in an upright position, and may be either standing or seated. A cephalostat is used to stabilize the patient in a fixed position in the x-ray beam. The patient's head is then positioned with the Frankfort Horizontal plane parallel with the floor.

The x-ray source is positioned on the right side of the patient at a standardized distance of 5 feet (1.5 m) from the midsagittal plane of the patient (Fig 1). The patient is positioned in the x-ray beam with both the external auditory meati in the central ray, thus superimposing them on each other. The film is placed perpendicular to the central ray of the x-ray beam in both the horizontal and vertical planes. In this position, the midsagittal plane of the patient is plano-parallel with the film.

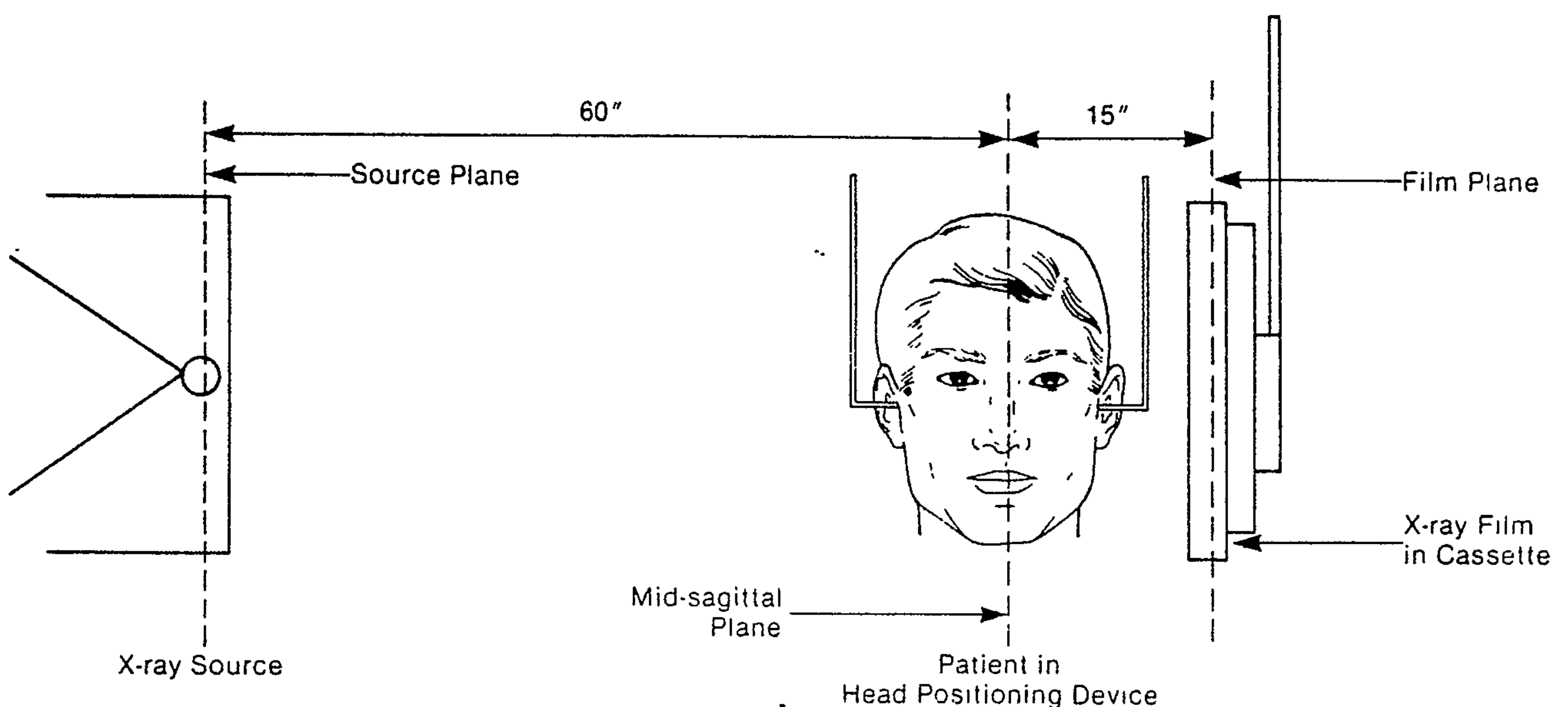


Fig. 1
Diagrammatic representation of the standard cephalometric arrangement (Proffit, 1986).

The patient-to-film distance varies among practitioners of cephalometric radiography. Some practitioners maintain a constant patient-to-film distance in order to standardize the amount of magnification in the images of all radiographs. Other practitioners prefer to place the film as close as possible to the patient to obtain maximum image sharpness.

Film exposure factors depend upon the speed of the film, the speed of the screens, the tube to film distance, the size of the patient's head, the milliamperage and kilovoltage used in generating the x-ray beam, and the film exposure time. Since the patient's head size cannot be varied by the operator, one of the other factors must be adjusted to produce radiographs having similar density or blackness. The most common practice is to adjust either exposure time or kilovoltage to compensate for patient head size. A short exposure time is desirable to reduce image blurring or unsharpness in the radiograph due to patient movement. With medium speed film and screens, the exposure time is approximately 0.6 to 1.2 seconds.

1.2 FACTORS AFFECTING THE QUALITY AND ACCURACY OF THE IMAGE (Thurow, 1951; Reiskin, 1980)

Blurring of the image can be caused by:

1. Motion of the subject or machine.
2. Optical blurring, which is dependent on the size of the x-ray anode focal spot.
3. Grain, caused by intensifying screens and film.

1.2.1. MOTION OF THE SUBJECT OR MACHINE

In cephalometric work, the exposure time is measured in seconds, giving ample time for movement to blur the film. The equipment is usually installed in such a way that it will not move, but is quite impossible to make patients completely immobile.

Slight inaccuracy in head positioning may lead to substantial errors of interpretation (Thurrow, 1951; Shaw, 1977; Reiskin, 1980; Houston, 1983).

However, there are a few measures to minimize their movement (Thurrow, 1951).

1. Make sure that the patient is comfortable, and not bent down or stretched too far.
2. Adjust earposts carefully to ensure that it is not too loose as to give inadequate support, and not too tight as to make the patient squirm.
3. Have the patient arrest his/her breathing during the exposure.
4. Reduce the exposure time with intensifying screens and the highest milliamperage available. Doubling milliamperes cuts time and movement in half.

1.2.2 OPTICAL BLURRING (Thurrow, 1951)

The width of the fuzzy part of the shadow (penumbra) is directly proportional to the size of the anode target in the x-ray and to the distance of the subject from the film. Blurring is increased whenever these are increased. The width is inversely proportional to the distance of the x-ray target from the subject.

Therefore, in order to reduce optical blurring, the patient has to be as close as possible to the film, as far as possible from the source of the x-ray, and to use the smallest possible target.

In the cephalometric technique, the patient is near enough to the film to keep the effect of this distance at a practical minimum. The source of the x-rays are standardized at a distance of 5 feet, which is a good compromise, as the reduction of blurring between the five feet and six feet distances is 0.5% (Adams, 1940).

The target size is a fixed characteristic of each x-ray tube, and may vary from one to several millimetres square. For a target with an effective size of 1.5 mm. square, the

width of the penumbra will be as much as 0.14 mm. square. This means that there is a blurred area this wide along the edge of every image on the film, making a total possible error of 0.28 mm. Initial choice of an x-ray tube is the only important control to be had over the optical blurring, and here there are two opposing problems. A small target cannot handle as much current as a larger one, so what is gained in a small target size is lost in potential exposure speed and motion. The best way is to obtain a favourable balance of size and current and to use it to best advantage. The selection of milliamperage is usually limited to between 10 and 30 milliamperes. Once the tube is selected, it must be operated at the highest possible amperage to get the balance between optical blurring and motion.

1.2.3 INTENSIFYING SCREENS

(Thurrow, 1951; Reiskin, 1980; Manson-Hing, 1985)

These screens depend for their intensifying action on the fact that they contain many crystals of heavy (high atomic number) material that absorb x-rays efficiently and convert the energy into light. (i.e. the crystals fluoresce). The visible light image is then absorbed by light-sensitive film (screen-film) which is then processed to produce a radiograph. Screen-film systems need less radiation to produce a radiograph than films used alone. Exposure time and patient radiation dose are reduced when the screens are used.

The larger the size of the crystals used, or the thicker the layer, the faster is the screen or film. However, the detail and sharpness of the radiographic image is inversely proportional to the speed of the film. The choice of a film-screen system is dependent on the type and amount of information necessary for the diagnostic task. Enough information can be obtained from an extremely fast imaging system for a satisfactory cephalometric tracing in orthodontic diagnosis.

1.2.4 ENLARGEMENT (Adams, 1940; Thurow, 1951)

In the cephalometric technique the film and the sagittal plane of the patient are parallel. However, as the source of the x-rays is a very small area, divergence of rays creates enlargement purely on the basis of successive triangulation. Therefore the enlargement increases as the object-film distance increases. It also follows that the rays closest to the central axis are more nearly parallel and hence gives less distortion than those nearer the periphery of the picture. This has been stated by the roentgenologist in terms of the formula,

$$\frac{\text{object size}}{\text{image size}} = \frac{\text{target-object distance}}{\text{target-film size.}}$$

The simplest solution is to make enlargement constant for all films and then ignore it. Obtaining constant enlargement merely requires using the same subject-film distance for all pictures. With enlargement constant, it can be safely ignored for angular measurements, superimposing serial tracings, and for ratios of linear measurements. Correction for constant enlargement is simple, since the same correction factor or scale can always be used.

With variable enlargement, correction for enlargement is still not necessary for comparison of angles or for linear ratios where the figures in each ratio come from the same film. Correction is necessary for superimposing serial tracings when linear distances are being compared, for linear ratios where the figures in the ratios are from different films, and for absolute linear measurements.

Correction for enlargement can be done in many ways. It can be done with scales projected on the film, as described by Broadbent (1931), or it can be done by determining the actual ratio, as described in the formula given above. Another way

would be by using a slide rule, by-passing the actual ratio itself and reading the correct dimension.

1.2.5 DISTORTION (Thurrow, 1951)

Distortion is considerably more serious than simple enlargement, since it can play havoc with just about everything which might be done with a cephalometric film. Angles, lines and proportion are all altered by distortion. Distortion is the result of the fact that the patient is three-dimensional, and those parts which lie outside the sagittal plane (example: orbitale, first molars, mandibular border, and pterygomaxillary fissure) are enlarged varying amounts. The points on the side farthest from the film are affected more by enlargement than their mates, giving a distorted view.

Accordingly, in the ideal cephalometric film, two distinct mandibular outlines should be seen, with the image of the side nearest the film slightly behind and above that of the other side (Shaw, 1977).

This distortion is dependent only on the perpendicular distance of the points involved from the film. Position on the film or position in relation to the central ray has no bearing on enlargement or distortion. As a result, there can be no distortion within a single plane parallel to the film; distortion exists only between such planes.

Correction of this error is simple. All that has to be done is to use the midpoint between bilateral points instead of the left or the right point alone. This has the effect of projecting the points to the sagittal plane and making all measurements from this common base where the enlargement is the same. However, this approach cannot differentiate between geometric distortions and actual subject asymmetry, so that it obliterates asymmetry by averaging asymmetric structures (Spolyar, 1987).

2. THE RELIABILITY OF THE CEPHALOMETRIC TECHNIQUE

Prior to the use of radiographs, orthodontic case analysis was necessarily subjective and the determination of skeletal class was largely based on clinical assessment. The advent of x-rays provided new opportunities for skeletal analysis but, until standardization of the x-ray view was possible, the subjective element in the radiographic image remained. The development of the cephalostat by Broadbent (1931) began the era of radiographic cephalometrics by producing the means of repeating the x-ray view of the head in a reproducible way.

Measurements based on cephalometric radiographs are subject to error, and this must be borne in mind in the interpretation of clinical and research findings based on this technique (Houston, 1983; Cohen, 1984).

Baumrind and Frantz (1971b) listed three general types of error in head film measurement. These were:

1. errors of projection;
2. errors of landmark identification;
3. the variability or inconsistency of measurement by a single observer or group of observers.

Moyers and Bookstein (1979) suggested that conventional cephalometric techniques had conceptual as well as technical handicaps. Thus to the above list may be added:

4. errors due to the invalidity of applying conventional cephalometrics to the living skull.

2.1 ERRORS OF PROJECTION

Errors of projection resulted from the fact that the head film was a two-dimensional shadow of a three-dimensional subject. Since the rays which produced this shadow were non-parallel and originated from a very small source, head films are always distorted enlargements, the enlargement factor varying with the plane at which the estimated point lay. Head films were further distorted by the foreshortening of distances between points and structures not on the central ray (Adams, 1940; Baumrind and Frantz, 1971a; Houston, 1983; Cohen, 1984).

In theory, points that lay in the midsagittal plane were held at a constant distance from both the film and the x-ray emitter by the nature of the cephalostat design. Hence, these points all had a similar enlargement factor.

An attempt is conventionally made to reduce the impact of projection errors by the use of angular rather than linear measurements wherever feasible. In addition, those linear measurements which are used are conventionally defined as lying in the midsagittal plane. According to Baumrind and Frantz (1971b) and Houston (1983), precise positioning of patients in any head holder is very difficult, resulting in a situation in which the true anatomic midsagittal plane coincides with the nominal midsagittal plane of the x-ray-cephalostat system only rarely and by chance. Studies by Bjork (1947), Midtgard et al (1974), Houston et al (1986) and Sandler (1988a), however, have shown that patient positioning is not a major source of error, provided that an appropriate amount of care is taken.

Adams (1940) and Bjork (1947) proposed that the differences in images occurring due to slight rotation of the head could be corrected by taking the midpoint between the images of the right and left sides. This was, however, disputed by Salzmann

(1966) as there is no exact symmetry of the human face, and taking the midpoint of the images of both sides is not really an exact method.

2.2 ERRORS OF LANDMARK IDENTIFICATION

These are the errors involved in identifying specific landmarks on head films. It is one of the most important sources of error in cephalometry (Hixon, 1956; Miller et al, 1966; Baumrind and Frantz, 1971a; Gravely and Benzies, 1974; Midtgard et al, 1974; Houston et al, 1986).

The operator is not always able to reproduce his location of a specific landmark, and there may be differences in opinion between two or more operators on the location of a landmark (Hixon, 1956; Richardson, 1981; Stabrun and Danielsen, 1982; Pancherz and Hansen, 1984; Savage et al, 1987).

The reliability of landmark identification is affected by (Houston (1983):

1. A lack of clarity of the cephalometric landmark due to superimposition of structures;
2. Blurring of the image brought about by secondary radiation or movement during exposure;
3. Lack of film contrast and emulsion grain;
4. The conditions under which they were measured; and,
5. The skill of the operator.

Cephalometric tracing errors were found to be high even when tracings were done by experienced orthodontists but are even higher when ancillary staff are used (Gravely and Benzies, 1974). It is a process that cannot be done mechanically and it follows that the use of digitizers are unlikely to reduce errors substantially although these methods may reduce the time spent analyzing the head films.

Baumrind and Frantz (1971a) and Houston (1983) found that errors in landmark identification were large even when one was replicating assessments of the same head film. The magnitude of error varied from landmark to landmark (Baumrind and Frantz, 1971a; Gravely and Benzies, 1974), and the distribution of errors for most landmarks was not random. Each landmark had its own characteristic and usually non-circular envelope of error (Richardson, 1966; Baumrind and Frantz, 1971a; Broch et al, 1981; Stabrun and Danielsen, 1982; Pancherz and Hansen, 1984) .

As a general rule, points that were on an edge which "folded sharply", such as the incisal edges, were easier to identify than those which curved gradually, such as B point or gonion, where the variability of location tended to be larger and to be distributed along the edge itself (Baumrind and Frantz, 1971a; Houston, 1983).

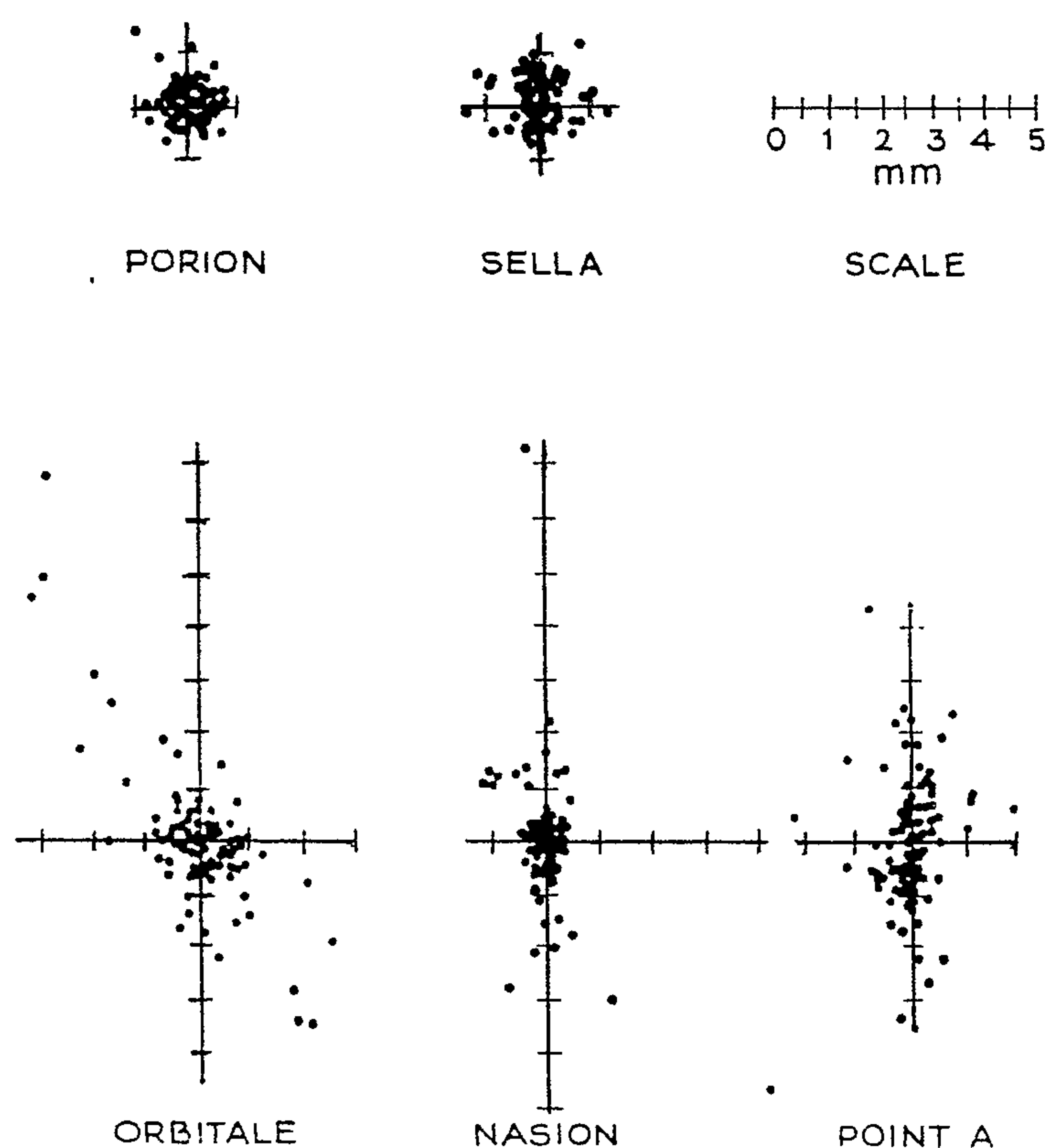


Fig. 2

Distribution of estimating errors, maxillary skeletal landmarks (Baumrind and Frantz, 1971a).

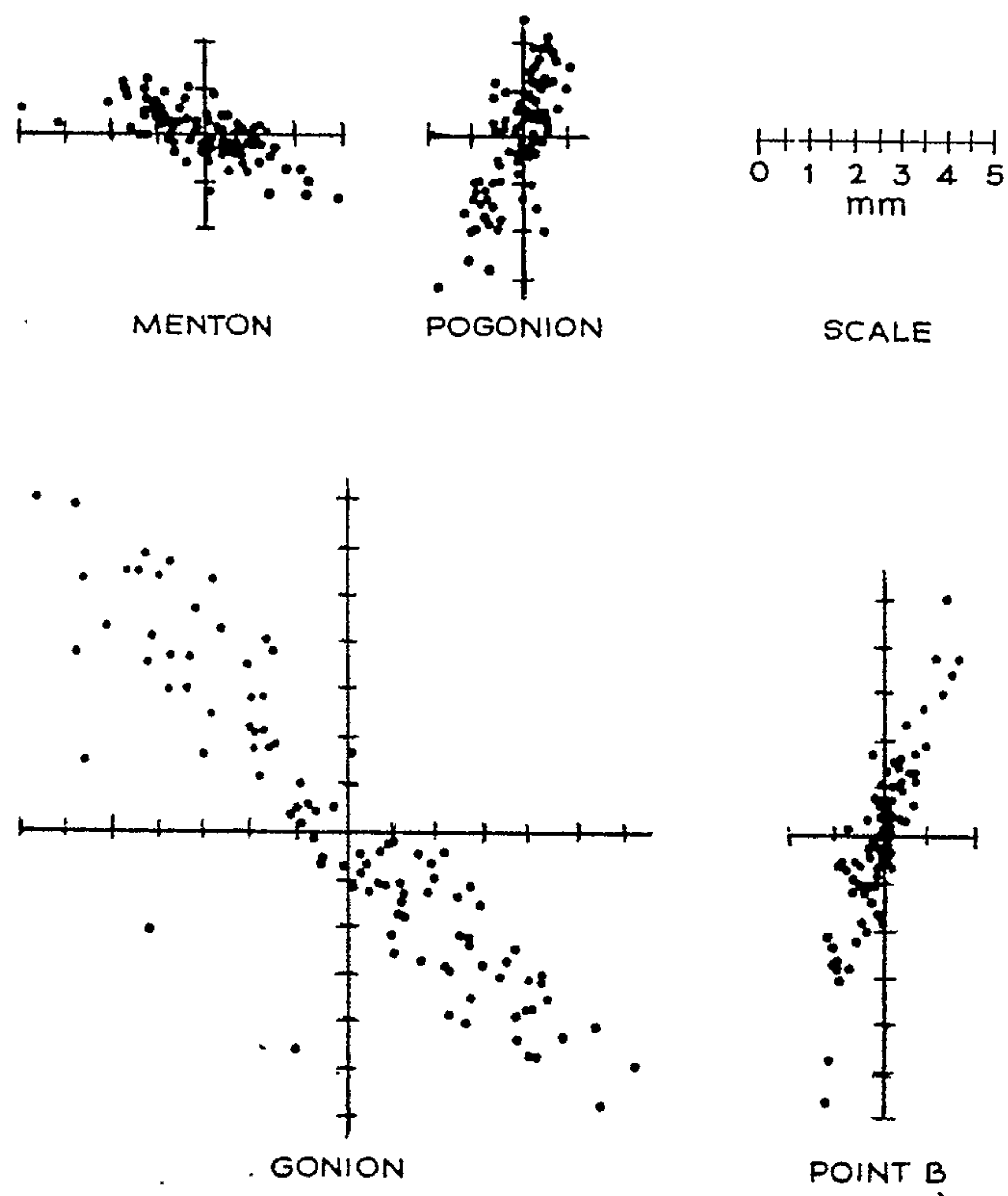


Fig. 3
Distribution of estimating errors, mandibular skeletal landmarks (Baumrind and Frantz, 1971a).

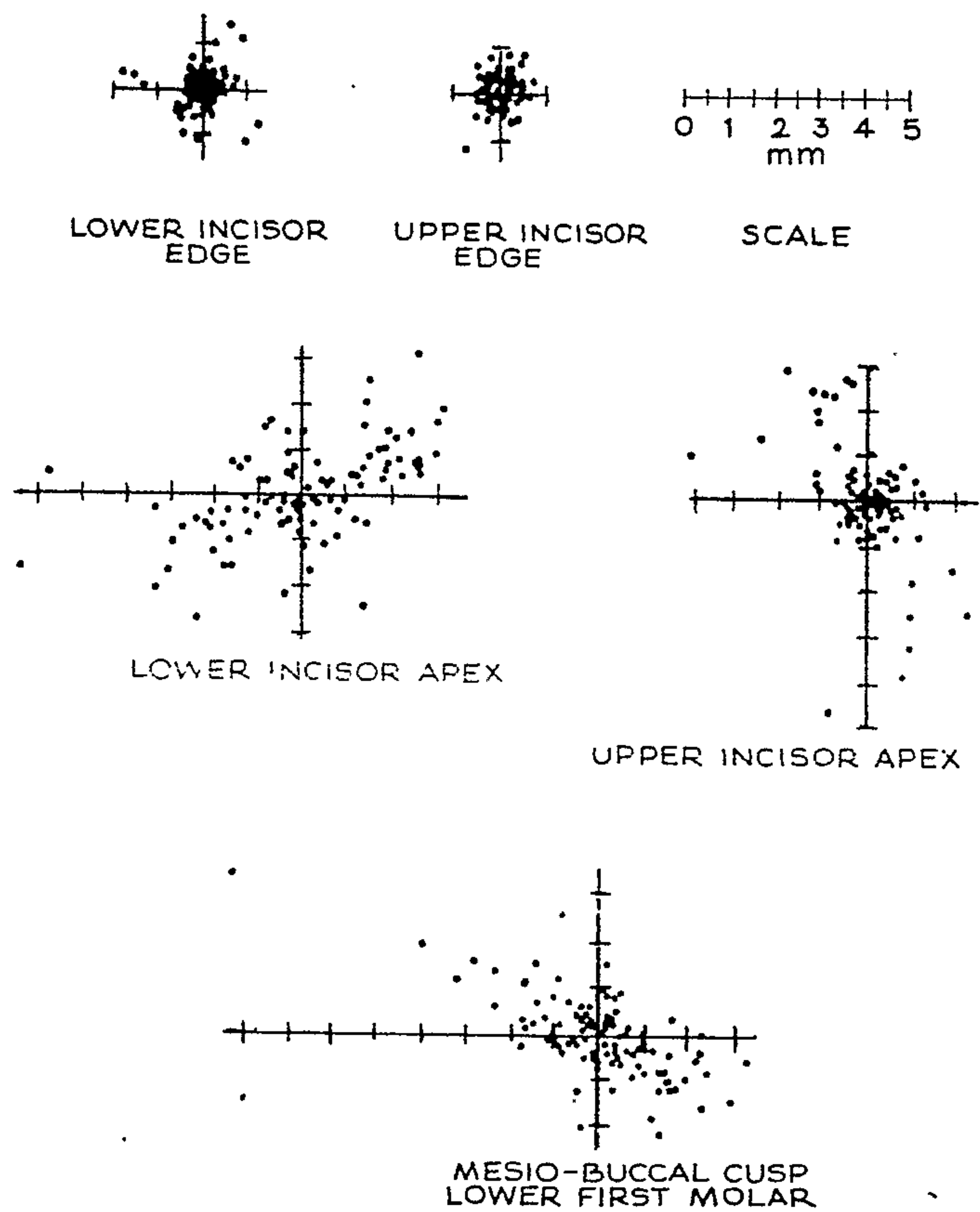


Fig. 4.
Distribution of estimating errors, dental landmarks (Baumrind and Frantz, 1971a).

Baumrind and Frantz (1971b) stated that there are three considerations which determine what impact the error in identification of a specific landmark will have on the linear and angular values involving that landmark:

1. The actual magnitude of the error involved in identifying the specific landmark.
2. The linear distance on the tracing between the point representing the landmark and the point representing the other landmarks with which it is connected in the process of computing a given measure. For linear measures, the shorter the distance between two points, the greater a proportion of the total linear distance a measurement error of a given magnitude constitutes. Therefore, the shorter the line segment measured, the greater is the percentage error introduced by a measurement error of a given size. In the case of angular measures too, the closer together the points determining either line segment, the greater will be the effect of measurement error on the angular value calculated (Krogman and Sassouni, 1957).
3. The direction from which the line segment between two landmarks intersects the envelope of error of each landmark. If the direction of a line segment is such that it intersects the envelope of error on its narrower dimension, the average error introduced would be smaller than if the line segment intersects the broader dimension of the envelope .

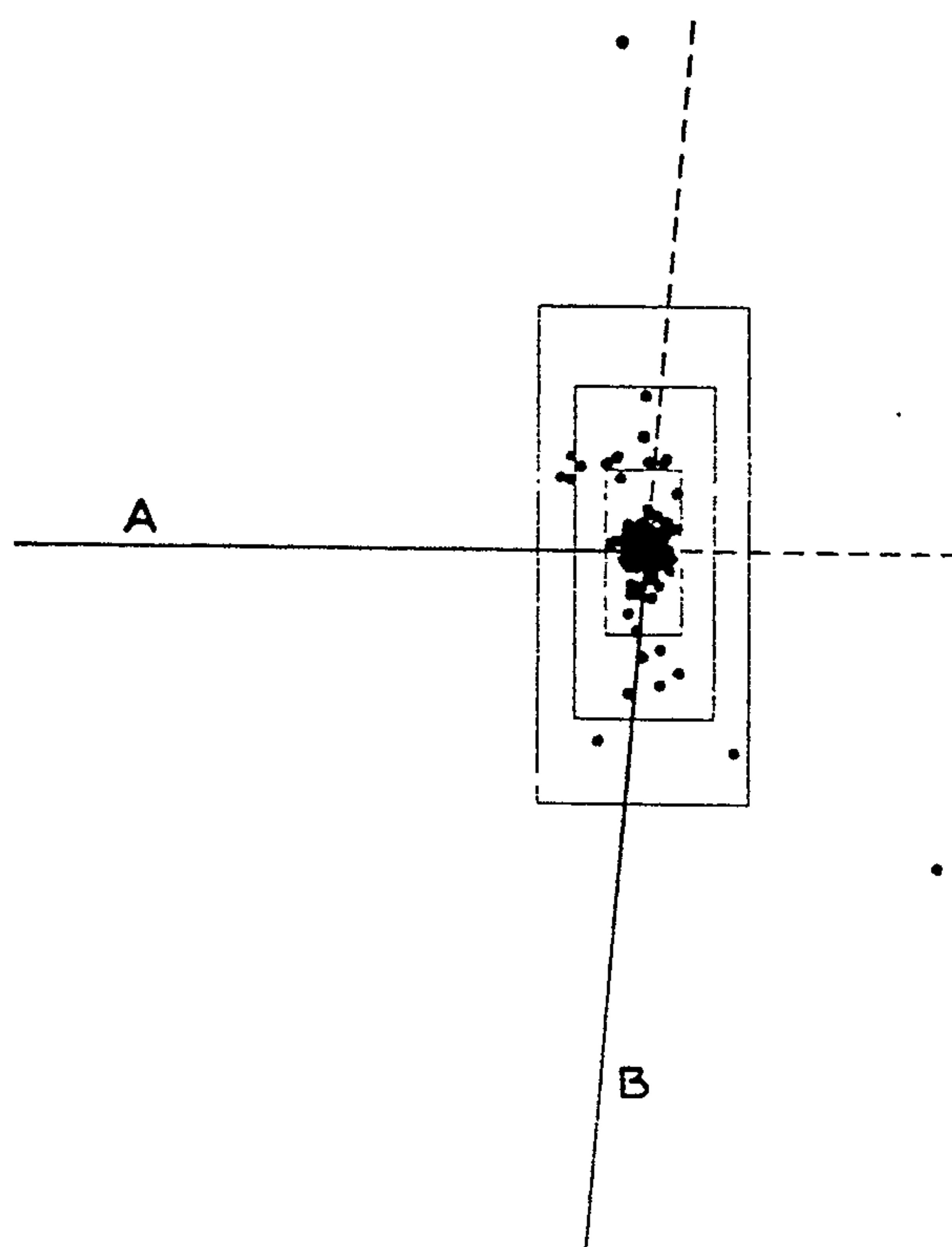


Fig. 5

The effect of a noncircular envelope of landmark error on the computational values of a representative measure. The scattergram of error for 100 estimates of nasion is shown, with boxes indicating zones 1,2, and 3 standard deviations of the estimating error in the x and y directions taken separately. It may be observed that the errors are greater in the vertical direction than in the horizontal direction. For this reason, other factors being equal, a greater error will be introduced in the computation of angle SN-pogonion by the line segment from sella (A) than by the line segment from pogonion (B) (Baumrind and Frantz, 1971b).

Some of the steps recommended to reduce errors in landmark identification are:

1. Obtain films of the best possible quality, taken under standard conditions (Baumrind et al, 1976).
2. More rigorous and uniform definitions of landmarks (Baumrind and Frantz, 1971b; Baumrind et al, 1976; Houston, 1983; Pancherz and Hansen, 1984; Houston et al, 1986; Ghafari et al, 1987).

3. Abandonment or reduction of reliance on those landmarks which could not be defined rigorously enough to make them reproducible with acceptable reliability (Broadway, 1962; Baumrind and Frantz, 1971b; Gravely and Benzies, 1974).
4. Routine use of replicated measurements (Baumrind and Frantz, 1971b; Stabrun and Danielsen, 1982; Houston, 1983; Pancherz and Hansen, 1984; Houston et al., 1986). It is the tracings which should be replicated, not just the measurements of tracings.

2.3 THE VARIABILITY OR INCONSISTENCY OF MEASUREMENT BY A SINGLE OBSERVER OR GROUP OF OBSERVERS

These are the errors introduced in manually measuring angles and linear measurements. Measurement errors associated with the thickness of the pencil line and the perceptive limits of the human eye are contributing factors to this type of error.

Bjork and Solow (1962) showed that by inserting lines or points on the radiographs, a false correlation may result for angles having a vertex or limb in common. This would also hold true for linear measurements. To avoid this source of error, measurements on films should be made without marking the reference points or lines. Bjork and Solow also found that indirect measurements could incorporate any errors in the values from which they were derived by addition or subtraction, and recommended that all measurements be made directly and not be obtained by calculation from other values.

Miller et al (1966) found that the measurement variability was small, and that landmark location variability was five times that due to measurement. Savara et al (1966) also found measurement variability to be small, and almost constant ($0.12 \pm$

0.06 mm.), and much smaller than landmark location variability. They also found that the intra- and inter-operator variability was similar.

Baumrind and Frantz (1971b) described the errors introduced in drawing lines by hand and in measuring with a protractor as "very real but conceptually trivial". They suggested that errors of this type could be entirely eliminated by delegating to computers (with digitizers) the task of calculating linear and angular relationships algebraically, given the landmark coordinates.

Sandler (1988b), however, in comparing the errors involved in taking linear and angular measurements using three different methods - hand instruments on tracings, digitization of tracings and direct digitization of radiographs - found that there is an appreciable amount of error in taking cephalometric measurements from radiographs whichever method was chosen. The errors in measurement with hand instruments were slightly less than those using digitized tracings, but slightly greater than those digitized directly. The differences were not marked, and where constructed points were involved, using hand instruments was found to be a more reproducible method.

Certain linear measurements had consistently high errors with all three methods of measurement, indicating the importance of rigid landmark identification and the selection of suitable landmarks when a particular dimension is required. However, Sandler also found that hand measurements, if done carefully, compare reasonably well with methods involving the digitizer, and there was no reason why results using traditional methods should be considered any less reliable.

Richardson (1981) compared the reproducibility of direct digitizing on cephalometric radiographs to the reproducibility using hand instruments. He found the standard deviations of the differences were less using the digitizer as compared to hand

instruments with the majority of landmarks, but felt that as the landmarks rely on anatomical features which cannot be located with a degree of accuracy as to match the digitizer, there was no gain in accuracy in using this precise instrument.

Cohen (1984) evaluated the use of the digitizer on tracings, untraced films and modified 'dot' tracings. He found that the errors in measurement of angles were comparable irrespective of the method chosen, but errors in landmark identification were smallest when measurements were made directly on radiographs. The reason was that two guesses have to be made when measuring a tracing; firstly, in drawing the tracing of the radiographic landmark and secondly, in attempting to record the exact position of the pencil line, which has an appreciable width. He felt that the more direct the observation, the less room there was for error.

2.4 ERRORS DUE TO THE INAPPROPRIATENESS OF APPLYING CONVENTIONAL CEPHALOMETRIC TECHNIQUES TO THE LIVING SKULL

Moyers and Bookstein (1979) criticised traditional cephalometrics largely on the grounds that it forces the reduction of information available on radiographs to point data. This reduced data misrepresented shape changes due to growth, in that growth was portrayed as a vector displacement rather than a generalized distortion. They suggested instead a method using "biorthogonal grids" which was a computer-based representation of a cephalogram, as a more biologically relevant tool for craniofacial growth research.

3. METHODS OF CEPHALOMETRIC SUPERIMPOSITIONS AND THEIR RELIABILITY

The reliability of any method of superimposition is dependent on the accurate identification of reference points or structures, their stability during the observation period, and the precision of the registration procedures. Other factors include the quality of the original radiographs, the position of the head in the cephalostat and the care and expertise of the operator and the protocol that is used to record the superimposition (Houston and Lee, 1985).

The actual process of making tracing comparisons is confounded by the existence of measurement errors as discussed in Chapter 2, plus an additional set of errors associated specifically with the inaccuracy of the act of tracing superimposition itself.

The planes of superimposition most commonly used in orthodontics are:

- (i) constructed planes such as the sella-nasion line registered on sella, as well as anatomic planes such as;
- (ii) anterior cranial base (De Coster's line)
- (iii) palatal plane, and
- (iv) mandibular border.

In their study on the accuracy of the four different superimposition planes mentioned above, Baumrind et al (1976) found that the errors involved in superimposition were considerable and that they varied with the reference plane or line chosen. They described errors of superimposition in terms of a translatory component and a

rotational component. Translatory errors were found to be constant for the entire measurement area, whereas rotational errors varied according to the distance of the landmark from the centre of rotation. In general, rotational effects were found to produce a larger portion of the total error of superimposition than translational effects.

In order to minimize these errors, multiple tracings of each individual film and multiple independent replications of each act of tracing superimposition are recommended to increase the reliability of measurements for research purposes.

3.1 SUPERIMPOSITION ON SELLA-NASION LINE REGISTERED ON SELLA

Many of the early authors (Broadbent, 1931; Brodie, 1941; Bjork, 1969) used the sella-nasion (SN) line as the reference line for superimposition. Sella was used as the registration point, since growth along the frontal-nasal suture can lengthen the SN line, taking nasion forward. If there is growth to a marked degree at the frontal sinuses, however, nasion may be moved above or below the SN line, making it unsuitable for superimposition purposes (Bjork and Skieller, 1983).

Steiner (1953) used the sella-nasion line registered at nasion to reduce the errors due to growth at nasion to relate the positions of A and B points.

Richardson (1966) investigated a number of cephalometric lines and planes and found that, while reliability varied considerably, reference planes defined by cephalometric landmarks showed greater precision than reference lines represented by anatomical structures, such as De Coster's line. He found nasion to be more reproducible horizontally than vertically, and that the angular variations of the sella-nasion line was small.

Foster et al (1981) reported the mean error of determining the angle of the various lines of superimposition to the vertical were 0.86 degrees for the sella-nasion line, 1.41 degrees for the Frankfort Horizontal, 1.29 degrees for the maxillary line, and 4.9 degrees for the mandibular line. However, they noted that the method errors were all small.

Houston and Lee (1985) tested the reproducibility of superimposition of tracings on the sella-nasion line, registered at sella and found that it had a method error of 1.41 mm. (standard deviation) at the mid-points of the registration lines, while Baumrind et al (1976) found the standard deviations of the errors of tracing superimpositions of various landmarks varied from 0.36 mm. (nasion) to 1.45 mm. (pogonion). The structures furthest away from the reference plane (i.e. pogonion, Point B), were found to have the greatest error (Baumrind et al, 1976; Pancherz and Hansen, 1984; Houston and Lee, 1985).

3.2 SUPERIMPOSITION ON THE ANTERIOR CRANIAL BASE

De Coster (1952, 1953) rejected sella-nasion because of appositional growth at the region of nasion, and recommended the use of the endocranial outline of the anterior cranial fossa, which is unaffected by growth changes after the age of 7 years. The important points of De Coster's line are: the anterior lip of sella turcica, the sphenoid ethmoidal suture, the planum or upper surface of the sphenoid body, the roof of the ethmoid masses, and the endocranial side of the frontal bone.

Ghafari et al (1987) found the method of best fit of the anterior cranial base as a reference for cephalometric superimposition to be better than superimposition on the SN line, as it takes into consideration the detailed individual anatomy of the cranial base, rather than simplifying this anatomy into lines or planes with different registration points which may be modified by growth.

Lewis and Roche (1988) found small increments of growth in the cranial base after 17-18 years of age. The maximum rates of growth after 18 years occurred from about 29-36 years of age, with marked variations in timing and rates of growth between individuals. They also found small decreases in the length of the cranial base after the maximum values were attained.

Richardson (1966) found De Coster's line to be only moderately good as far as tracing reproducibility was concerned. He suggested that the line might gain in reproducibility if two films were superimposed directly, since it will be possible to register the small detail of bone structure much more effectively than two tracings.

Houston and Lee (1985) tested the reproducibility of superimposition of tracings on the anterior cranial bases, and found that it had a method error of 1.74 mm. (standard deviation) at the mid-points of the registration lines.

Baumrind et al (1976) found landmark displacements due to error of tracing superimposition on the anterior cranial base ranged from 0.38 mm. (upper molar cusp) to 1.51 mm. (menton).

Buschang et al (1986) found the method errors for points defining the cranial base superimpositions ranged from 0.17 to 0.41 mm. In their study, they superimposed tracings on to radiographs. They claim that it reduces the errors due to the tracing process and makes the procedure more efficient.

Several authors (Kerr, 1978; Lee, 1980; McWilliam, 1982, 1983a, b) have described methods of superimposing directly on to the anterior cranial base, doing away with the tracing errors.

3.2.1 THE SUBTRACTION METHOD (Lee, 1980; McWilliam, 1982, 1983a, b)

Subtraction is the removal of the bony image of unchanging structures by superimposition. The standard radiograph is a negative image of the structure and a positive copy can be produced by means of a contact print on film. When a radiograph and a subtraction copy are superimposed, structures that match perfectly appear uniformly grey. This provides a very sensitive test of the fit of identical structures. However, matching is more difficult when radiographic images are not identical as which can happen in the cranial base, either because of remodelling with growth, or because the sagittal plane of the head was not parallel to the film on both radiographs (Houston and Lee 1985). As this technique permits direct superimposition of radiographs over reference points, tracing errors are eliminated.

Lee (1980) reported rather small errors in superimposition when pairs of radiographs separated by an average of 5 years were superimposed using this method, while McWilliam (1982) found that, when radiographs separated by an average of 1 year were used, errors with the subtraction method were low and appreciably less than with superimposition on the sella-nasion line. In a later paper McWilliam (1983a,b) studied the effect of increasing time intervals between radiographic pairs on the precision of superimposition by this method. He found that repeatability deteriorated as the time interval between radiographs increased, although even with a gap of 7 years, the errors were quite small.

Houston and Lee (1985) found the error of this method to be 1.62 mm (standard deviation) at the mid-point of the registration lines.

3.2.2 THE BLINK METHOD

Kerr (1978) described a method for superimposing and comparing serial lateral cephalometric films using De Coster's line, the Adams Blink Comparator (Adams, 1968) and correction for vertical movements of nasion due to growth. The Comparator consists of two film-viewing boxes which may be illuminated individually, simultaneously or alternately using a blink mechanism from two focused microscope lights and the image is viewed through an image combining unit above. The apparatus permits superimposition of the actual films rather than their tracings and allows an accurate check of film relationship, rapid blinking from one film to the other, showing the area of superimposition to be stationary when the superimposition is true.

Kerr believes that the errors in superimposing, tracing and measuring can be reduced by the use of this method, but he did not report the method error. Houston and Lee (1985) investigated the method error and found it to be 1.92 mm. (standard deviation) at the mid-points of the registration lines.

3.3 SUPERIMPOSING ON THE MANDIBULAR BORDER

Baumrind et al (1976) tested the reproducibility of superimposition on the mandibular border. The tracings were superimposed along the lower border of the mandible, placing greater importance to the region of the symphysis than to the region of gonion, and greater importance to the inner table of the ascending posterior portion of the symphysis than to the outer table at pogonion. They found the standard deviation of errors of tracing superimposition to vary from 0.41 mm. (pogonion) to 1.71 mm. (condylion). The rotational errors were found to be larger than those of the cranial base and sella-nasion line registrations, while the translational errors were of about the same magnitude.

Bjork (1969), from his implant studies, found that the lower border of the mandible undergoes radical restructuring and he criticised its use as a reference plane as it masked the amount of rotation the mandible undergoes. He found the anterior aspect of the chin to be very stable, and also found very little remodelling at the mandibular canal and at the lower border of a developing molar germ until the roots begin to form. He suggested a method of superimposing on the mandible based on the structures which he found to be stable.

Buschang et al (1986) checked the technical reliability of mandibular superimposition on Bjork's structures as described by Bjork and Skieller (1983) and found the method errors for the registration points ranged from 0.37 mm. to 0.93 mm.

Cook and Southall (1989) tested the reliability of superimposition on the mandibular plane (menton and gonion), the mandibular outline, and on the mandibular structures as described by Bjork (1969). They found sizeable errors associated with all three methods, but the tracings involving Bjork's mandibular structures were found to be the least reliable. The error levels for the mandibular plane and mandibular outline were found to be similar. They discussed the dilemma regarding mandibular superimposition in that, if the greater validity of the structures suggested by Bjork was accepted, then using one of the other methods suggested would mask any growth rotation of the mandible. On the other hand, if the Bjork structures were used for superimposition purposes, any real changes may be lost by the relatively high level of error of the method. They then supported the continued use of Bjork's structures for mandibular superimposition, preferably using the method suggested by Bjork and Skieller (1983) for any study involving a growing patient, especially over an extended period of time, or when a marked degree of mandibular growth rotation is expected. They suggested that either the mandibular plane or the mandibular outline be used for those studies involving patients who have ceased growing, or in cases where the time between radiographs is short and where no

marked degree of mandibular growth rotation is expected. Cook and Gravely (1988) have shown that, of the posterior structures, the lower third molars are more reliable for superimposition purposes than the outline of the inferior dental canal. The fact that the lower third molars in older individuals would be too advanced in their development to be used for superimposition purposes, gives additional weight to the argument for not using the Bjork structures in these cases.

3.4 SUPERIMPOSING ON THE PALATAL PLANE

The palatal plane superimpositions were found to be the least reliable of the four discussed (Baumrind et al, 1976). However, because of the relative proximity of dental landmarks to the palatal plane, the rotational errors were minimized for those points. The translational errors were found to be relatively large, ranging from 0.64 mm. (upper molar cusp) to 0.97 mm. (upper incisor edge). ANS and PNS were found to be much more reproducible vertically than horizontally (Richardson 1966).

Nielsen (1989) compared three methods of maxillary superimposition: the 'best fit' method - that is, superimposing along the palatal plane registered at ANS; the 'structural method' suggested by Bjork and Skieller (1977) - based on the use of stable structures in the maxilla; and the implant method. He found that the 'best fit' method significantly underestimated the eruption of teeth by 30%-50%. The 'structural' method showed no significant differences in the vertical displacement of selected landmarks in comparison with the implant method. From his findings he inferred that if we assume that the implant method to be the most accurate method for determining maxillary growth and treatment change, then the 'structural' method seemed to offer greater validity and reliability than the 'best fit' superimposition along the palatal plane registered at ANS.

Ghafari and Efstratiadis (1989) reported that superimposition on the maxilla provided an assessment of both the skeletal and dentoalveolar mandibular movements and their contribution to the occlusal change or development within the area of the face in which they occur. They found that, in many instances, such findings differ from the interpretations suggested by the superimposition on the cranial base. They explained that this discrepancy was not surprising, as firstly, the maxilla does not necessarily move parallel to itself - the maxilla undergoes both rotational and translational movements, and secondly, the vertical movement of the maxilla is transmitted directly to the mandible, which obscures the amount and direction of mandibular change with respect to the maxilla.

Johnston (1986) described a method of cephalometric superimposition which is based mainly on the palatal plane, but also using a few other reference planes and points of superimposition as well.

3.5 JOHNSTON'S METHOD OF CEPHALOMETRIC SUPERIMPOSITION

The main difference between his method and other methods is that he accounts for the molar correction by measuring the movement of the molars relative to basal bone and the translatory growth of the jaws, both with respect to the cranial base and each other. All measurements are made parallel to the mean of the functional occlusal planes of the two head plates; the reasoning being that the correction of a malocclusion was ultimately being reflected at the occlusal level.

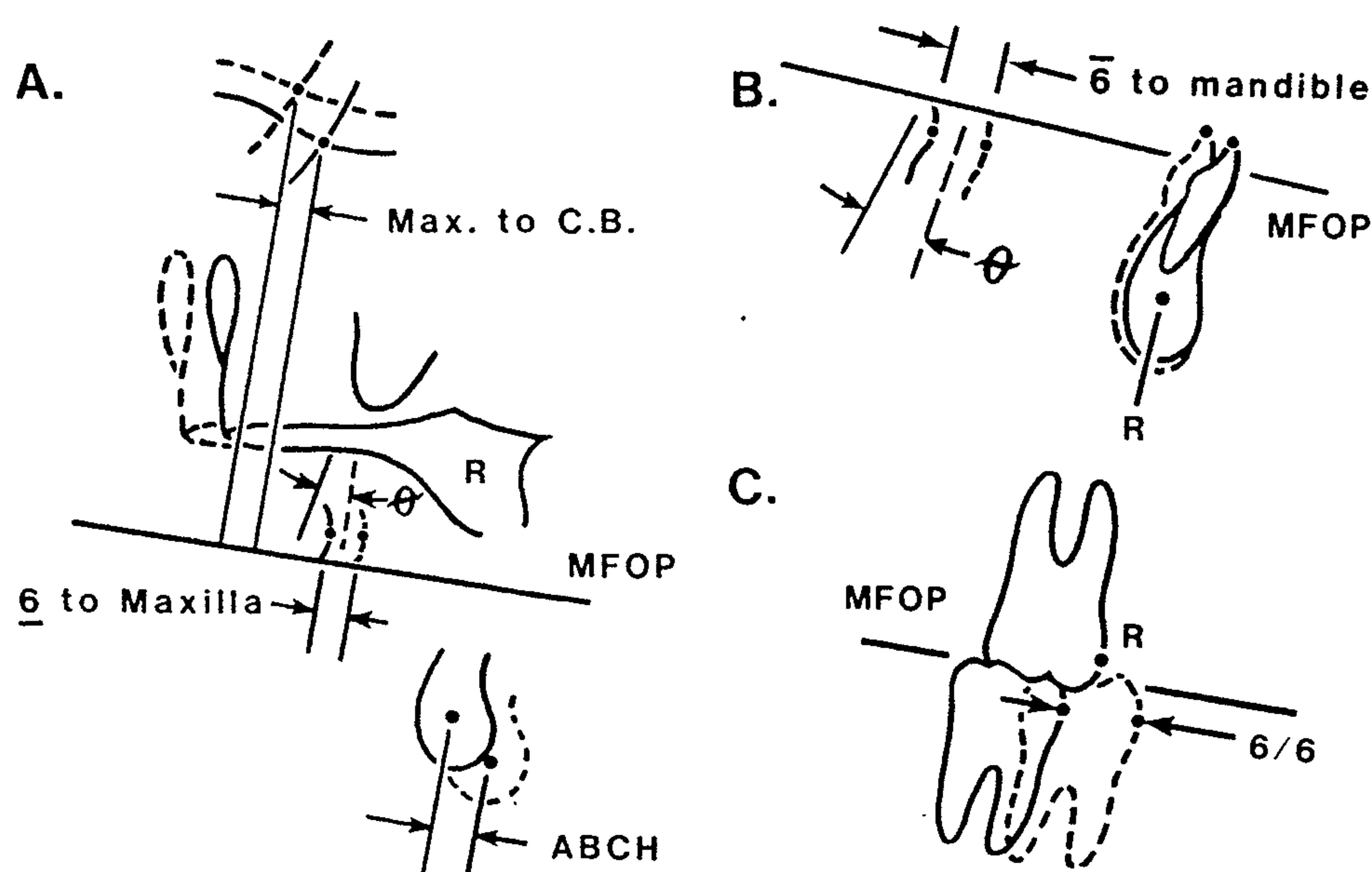


Fig. 6

Johnston's method of cephalometric analysis (1986).

A. Maxillary regional superimposition to obtain the movement of maxilla relative to cranial base (Max), mandible relative to maxilla (ABCH), and upper molars relative to maxillary basal bone ($\bar{6}$).

B. Mandibular regional superimposition to measure the movement of the lower molars relative to basal bone.

C. Dental superimposition to measure total molar correction ($6/6$). Orientation along MFOP, registration at R.

His main reference plane is the palatal plane, from where he measures the change in the position of the maxilla relative to the cranial base (Max), the movement of the upper first molar (U6), and the change in position of the mandible relative to the maxilla, which he terms as the apical base change (ABCH).

The second reference is Point D, a point constructed in the middle of the mandibular symphysis after superimposition of the mandibular tracings on natural reference structures as described by Bjork (1969). The movement of the lower first molar is measured (L6).

The third reference point is either the mesial or distal outline of the upper first molar, from where the change in position of the lower first molar is measured, and recorded as the total molar change (6/6).

The mandibular change is derived by subtracting the maxillary change from the apical base change (ABCH).

The formula: $\text{Mand.} = \text{ABCH} - \text{Max.}$

These measurements are given positive or negative values, indicating their relative contributions to the molar correction; for example, a forward movement of the upper molar in a Class II case would be given a negative sign, while forward movement of the lower molar would be accorded a positive sign. The measurements are then checked for accuracy using the formula:

$$6/6 = \text{Max.} + \text{U6} + \text{Mand.} + \text{L6.}$$

If the measurements did not agree to within 0.2 mm, the measurements were repeated.

Johnston also described a procedure for accounting for the change in the molar positions by tipping movement and bodily movement, using the formula:

$13.2 \sin (\varnothing + 24.6) - 5.5$ where $\varnothing$ was the change in axial inclination, measured relative to the mean functional occlusal plane.

The amount of bodily movement was then estimated for each molar by subtracting the tipping component from the total estimated for each molar by subtracting the tipping component from the total crown movement.

The advantage of Johnston's method is that superimposing on anatomic planes proximate to the landmarks in whose displacement we are interested makes it

easier to identify precisely the areas in which changes have actually occurred. Also, superimpositional comparisons are generally more sensitive for identifying small displacements in landmark position than are angular measures of the individual type.

3.6 SUMMARY COMPARING THE DIFFERENT METHODS

Houston and Lee (1985) compared four methods discussed previously:

1. registration of tracings on the cranial base structures;
2. registration of tracings on the sella-nasion line registered at sella;
3. the subtraction method; and
4. the blink method.

They found that for reproducibility there was little difference between the different techniques. The method error for relating radiograph pairs by the sella-nasion line was the lowest, though not significantly so than for superimposition on the cranial base structures. Their results were similar to Baumrind et al (1976), although that study found the superimposition of tracings on the anterior cranial base to be marginally more reproducible than using the sella-nasion line. Baumrind et al used radiographs of very high quality while Houston and Lee used radiographs of average quality. Superimposition may be less sensitive to radiograph quality when using the sella-nasion line rather than cranial base structures. As they found no one method of cephalometric superimposition to be outstandingly better than any other, Houston and Lee recommended that the choice of method be influenced by the cost and convenience. They considered the blink method to be the most awkward to use, being tiring and time-consuming and it had the lowest reproducibility. The subtraction method was found to be the most reproducible, but more expensive than the others because a subtraction copy had to be made, making it impractical for

routine clinical use. Direct superimposition was found to be simple and quick, and requiring no special materials. Its level of reproducibility was found to compare favourably with the other methods. They also found that the reproducibility of the superimposition of tracings to be good, provided that the tracings were done with the greatest care.

Baumrind et al (1976) rated the mandibular border third after the anterior cranial base and the sella-nasion line, with the palatal plane last.

Foster et al (1981) found the mean error of determining the angle of the various lines to the vertical were 0.86 degrees for the sella-nasion line, 1.41 degrees for the Frankfort Horizontal line, 1.29 degrees for the maxillary line and 4.9 degrees for the mandibular line. The sella-nasion line appears to be the most accurately assessed, and the mandibular line the least, but the method errors were all small.

Buschang et al (1985) found that superimposition on structures on the anterior cranial base was more reliable than superimposition on the mandibular structures as described by Bjork and Skieller (1983).

As far as this author can ascertain, no evaluation of the reproducibility of Johnston's method has been published so far.

4. THE ACTIVATOR.

4.1 THE ANDRESEN APPLIANCE

The Andresen appliance is probably the most frequently used of the activator group of appliances (Graber, 1985). It was originally designed as a loose-fitting appliance inserted between the teeth, lying against them at selected points and also making contact with the palate and soft tissues covering the inner side of the mandibular alveolar process (Adams, 1984).

The muscular forces generated by the forward mandibular positioning were transferred to the maxillary and mandibular teeth through the acrylic body and the labial bow, which contacted the maxillary incisors. In theory these forces were transmitted through the teeth onto the periosteum and bone, where they produced a restraining effect on the forward growth of the maxilla, while stimulating mandibular growth and causing maxillary-mandibular dentoalveolar adaptations.

The sagittal correction of Class II cases may be brought about in several ways (Pfeiffer and Groberty, 1975):

1. Relocating the maxilla backward.
2. Slowing down or inhibiting its growth.
3. Moving the upper teeth distally.
4. Releasing forward growth of the mandible.
5. Moving the lower teeth mesially.
6. Inhibiting vertical growth of the maxilla.

7. Inhibiting eruption of the upper posterior teeth while permitting eruption of lower posterior teeth.

Interocclusal and acrylic guide planes were provided to direct the dentoalveolar adaptations in a desirable direction. For a Class II correction, the mandibular posterior segments were directed to erupt vertically and mesially, while the maxillary teeth were directed distally and buccally. Vertical eruption of the maxillary teeth was impeded by the acrylic occlusal stops and the intrusive forces generated by the appliance. Incisal acrylic coverage was intended to inhibit the eruption of the maxillary and mandibular anterior teeth while reducing the flaring of the lower incisor teeth. Uncontrolled incisor flaring could result in a rapid correction of the overjet, which would minimize the orthopedic effects of the appliance on the maxilla and mandible.

The appliance is recommended to be worn all night, and also for a few hours during the day (Harvold, 1974; Reed and Hathorn, 1978; Teuscher, 1978; Birkebaek et al, 1984; Graber, 1985; Chang et al, 1989).

4.1.1 MODIFICATIONS

A number of modifications have been introduced to the Andresen appliance through the years.

The bulk of the original appliance has been reduced by many clinicians, and a cross-palatal wire or Coffin spring has been substituted for the acrylic (Teuscher, 1978; Wieslander and Lagerstrom, 1979; Isaacson et al, 1983; Graber et al, 1985).

Acrylic capping of the lower incisors, or a lower labial wire, was introduced to reduce their labial tipping tendency and to control the vertical growth of the anterior

alveolar bone and teeth (Harvold, 1974; Pfeiffer and Groberty, 1975; Ahlgren and Laurin, 1976; Calvert, 1982; Graber, 1985; Graber et al, 1985; Chang et al, 1989).

An airhole is sometimes incorporated to make breathing easier (Tulley, 1972; Harvold, 1974), and enable patients to speak with the appliance in place (Reed and Hathorn, 1978; Isaacson et al, 1983).

The lingual flange has been extended deep into the sulcus to maintain mandibular position and prevent loss of the appliance during sleep (Levin, 1985).

Jackscrews or Coffin springs are sometimes incorporated into the appliance to expand the upper, lower, or both dental arches (Jorgensen, 1974; Graber et al, 1985; Lehman et al, 1988). Finger springs have been added for limited tooth movement.

The original sagittal and vertical mandibular displacements have been varied, mostly by increasing the vertical bite-opening (Harvold and Vargervik, 1971; Woodside, 1973; Harvold, 1974; Reey and Eastwood, 1978; Isaacson et al, 1983; Pancherz, 1984; Remmer, 1985).

Some clinicians (Pfeiffer and Groberty, 1972; Teuscher, 1978; Heath, 1985; Levin, 1985; Vargervik and Harvold, 1985; Kigele, 1987; Lehman et al, 1988) used headgears in combination with activators in an attempt to reduce the vertical and sagittal maxillary displacement.

4.2 THE CONSTRUCTION BITE

The construction bite determines the sagittal and vertical displacements of the mandible and therefore the degree and direction of appliance activation.

Andresen (Graber, 1985; Graber et al, 1985) advocated an interocclusal clearance between the upper and lower jaw of 2-4 mm., which is within the freeway space limits of most patients. Most clinicians advocate a bite-opening of 4-6 mm., or just slightly beyond the freeway space (Bjork, 1951; Jakobsson, 1967; Ahlgren and Laurin, 1976; Teuscher, 1978; Lagerstrom et al, 1990) while others (Harvold and Vargervik, 1971; Tulley, 1972; Woodside, 1973; Harvold, 1974; Pfeiffer and Groberty, 1975; Reed and Hathorn, 1978; Reey and Eastwood, 1978; Isaacson et al, 1983; Birkebaek et al, 1984; Pancherz, 1984; Remmer et al, 1985) open the bite at least 5-6 mm. beyond the freeway space, as they believe that a small increase was ineffective because the vertical dimension normally increased during sleeping, which allowed the mandible to slip out of the appliance.

Luder (1981, 1982) reported two different types of reaction to activator treatment. The first type of reaction resulted in a significant increase in SNB, and no change in SNA, while the second type of reaction resulted in a reduction in SNA, and no change in the SNB angle. He concluded that the two patterns of effects were due to different construction bites, in that the first type of reaction was brought about by a higher construction bite, and the second type of reaction by a lower construction bite. He then theorized that if the two types of reaction occurred with about the same distribution in a sample, it would explain why researchers were sometimes unable to detect significant effects of the activator on the sagittal change of either Point A or Point B.

This finding, however, is directly the opposite of the findings of Woodside (1973), who found that activators with extreme vertical bite openings were more successful in restricting development of the midfacial area at subnasale than activators with more moderate bite openings.

Generally, the mandible was postured to an end-to-end incisal relationship (Reed and Hathorn, 1978; Graber, 1985; Chang et al, 1989). However, some authors have cautioned that the displacement should not exceed 6 mm. for the sake of patient comfort and cooperation, and in severe cases it was better to bring the mandible forward in two or three steps of 2 or 3 mm. each (Jorgensen, 1974; Reed and Hathorn, 1978; Graber, 1985). As a general rule, the anterior positioning should be always 3 mm. or more distal from the most protrusive mandibular position possible (Graber, 1985; Remmer et al 1985; Lagerstrom et al, 1990).

4.3 PATIENT SELECTION (Graber, 1985; Roberts, 1985)

The ideal types of cases for activator treatment are non-extraction Class II division 1 malocclusion with procumbent maxillary incisors and lingually tipped mandibular incisors, a deep bite, and in middle to late mixed dentition. The dental arches should be well arranged, without crowding, impaction or rotation of teeth.

The maxilla may exhibit mild prognathism but should not show any features of vertical maxillary excess. The mandible is mild to moderately retruded. The vertical proportions should err on the side of decreased lower face height.

They should have good growth potential, a favourable growth pattern and be good cooperators. They should also be nose-breathers and sleep with their mouths closed, in order to keep the appliance in place during sleep.

The success of treatment is dependent on the timing of treatment during periods of growth. Theoretically, active treatment should begin just prior to the period of peak facial growth, that is, when the child begins to show early signs of adolescence.

Pfeiffer and Groberty (1972) recommend that treatment be started at the age of 9-10 for girls and 10-11 for boys. Adams (1984) feels that children up to the age of 11-12 or older can be successfully treated by functional appliances. Bjork (1951), however, is of the opinion that this type of treatment is most effective in the treatment of deciduous dentitions (ages 4-7 years), and a little less effective in the mixed dentitions (ages 8-12 years). In permanent dentitions, he finds that the effect of this type of treatment is very limited.

5. THE EFFECTS OF FUNCTIONAL TREATMENT

The nature of the changes contributing to Class II correction in functional treatment is controversial. Demonstration of anatomic structures affected by treatment is complicated because of individual variability in human growth and development.

Some investigators claim that treatment is limited to the dentoalveolar area (Bjork, 1951; Tulley, 1972; Weinberger, 1974; Wieslander and Lagerstrom, 1979; Calvert, 1982; Robertson, 1983). Other studies show a more orthopedic influence with a restricting effect upon the growth of the maxilla (Moss, 1962; Jakobsson, 1967; Harvold and Vargervik, 1971; Reed and Hathorn, 1978; Pancherz, 1984; Johnston, 1986).

Different opinions have also been reported concerning the effect of functional treatment upon the growth of the mandible. Some reports indicate that growth of the mandible could possibly be affected during treatment with the functional appliance (Marschner and Harris, 1966; Meach, 1966; Remmer et al, 1985; Chang et al, 1989; Derringer, 1990). Others have reported that the effect on the mandible is insignificant and no more than can attributed to normal growth (Jakobsson, 1967; Harvold and Vargervik, 1971; Woodside, 1973; Reey and Eastwood, 1978; Wieslander and Lagerstrom, 1979; Pancherz, 1984; Vargervik and Harvold, 1985).

5.1 DENTOALVEOLAR EFFECTS

In the literature, it is generally agreed that dentoalveolar changes contribute to the correction of Class II malocclusions with functional appliances. The upper dentition

either moved distally, or were prevented from erupting mesially, effecting a relative distalization. The lower dentition was encouraged to erupt upwards and mesially. There was, however, great variation in the amount of dentoalveolar changes obtained.

Pancherz (1984) found the upper molars had moved 0.4 mm. (S.D. 1.7 mm.) distally relative to ANS in the activator group, compared with a mesial movement of 1.5 mm. in the Bolton group. The lower molars moved mesially 2.3 mm. (S.D. 1.3 mm.) relative to pogonion compared with a 0.5 mm. mesial movement in the Bolton group. These differences were found to be significant.

Birkebaek et al (1984) found the upper molars in activator patients moved posteriorly an average of 0.3 mm. compared to controls, where the upper molar moved forward a mean of 0.2 mm. The lower molars were displaced anteriorly by 0.3 mm. in both groups.

Wieslander and Lagerstrom (1979) found the upper molars in activator-treated patients moved forward 2.71 mm. (S.D. 2.44 mm.) compared to 3.54 mm. in a Class II control group. The lower molars moved mesially 4.65 mm. (S.D. 2.49 mm.) compared to 3.85 mm. in the control group.

Reey and Eastwood (1978) found the upper molars in activator treated patients mesialized by 0.5 mm., but were positioned 1.3 mm. more distally than their forecast positions according to the Rocky Mountain Data Services (RMDS), while the mandibular molars were carried 1.5 mm. more mesially than their forecast positions.

Jakobsson (1967) found the upper molars of patients treated with activators were 1.2 mm. (S.D. 1.59 mm.) more posterior than a control group, but found patients who

had been treated with headgears had even more distal upper molar movement (3.7 mm. $\pm$ 2.05 mm.).

Weinberger (1974) found the upper molars in control groups moved forward an average of 0.9 mm. per year while the headgear group moved distally 1.6 mm. per year, producing a total distalization of 2.5 mm. per year. The upper molars in the activator group hardly moved horizontally at all, giving a total distal effect of 1.2 mm. per year. The lower molars in the activator group showed 2.15 mm. mesial movement per year, in comparison to the controls which moved mesially 1.2 mm. per year, and the headgear group which mesialized 0.68 mm. per year.

Lagerstrom et al (1990), found that the upper molars of headgear-activator treated patients were distalized a mean of +0.07 mm (S.D. 2.92 mm), with a range of +7.5 to -5 mm. The lower molars moved mesially a mean of 3.25 mm. (S.D. 2.35 mm.). Pfeiffer and Groberty (1972) found the upper molars distalized an average of 3.4 mm. after headgear-activator therapy.

Johnston (1986) found the upper molars in activator patients moved forward a mean of 0.1 mm., while in untreated controls it moved forward 1.1 mm., and in a sample with edgewise appliances (with headgear), the upper molars distalized 1.2 mm. The lower molars in activator patients moved mesially by 0.7 mm., while in the untreated controls it moved forward by 0.4 mm. The lower molars in the edgewise group mesialized by 0.9 mm.

5.2 INHIBITION OF FORWARD MAXILLARY GROWTH

Several investigators have found that functional appliances exert a restricting influence upon the growth of the maxilla (Moss, 1962; Trayfoot and Richardson, 1968; Harvold and Vargervik, 1971; Pfeiffer and Groberty, 1972; Reed and Hathorn,

1978; Forsberg and Odenrick, 1981; Pancherz, 1984; Vargervik and Harvold, 1985). However, some reports have claimed activators were no more effective in restricting maxillary growth than headgear or fixed appliance treatment (Jakobsson, 1967; Gianelly et al, 1984; Remmer et al, 1985; Johnston, 1986), while still others found no orthopedic effect on the maxilla (Reey and Eastwood, 1978; Wieslander and Lagerstrom, 1979; Calvert, 1982; Chang et al, 1989).

Trayfoot and Richardson (1968) and Forsberg and Odenrick (1981), found a significant decrease in SNA after activator therapy, but no significant increase in SNB, giving a significant decrease in ANB. Pfeiffer and Groberty (1972) found similar changes with headgear-activator therapy.

Jakobsson (1967) found Point A in activator patients moved 0.7 mm. (± 1.42 mm.) distally compared to controls, while in headgear patients it moved 1.6 mm. (± 1.35 mm.) distally. Remmer et al (1985) found Point A in activator treated patients were 0.9 mm. (S.D. 1.4 mm.) more anterior after treatment, compared to patients treated with fixed appliances and headgear, in which Point A had distalized by 0.7 mm. (S.D. 1.8 mm.) Gianelly et al (1984) found no significant difference in Point A between groups of patients treated with functional, edgewise appliances with headgear, and Begg appliances. In the three groups, SNA decreased 0.6 degrees, 1.47 degrees, and 0.37 degrees respectively.

Point A, however, is not a reliable landmark for measuring orthopedic change of the maxilla, as it is not a true basal point, but a deep alveolar point. If the apices of the incisor teeth are moved, then the alveolar outline will follow them (Bernstein et al, 1977; Mills, 1978; Birkebaek, et al 1984; Gianelly et al, 1984; Pancherz and Hansen, 1985; Jarvinen, 1987).

Pancherz (1984) found ANS in activator patients moved significantly less mesially (2.3 mm.) compared to controls from the Bolton Study (4.0 mm.).

Williams and Melsen (1982) conducted a study on patients with implants, and found that with activator treatment, the maxillary implant underwent an average forward displacement of 0.82 mm.

Johnston (1986) found the maxilla in activator patients moved anteriorly by 1.0 mm, while in patients with edgewise appliances with headgear, it moved forward by 0.9 mm., and in untreated controls in moved forward 2.0 mm.

Reey and Eastwood (1978), found maxillary convexity to be unaffected by activator therapy. They found a 0.5 degree reduction in angle SNA, which is a normal growth change (Reey and Eastwood, 1978; Creekmore and Radney, 1983).

Wieslander and Lagerstrom (1979), Calvert (1982) and Derringer (1990) found no significant difference in the change in Point A after activator treatment compared to controls.

5.3 GROWTH OF THE MANDIBLE

Although some authors have reported finding significant mandibular growth with functional treatment (Marschner and Harris, 1966; Meach, 1966; Chang et al, 1989; Derringer, 1990), the majority of the reports in the literature seem to indicate that the magnitude of mandibular growth is not significantly affected by functional treatment (Jakobsson, 1967; Harvold and Vargervik, 1971; Reey and Eastwood, 1978; Wieslander and Lagerstrom, 1979; Creekmore and Radney, 1983; Pancherz, 1984; Adenwalla and Kronman, 1985; Remmer et al, 1985; Vargervik and Harvold, 1985).

Marschner and Harris (1966) found the incremental change in mandibular length from the condyle to the symphysis to be significantly greater by about 1 mm. per year in the activator group than in an untreated Class II group. Derringer (1990) reported finding a significant increase in the mandibular body length (Go-Gn) after activator treatment compared to controls, but the amount of growth was less than 1 mm.

Chang et al (1989) found significant forward growth of the mandible in activator-treated patients compared to controls. Mandibular length increased by 1.9 mm. more in the treated patients, while SNB increased by 1.7 degrees.

Meach (1966) did a comparative study of the bony profile changes in patients treated with functionals and headgear. He concluded that, in comparison to extraoral force, functional jaw orthopedics had a more favourable influence on the position of pogonion in the bony profile, as evidenced by a statistically significant increase in the facial angle, and a high percentage of forward positioning of chin point.

Johnston (1986) found the mandibles in activator-treated patients grew 4.2 mm., while in patients with edgewise appliances and headgear it grew 2.9 mm., and in untreated controls it grew 3.0 mm. He described the difference as significant, but did not give it much clinical significance.

Jakobsson (1967) found the anteroposterior position of the mandible represented by the points articulare, pogonion, and Point B was not significantly different between patients who had been treated with activators, headgears and the untreated controls. Calvert (1982) found Point B slightly more forward in activator patients compared to controls, but the difference was not significant.

Pancherz (1984) found the mandibular length (Pog-Ar) did not increase more in the activator group (5.8 mm.) than the Bolton standard of persons with Class I occlusion (6.5 mm.). Wieslander and Lagerstrom (1979) found the length of the mandible in an activator-treated group increased by 3.30 mm. compared to 3.10 mm. in a Class II control group. Reey and Eastwood (1978) found the mandibular corpus length in activator treated cases increased on average by 3.8 mm., but the total length of the mandible (72.2 mm.) was not significantly more than was forecast (71.1 mm.) by Rocky Mountain Data Services.

Remmer et al (1985) found a 2.3 mm. (S.D. 1.8 mm.) increase at pogonion, but noted that the treatment change observed was similar to that caused by growth, as reported in the Burlington Growth Study.

Williams and Melsen (1982) reported that with activator treatment, implants in the mandible were found to have undergone a mean forward displacement of 1.76 mm.

Harvold and Vargervik (1971) and Vargervik and Harvold (1985) compared mandibular growth during the activator treatment period with that in the pretreatment period, and found no significant difference. The mandibular length increment from condyle to pogonion was 2.9 mm. per year during the treatment period, compared to 2.66 mm. per year in the pretreatment period. They concluded that activator treatment did not stimulate condylar growth beyond that was expected through normal growth.

Creekmore and Radney (1983) found no significant difference in yearly growth increments for mandibular length or maxillary length, in Class II patients who had been treated with the Frankel appliance, compared to Class I Frankel appliance patients, who had less protraction of the mandible. They claim that this finding questions the precept that habitual forward posturing of the mandible elicits an

appreciable additional mandibular growth response in human beings. They also claim that the precept is further weakened since both the Frankel groups grew the same as an untreated sample group.

Gianelly et al (1984) found the annualized mandibular growth (Ar-Gn) recorded in patients treated with functional appliances, edgewise appliances and headgear, and Begg appliances were 3.1 mm./year, 2.7 mm./year, and 2.9 mm./year respectively. There were no statistical difference between the findings. They concluded that the growth obtained by the functional appliance did not represent a useful orthopedic response, as there was little difference from that observed from the other techniques. Moreover, there was no dramatic increase in mandibular prognathism, reflecting the fact that neither the amount nor the direction of mandibular growth changed appreciably.

5.4 DISCUSSION

The literature shows the effects of functional appliances have been reported in numerous studies with great variability in the findings. It is generally agreed that they can be used successfully to treat Class II malocclusions in growing and cooperative patients. However, there is a lack of consensus regarding the relative orthodontic and orthopedic correction obtained by functional appliances in Class II correction.

Most of the functional appliances studies reported in the literature have these common findings regarding the Class II correction:

- (a) reduced forward growth of the maxilla,
- (b) distalization of the upper molars,
- (c) mesialization of the lower molars.

The one observation that is not consistently found is an increase in the amount of forward growth of the mandible (Creekmore and Radney, 1983). The mandibular prominence which may arise in the course of the treatment usually lies within the range of normal growth.

Most corrections that occurred in growing patients involved a combination of both orthodontics and orthopedics. The magnitude of the orthodontic and orthopedic changes varied widely between patients. Gianelly et al (1984) suggested that the orthopedic component in most patients comprised no more than 20% to 30% of the correction. Creekmore and Radney (1983) also indicated that the Class II correction with functional appliances was 30%-40% maxillomandibular orthopedic and 60%-70% orthodontic.

5.5 LIMITATIONS ON THE INTERPRETATION OF THE RESULTS

There are limitations on the interpretation of the results of the various studies in the literature. Among them are:

1. Inconsistencies in the design and use of the various appliances. The types of construction bites used were variable, as well as the amount of mandibular advancement (Luder, 1981,1982; Vargervik and Harvold, 1985; Bishara and Ziaja, 1989). The number of hours the patient was expected to wear the appliance also varied.
2. Relatively small samples that included patients with a wide age variation, and facial type variation, were used in most studies (Creekmore and Radney, 1983; Vargervik and Harvold, 1985; Bishara and Ziaja, 1989).
3. The method of superimposition, and the planes of reference were different. The cephalometric landmarks used to assess the changes also varied widely (Houston, 1983).

Bishara and Ziaja (1989) also cautioned that after activator treatment, it was fairly common for the condyle, initially at least, to be positioned forward and inferior in the fossa, and that most authors did not check for it. They recommend a leaf gauge be used to ensure an accurate seating of the condyle before taking post-treatment cephalograms.

C. ORIGINAL WORK

6. AIMS OF THE STUDY

The first aim of this study was to evaluate the reliability of the method of cephalometric superimposition as described by Johnston (1986). The second aim was to use this method of superimposition to evaluate the effects of activator treatment.

The sample consisted of thirty-six cases which had been treated with activators. Each pair of before- and after-treatment radiographs was set side-by-side on an illuminating box and were traced simultaneously. The tracings were then superimposed and measured according to the method described by Johnston.

The first fifteen pairs of tracings and measurements were done five times, with an interval of a minimum of five days between each set of readings. The error variances of the measurements (of the change in each of the landmarks measured) was then calculated to determine the accuracy of the method.

Once the method was determined to be reproducible, the rest of the sample, consisting of twenty-one cases, was traced and measured twice, also under the same conditions as the first sample.

The measurements obtained for each patient in both samples were then averaged, giving the mean treatment change and standard deviations for that patient.

The average change for each landmark (i.e. maxilla, mandible, upper molar and lower molar) was then calculated for the sample. These changes would then be compared with the changes reported in other studies.

7. MATERIALS AND METHODS

7.1 THE SAMPLE

Thirty-six pairs of before- and after-activator treatment lateral cephalometric roentgenograms were used in this study. Thirty-one of the cases came from the records of three orthodontists in private practice in Sydney, while the other five came from the records at The United Dental Hospital. All the cases were Class II division 1 malocclusions, in either mixed or permanent dentition. No differentiation was made as to whether they might be classified as dental or skeletal Class II. Otherwise, these cases were selected based solely on the fact that they had completed a phase of treatment with the activator.

The sample consisted of twenty-five female and eleven male patients. The distribution of age and sex is shown on Table 1. Their ages at the start of treatment ranged between 9 years 0 months and 13 years 9 months with a mean of 12 years 2 months and standard deviation of 12.9 months. The treatment time ranged from 4 months to 32 months with a mean of 10 months and standard deviation of 5.5 months. The period between the first and second radiograph ranged from 6 months to 34 months, with a mean of 12.7 months and standard deviation of 5.6 months.

Table 1: The Sample

Sample	n	Mean age at start of treatment	Mean treatment duration (months)	Mean duration between cephalograms (months)
Male	11	12 yr 2 mth	10.5	12.8
SD		15.2 mth	5.3	5.3
Female	25	12 yr 1 mth	9.8	12.6
SD		12.1 mth	5.8	5.9
Overall	36	12 yr 2 mth	10	12.7
SD		12.9 mth	5.5	5.6

Whilst it might have been desirable to have a sample of untreated control as a group or as matched pairs, this was considered impractical, firstly, because of the difficulty of obtaining a comparable sample, and secondly, because of the ethical issue of requiring subjects' permission to take x-rays without intending their immediate use for diagnosis.

No age, sex, or treatment time factors were taken into consideration as the sample size was small, and the main purpose of this study was to determine the reproducibility of the method of superimposition.

The radiographs used in this study were of adequate, but not of exceptional quality, as the interest was centered on clinical application.

7.2 MATERIALS USED

The materials used were a mechanical pencil with 0.3 mm. HB lead, a plastic ruler for drawing lines, a plastic set square, a hand-held magnifying glass and a "Helios" digital caliper accurate to 0.01 mm.

All radiographs were traced on conventional translucent acetate tracing paper, using a transilluminating light box in a darkened room.

7.3 DEFINITION OF CEPHALOMETRIC LANDMARKS, PLANES, AND LINEAR MEASUREMENTS USED IN THIS STUDY

(Johnston, 1986; Proffit, 1986).

Cephalometric Landmarks

ANS	Anterior Nasal Spine. The tip of the anterior nasal spine.
D point	A point in the middle of the inner cortical structure of the mandibular symphysis, determined by inspection.
L6	The averaged mesial contact point of the mandibular first molar.
PNS	Posterior Nasal Spine. The tip of the posterior spine of the palatine bone, at the junction of the soft and hard palate.
PTM	Pterygomaxillary fissure, the point at the base of the fissure where the anterior and posterior walls meet.

SE point The intersection of the averaged greater wings and planum of the sphenoid.

U6 The averaged mesial contact point of the maxillary first molar.

Cephalometric Planes

Functional occlusal plane

A line drawn through the occlusal surfaces of the molars and premolars.

MFOP Mean functional occlusal plane. The average of two functional occlusal planes.

Palatal Plane

A line connecting the anterior nasal spine (ANS) with the posterior nasal spine (PNS).

Linear Measurements

6/6 Total molar correction. The distance between the average of the mesial or distal contact points of the maxillary first molar to the mandibular first molar.

ABCH Apical Base Change. The anterior change in the position of the mandible (D point) relative to maxilla. Measured parallel to the MFOP.

Mand. Mandibular translatory growth relative to the cranial base. Calculated by taking the sum of maxillary displacement relative to cranial base and mandibular displacement relative to maxilla (algebraically, $\text{Mand} = \text{ABCH} - \text{Max}$).

7.4 METHOD OF THIS STUDY

1. Each pair of lateral cephalometric roentgenograms were placed side-by-side on a light box and were traced and measured for changes according to the method described by Johnston (1986).

SE point, the first molars and the functional occlusal plane, the outline of the key ridge, the PTM fissure, and the palatal and mandibular symphyseal trabecular architecture common to both films were traced.

2. The tracings of the maxillae were then superimposed by orientating on palatal plane and registering on the palatal trabeculae and lingual palatal curvature. To record the maxillary superimposition, 2-4 registration crosses were drawn on one tracing and transferred to the other. The two functional planes were then averaged, and the resulting mean functional occlusal plane (MFOP) was recorded on each tracing to serve as the basis for the measurement of change (film 2- film 1).

3. Point D was determined on one film and transferred to the other by superimposition on the bony architecture of the labial cortical plate of the symphysis (according to Bjork, 1969). The maxillary superimposition was reestablished by superimposing the registration marks, and the following measurements executed parallel to MFOP.

1. Upper molar crown movement (U6): The change in position of the averaged mesial or distal contact point of the upper first molars;
2. Apical base change (ABCH): The anteroposterior change in the position of mandible (D point) relative to maxilla; and
3. Maxillary translatory growth relative to cranial base (Max): The distance between the initial and final position of SE.

Mandibular translatory growth relative to cranial base (Mand) was then calculated by taking the sum of maxillary displacement relative to cranial base and mandibular displacement relative to maxilla (algebraically, $Mand = ABCH - Max$).

4. The mean functional planes were then superimposed and the mandibular tracings registered on perpendiculars to the MFOP erected through D Point. The distance between the averaged mesial or distal contact points of the mandibular first molars, measured parallel to MFOP, constituted an estimate of lower molar crown movement relative to basal bone. To measure the total molar correction (6/6), the contact points of the maxillary first molars were registered, and the distance between lower molar contact points measured parallel to MFOP.

All linear measurements were executed to the nearest 0.01 mm with the aid of digital calipers and a small magnifying glass.

The various dental and skeletal changes were accorded signs that reflect their significance to the correction of the molar relationship: those that would aid in the establishment of a Class I relationship were given a positive sign; those that would detract were given a negative sign. For example, distal movement of the maxilla or the upper molars and forward displacement of the mandible or the lower molars received positive signs. Given the present sign convention and scheme of analysis, the independently measured total molar correction (6/6) had to equal the algebraic

sum of upper 6, maxilla, lower 6, and mandible; if it did not add up (± 0.2 mm), the measurement was repeated.

A modification of Johnston's method was made where the change in axial inclination of the maxillary and mandibular molars was not measured, and therefore the tipping component of each molar was not taken into account. It was felt that as the sample was non-extraction, the tipping component was very small. Also, the radiographs were of not sufficient quality to accurately determine the amount of tip. The tracing of the axial inclination of the teeth is also subject to large errors (Krogman and Sassouni, 1957).

Where bilateral structures gave rise to double images, the mid-point by estimation or construction, as appropriate, was chosen.

5. The tracings and measurements of the first sample were then repeated 4 more times by the same operator to make a total of 5 sets of readings, while those of the second sample were repeated only once. No more than three sets of radiographs were traced in any one session to avoid operator fatigue. The same set of radiographs were not retraced within five days to avoid memorization of the landmarks.

8. RESULTS

8.1 ERROR VARIANCES OF THE METHOD

An analysis of variance (ANOVA) test for multiple comparisons was carried out on the five sets of measurements obtained. It showed that there were no statistically significant (>0.05 confidence level) between-group differences between the five sets of data for the measurements of U6, L6, Max, Mand, and ABCH. However, statistically significant differences were found in the measurements for 6/6 (Table 2.1 - 2.6).

Table 2.1: Analysis of Variance (Maxillary Molar)

Maxillary Molar	SS	df	MS	F
Total	96.289	74		
Within groups	92.78	14		
Between groups	0.148	4	0.037	1.622
Error	3.342	56	0.06	

* $p > 0.20$
d.f. 56 and 4

Table 2.2: Analysis of Variance (Mandibular Molar)

Mandibular Molar	SS	df	MS	F
Total	82.302	74		
Within groups	78.126	14		
Between groups	0.307	4	0.077	1.111
Error	3.869	56	0.069	

* $p > 0.20$
d.f. 4 and 56

Tables 2.3: Analysis of Variance (Maxilla)

Maxilla	SS	df	MS	F
Total	159.441	74		
Within groups	149.229	14		
Between groups	0.592	4	0.148	1.162
Error	9.62	56	0.172	

* p > 0.20
d.f. 56 and 4

Table 2.4: Analysis of Variance (Mandible)

Mandible	SS	df	MS	F
Total	360.066	74		
Within groups	350.73	14		
Between groups	1.269	4	0.317	2.202
Error	8.067	56	0.144	

* p > 0.10
d.f. 4 and 56

Table 2.5: Analysis of Variance (Apical Base Change)

ABCH	SS	df	MS	F
Total	205.059	74		
Within groups	199.59	14		
Between groups	0.079	4	0.019	0.202
Error	5.391	56	0.096	

* p > 0.05
d.f. 56 and 4

Table 2.6: Analysis of Variance (Relative Molar Change)

6\6	SS	df	MS	F
Total	98.695	74		
Within groups	93.332	14		
Between groups	0.015	4	0.004	23.875
Error	5.349	56	0.096	

* p < 0.001 (not significant)
d.f. 56 and 4

As the between-group differences of the measurements U6, L6, Max, Mand, and ABCH were not significant, these measurements could then be considered reliable. Significant between-group differences in the 6/6 measurements were found, and this measurement could not be considered reliable.

The standard deviations of the five sets of measurements were tabulated (Table 3) and taken as the method error (Houston and Lee, 1985).

Table 3: Method Error

	(mm.)
U6	0.22
L6	0.25
Max	0.37
Mand	0.35

8.2 ACTIVATOR TREATMENT CHANGES OF THE SAMPLE

The treatment changes for upper molar (U6), lower molar (L6), maxilla (Max), mandible (Mand), and apical base change (ABCH) were averaged and tabulated (Table 4). The mean treatment changes were then t-tested to check if the changes measured were significant from zero. The treatment change for U6 was found to be not significant, but the treatment changes for the other measurements, were significant.

Table 4: Activator Treatment Effect

	Mean (mm.)	S.D.	t	significance level
U6	-0.24	1.57	0.91	no sig. difference
L6	1.26	0.84	8.99	sig. to > 0.001
Max	-1.41	1.32	6.43	sig. to > 0.001
Mand	3.92	2.02	11.63	sig. to > 0.001
ABCH	2.41	1.46	9.91	sig. to > 0.001

(-) denotes a change which detracts from Class II correction
n = 36
d.f. 35

1. The upper molars had come forward a mean of 0.24 mm. (S.D. 1.57 mm.). This change was not statistically significant. There was wide variation in the upper molar movement, ranging from the upper molars coming forwards 5.35 mm. to a posterior movement of 2.60 mm.
2. The lower molars moved mesially a mean of 1.26 mm. (S.D. 0.84 mm.). This was a statistically significant change. The lower molar movement in this sample ranged between 0.00 mm. to 3.55 mm.
3. The maxilla had come forward 1.41 mm. (S.D. 1.32 mm.). This was a statistically significant change. The maxillary change ranged from a posterior repositioning of 1.11 mm. to a forward growth of 6.08 mm.
4. The mandible had come forward 3.92 mm. (S.D. 2.02 mm.). This change was statistically significant. The mandibular change ranged from 0.00 mm. to an 8.35 mm. change.
5. The apical base change was 2.41 mm. (S.D. 1.46 mm.) This was a statistically significant change. The apical base change ranged from 0.00 mm. to 6.43 mm.

9. DISCUSSION

9.1 COMPARISON OF THE METHOD ERROR WITH OTHER METHODS

The repeated measurements for U6, L6, Max, Mand, and ABCH, done using Johnston's method of superimposition, had insignificant between-group differences. This demonstrates that the method is consistent and reliable.

The measurement of relative molar change (6/6), however, was found to be not reliable. The irony of this fact is that, this measurement has a built-in safe-guard, where Johnston (1986) rechecks this measurement using the formula:

$$6/6 = U6 + \text{Max.} + L6 + \text{Mand.}$$

The independently measured total molar correction (6/6), had to equal this derived value (± 0.2 mm). If it did not, the measurement was to be repeated.

From my experience, the independently measured value of 6/6, frequently had to be adjusted to 'fit-in' with the derived value, and this probably was a mistake, for indirect values will tend to incorporate any errors in the values from which they are derived by addition or subtraction (Bjork and Solow, 1962). This step should be deleted from the method.

The method error (Table 3) for most of the parameters were smaller than the actual changes taking place. However, the smaller the changes measured, the less protection the investigator had against measurement errors.

The method error of this method of superimposition was found to be lower than other commonly used methods (refer to Chapter 3). However, it may be argued that the standard deviations measured in this experiment were low because only one person carried out all the tracings, superimpositions and measurements. In all the other studies mentioned, more than one observer was used. While one observer could reproduce his/her measurements with an acceptable degree of accuracy, the discrepancies between measurements made by different observers were more serious (Hixon, 1956; Stabrun and Danielsen, 1982; Pancherz, 1984). Savara et al (1966), however, found that intra- and inter-observer variability was similar.

Nevertheless, this study has demonstrated that Johnston's method of superimposition is reliable. A follow-up study can be carried out later to investigate its method error with more than one operator.

A criticism of this method, however, is that it does not take into account the vertical component of growth. The analysis is confined to changes along the functional occlusal plane only. Johnston (1986), however, explained that although vertical growth is an important factor in the management of sagittal malocclusions, it is the horizontal component during growth, along with horizontal tooth movements along the functional occlusal plane, that is decisive for the treatment outcome of anteroposterior occlusal discrepancies.

9.2 THE ACTIVATOR TREATMENT CHANGES OF THIS STUDY IN COMPARISON WITH OTHER STUDIES.

1. Comparison of upper molar change (Table 5).

Table 5: Comparison of upper molar change.

Study	Year	Molar change in mm.
Jakobsson	1967	1.2
Harvold & Vargervik	1971	0.70
Pfeiffer & Groberty*	1972	3.4
Weinberger	1974	-0.9
Reey and Eastwood	1978	-0.5
Wieslander & Lagerstrom	1979	-2.71
Birkebaek	1984	0.3
Pancherz	1984	0.4
Johnston	1986	-0.1
Lagerstrom et al*	1990	0.07
Hashim	1990	-0.24

(-) denotes a forward displacement

* denotes headgear-activator

The mean upper molar change reported in this study, -0.24 mm. (S.D. 1.57 mm.), was not a significant change. This is in agreement with the findings of Harvold and Vargervik (1971), Weinberger (1974), Reey and Eastwood (1978), Birkebaek (1984), Pancherz (1984), Johnston (1986), and Lagerstrom (1990), who reported very little upper molar movement during treatment. This is a positive effect, as there is a normal mesial migration of the upper dentition (Weinberger, 1974; Reey and Eastwood, 1978; Wieslander and Lagerstrom, 1979; Birkebaek et al, 1984; Pancherz, 1984).

The wide variation in the upper molar change of this sample (Table 18), ranging from -5.35 mm to +2.60 mm., was also reported by Lagerstrom et al (1990), where the change ranged from -5 mm. to +7.5 mm. A quick glance at Table 5 also confirms

the findings. Pfeiffer and Groberty (1972), with headgear-activator therapy, achieved the greatest distal movement of the upper molar. Lagerstrom et al (1990), however, did not manage to achieve the same amount of change with headgear-activator therapy.

In summary, the upper molar change with activator therapy was not consistent, with wide variation in the findings reported. The majority of the studies reported little change in upper molar position. Given that the dentition migrates mesially naturally, this withholding of the mesial movement of the upper molars is a positive contribution to the Class II correction.

2. Comparison of lower molar change (Table 6).

Table 6: Comparison of lower molar change.

Study	Year	Molar change in mm.
Harvold & Vargervik	1971	0.00
Weinberger	1974	2.15
Reey and Eastwood	1978	3.7
Wieslander & Lagerstrom	1979	4.65
Birkebaek	1984	0.3
Pancherz	1984	2.3
Johnston	1986	0.7
Lagerstrom et al	1990	3.25
Hashim	1990	1.26

The lower molars in this sample moved forward a mean of 1.26 mm. Other studies also reported the lower molars in activator-treated groups were generally more mesial than before treatment, but the magnitude of the movement varied between 0.0 mm. and 4.65 mm. Some authors have reported that the normal mesial migration of lower molars was between 0.3 mm. and 3.85 mm. (Weinberger, 1974; Wieslander and Lagerstrom, 1979; Birkebaek, 1984; Pancherz, 1984; Johnston,

1986). Given that mesial migration of the dentition occurs without treatment, it is not clear whether the contribution of the activator effect was significant, or whether the change was more than normal mesial migration.

3. Comparison of maxillary change (Table 7)

Table 7: Comparison of maxillary change.

Study	Year	Maxillary change	
Jakobsson	1967	0.7 mm	(Pt. A)
Trayfoot & Richardson	1968	dec. 1.97 deg.	(SNA)
Harvold & Vargervik	1971	(-) 0.80 mm	(ANS)
Pfeiffer & Groberty*	1972	dec. by 2.3 deg.	(SNA)
Reey and Eastwood	1978	dec. by 0.5 deg	(SNA)
Wieslander & Lagerstrom	1979	(-) 1.90 mm.	(Pt. A)
Forsberg & Odenrick	1981	no change	(SNA)
Calvert	1982	no change	(Pt. A)
Williams & Melsen	1982	(-) 0.82 mm	(implant)
Creekmore & Radney	1983	no change	(SNA)
Gianelly et al	1984	dec. by 0.6 deg.	(SNA)
Pancherz	1984	(-) 2.3 mm.	(ANS)
Remmer et al	1985	(-) 0.9 mm.	(Pt. A)
Johnston	1986	(-) 1.0 mm.	(Max)
Derringer	1990	no change	(Pt. A)
Hashim	1990	(-) 1.41 mm.	(Max)

(-) denotes a forward displacement

* denotes headgear-activator

The maxilla in this sample came forward 1.41 mm. (S.D. 1.32 mm.). This finding is in agreement with Harvold and Vargervik (1971); Wieslander and Lagerstrom (1979); Williams and Melsen (1982), Pancherz (1984), Remmer et al (1985), and Johnston (1986).

It does not support the findings of Jakobsson (1967) and Trayfoot and Richardson (1968), who found significant decreases in Point A after activator therapy compared to untreated controls. Pfeiffer and Groberty (1972) also reported significant decreases in SNA after headgear-activator therapy.

Other studies (Reezy and Eastwood, 1978; Forsberg and Odenrick, 1981; Calvert, 1982; Creekmore and Radney, 1983; Gianelly et al, 1984; Derringer, 1990) reported no significant change in the maxilla with functional treatment.

It is interesting to note that the studies which reported distal change of the maxilla, had measured the changes at Point A. Point A, as explained in Chapter 5, undergoes remodelling with tooth movement, and is not a reliable landmark for measuring orthopedic change of the maxilla.

Pancherz (1984) reported ANS in his untreated control group grew forward by 4.0 mm., while Johnston (1986) reported a forward movement of the maxilla of 4.3 mm. in untreated controls. As their activator-treated group exhibited less forward movement of the maxilla, it appears that the activator had exerted a restricting influence on the maxillary growth. However, Remmer et al (1985) and Gianelly et al (1984) reported no difference at Point A between activator treatment and other treatment modalities such as Edgewise appliances with headgear, and Begg appliances.

In conclusion, activator treatment appears to have a slight restricting effect on the forward growth of the maxilla, but it is not any more effective than headgear treatment. Headgear therapy, and combination appliances of the headgear-activator type consistently have a greater inhibitory effect on the forward growth of the maxilla than functional appliances alone (Jakobsson, 1967; Gianelly et al, 1984; Remmer et al, 1985; Vargervik and Harvold, 1985; Kigele, 1987).

4. Comparison of mandibular changes (Table 8)

Table 8: Comparison of mandibular change.

Study	Year	Mandibular change	
Marschner & Harris	1966	3.42 mm.^	(Co-Pog)
Jakobsson	1967	no sig. change	(Pog, Pt. B)
Trayfoot & Richardson	1968	inc. by 0.18 deg.*	(SNB)
Harvold & Vargervik	1971	2.9 mm.*	(Co-Pog)
Pfeiffer & Groberty	1972	no sig. change	(SNB)
Reey & Eastwood	1978	3.8 mm.^	(Pog)
Wieslander & Lagerstrom	1979	3.30 mm*	(Pog)
Forsberg & Odenrick	1981	no sig. change	(SNB)
Calvert	1982	inc. by 0.9 deg.*	(SNB)
Williams & Melsen	1982	1.76 mm.	(implant)
Creekmore & Radney	1983	inc. by 0.6 deg.*	(SNB)
Gianelly et al	1984	3.1 mm.*	(Ar-Gn)
Pancherz	1984	5.8 mm.*	(Ar-Pog)
Remmer et al	1985	2.3 mm.*	(Pog)
Johnston	1986	4.2 mm.	(Mand)
Chang et al	1989	4.8 mm.^	(Ar-Gn)
Derringer	1990	inc. by 1deg.^	(SNB)
Hashim	1990	3.92 mm.	(Mand)

* not significantly more than controls

^ p < 0.01 level

^^ p < 0.001

The mandibular change in this sample was 3.92 mm. (S.D. 2.02 mm.). This finding is similar to reports by Wieslander and Lagerstrom (1979), who reported 3.30 mm. growth at pogonion; Remmer et al (1985), who found a 2.3 mm. increase at pogonion; Reey and Eastwood (1978), who found the mandibular corpus length in activator treated cases increased on average by 3.8 mm.; and Johnston (1986), who found an increase of 4.2 mm. It also compares favourably with Gianelly et al (1984), who reported mandibular growth (Ar-Gn) of 3.1 mm./year in patients treated with functional appliances. However, Wieslander and Lagerstrom, Remmer et al, Reey and Eastwood, and Gianelly et al, reported that these increases were not significantly more than found in controls.

Reports by Harvold and Vargervik (1971), Creekmore and Radney (1983), Pancherz (1984), Vargervik and Harvold (1985), and Lagerstrom et al (1990), also found that the length of the mandible after activator treatment was not significantly greater than the control group, while Jakobsson (1967) and Calvert (1982) found no significant differences in the anteroposterior position of the mandible compared to untreated controls.

In conclusion, the mandibular change found in this sample was a significant change, but it was no more than could be expected from normal mandibular growth. The findings of this study do not support the findings of Marschner and Harris (1966) and Meach (1966).

5. Comparison of apical base change.

The apical base change relates the anteroposterior position of the mandible relative to the maxilla. The apical base change found in this sample was 2.41 mm. (S.D. 1.46 mm.), meaning that, on average, the mandible has out-grown the maxilla by 2.41 mm. This supports the findings of Johnston (1986), who reported an apical base change of 3.2 mm., and Trayfoot and Richardson (1968), Pfeiffer and Groberty (1972), Forsberg and Odenrick (1981), who found a significant sagittal base change, as reflected in a significant decrease in angle ANB.

9.3 SUMMARY OF THE VARIOUS STUDIES

The results of this sample were compared with Johnston's results (Table 9). A t-test for the difference between two independent means was carried out between the two samples. No significant differences between the two samples were detected (Table 10).

Table 9: Johnston's Activator Sample (1986)

	Mean	SD
U6	0.10	1.60
ABCH	3.20	2.10
Max	-1.00	0.70
Mand	4.20	2.40
L6	0.20	1.20
6/6	3.60	1.60

n = 20

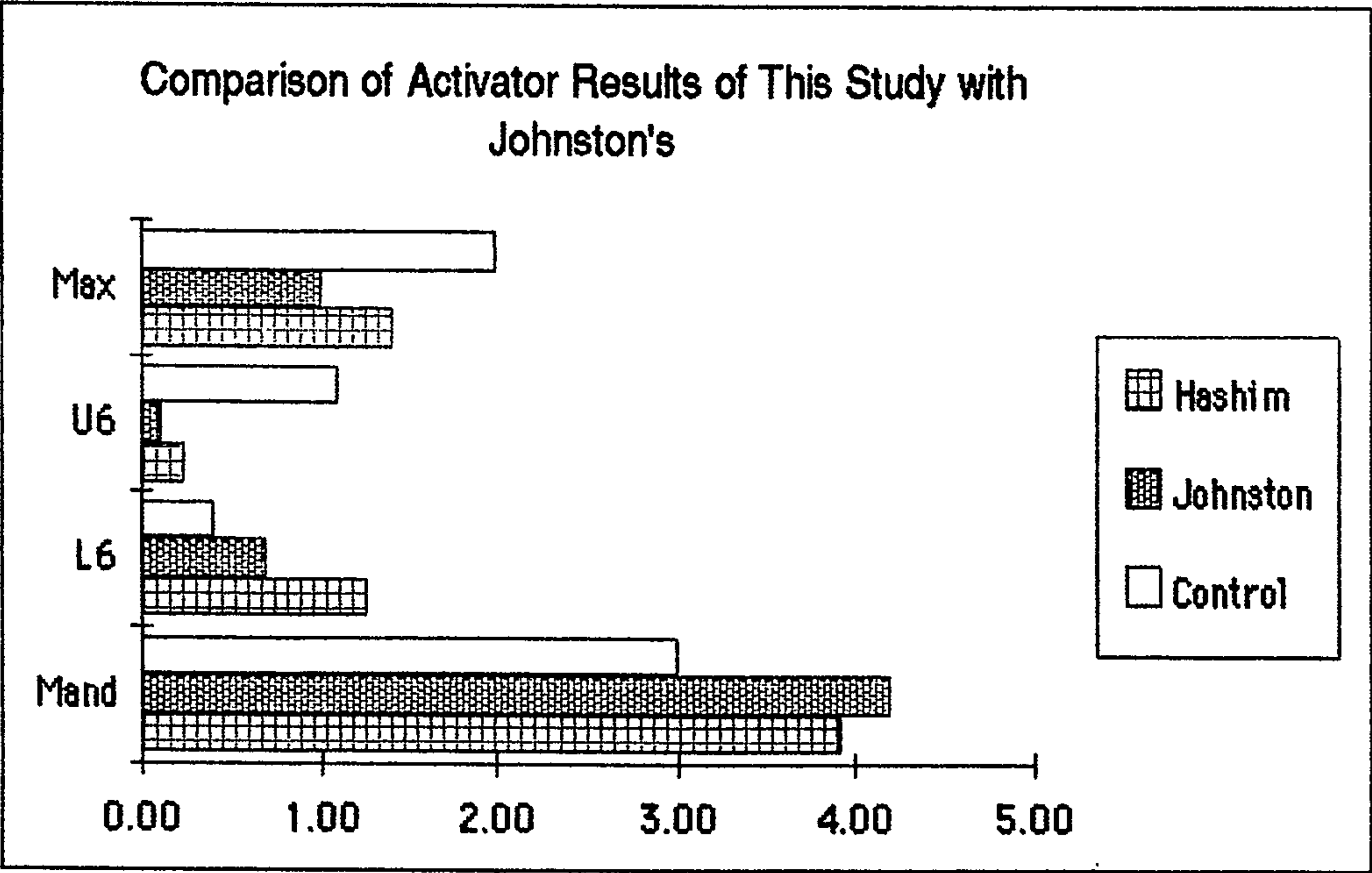
Table 10: Comparison of the Results of This sample and Johnston's Sample.

	This Sample (n=36)	Johnston Sample (n=20)	t	
U6	-0.24	0.10	1.02	not sig.
ABCH	2.41	3.20	0.20	not sig.
Max	-1.41	-1.00	0.20	not sig.
Mand	3.92	4.20	0.05	not sig.
L6	1.26	0.20	0.62	not sig.

d.f. = 54

The results of this sample were then compared with Johnston's results and controls in the form a bar-graph (Fig. 7).

Fig. 7



The results of various studies were also compared with their controls in the form of bar-graphs (Fig. 8-11).

Fig. 8

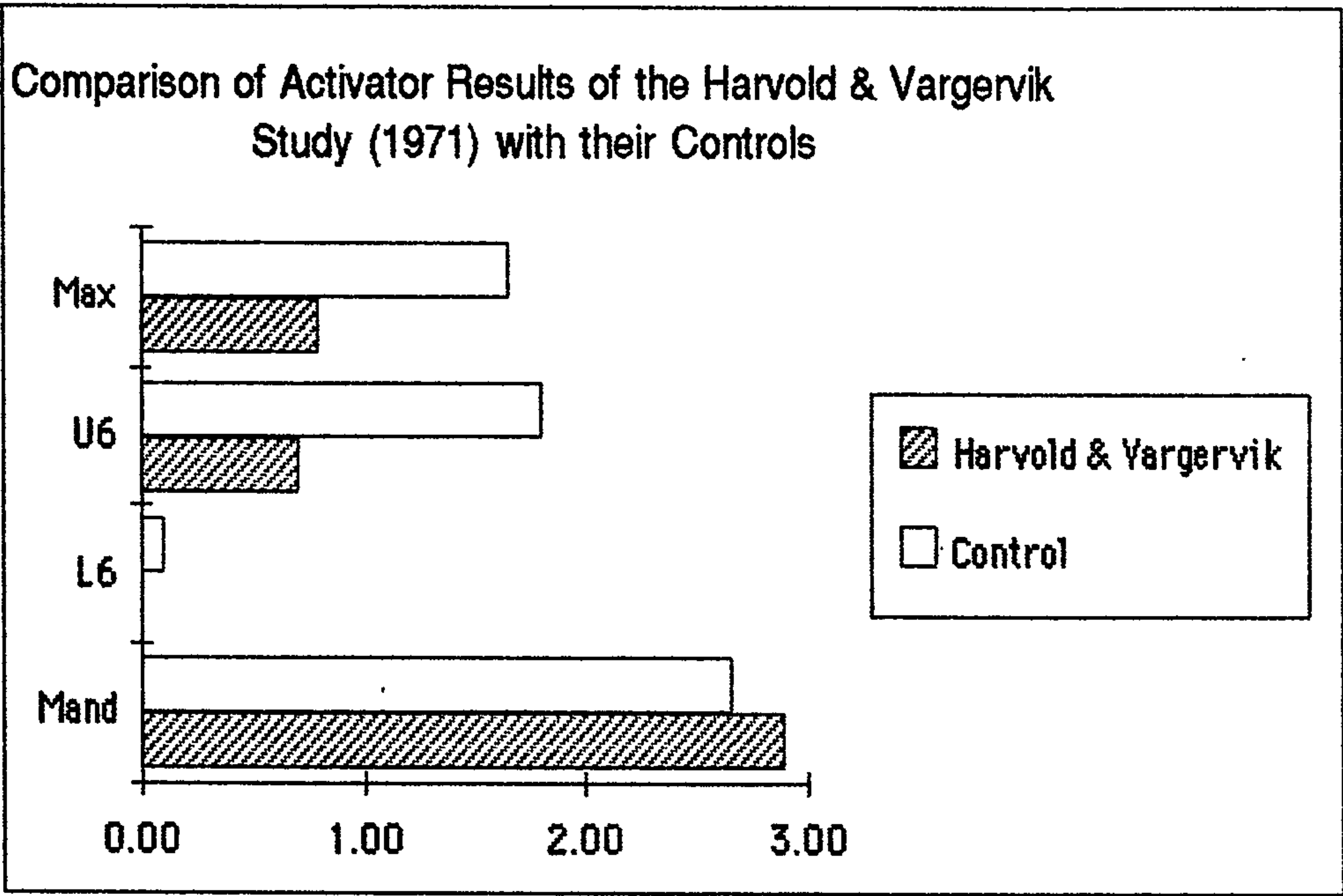


Fig. 9

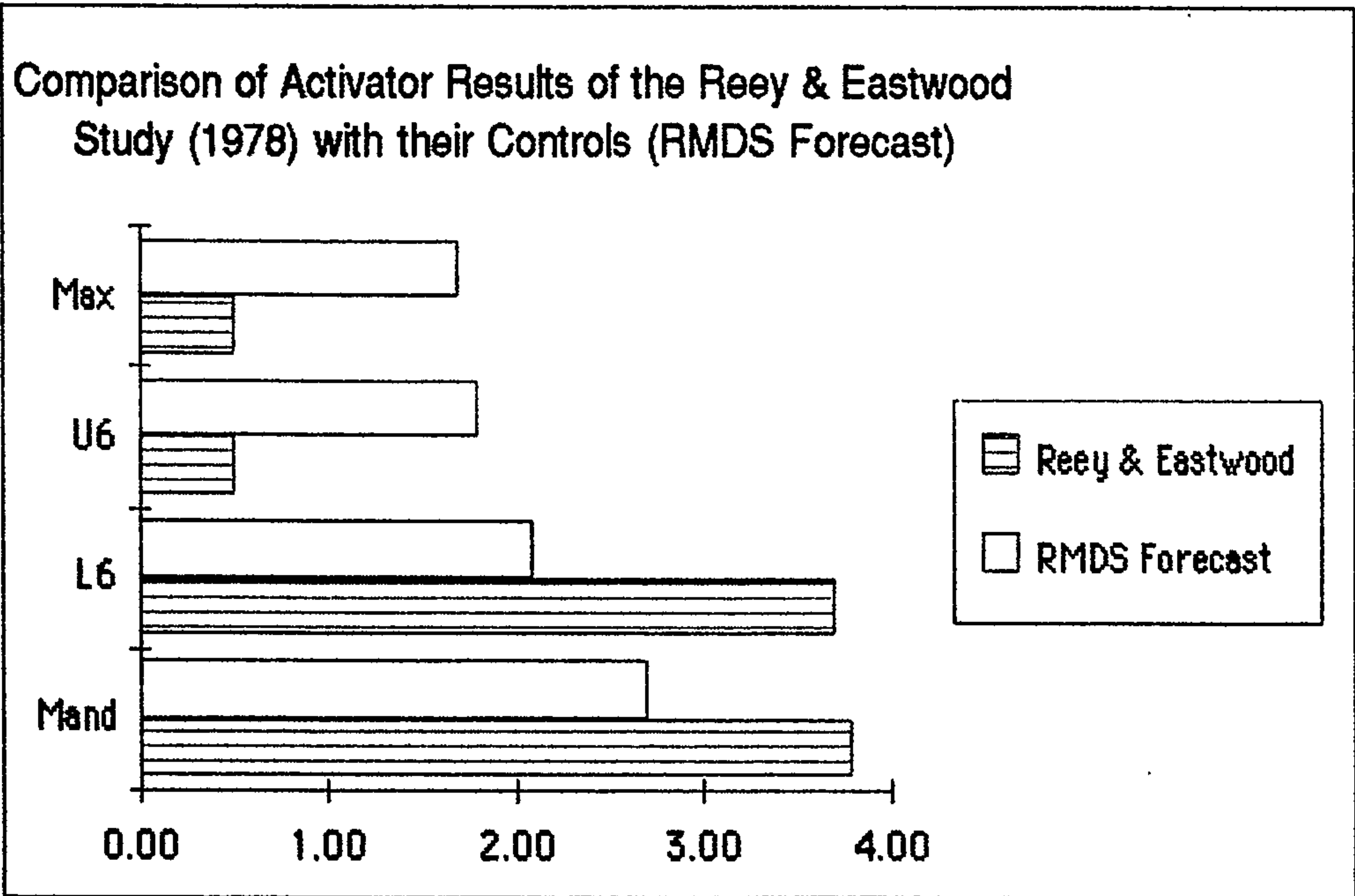


Fig. 10

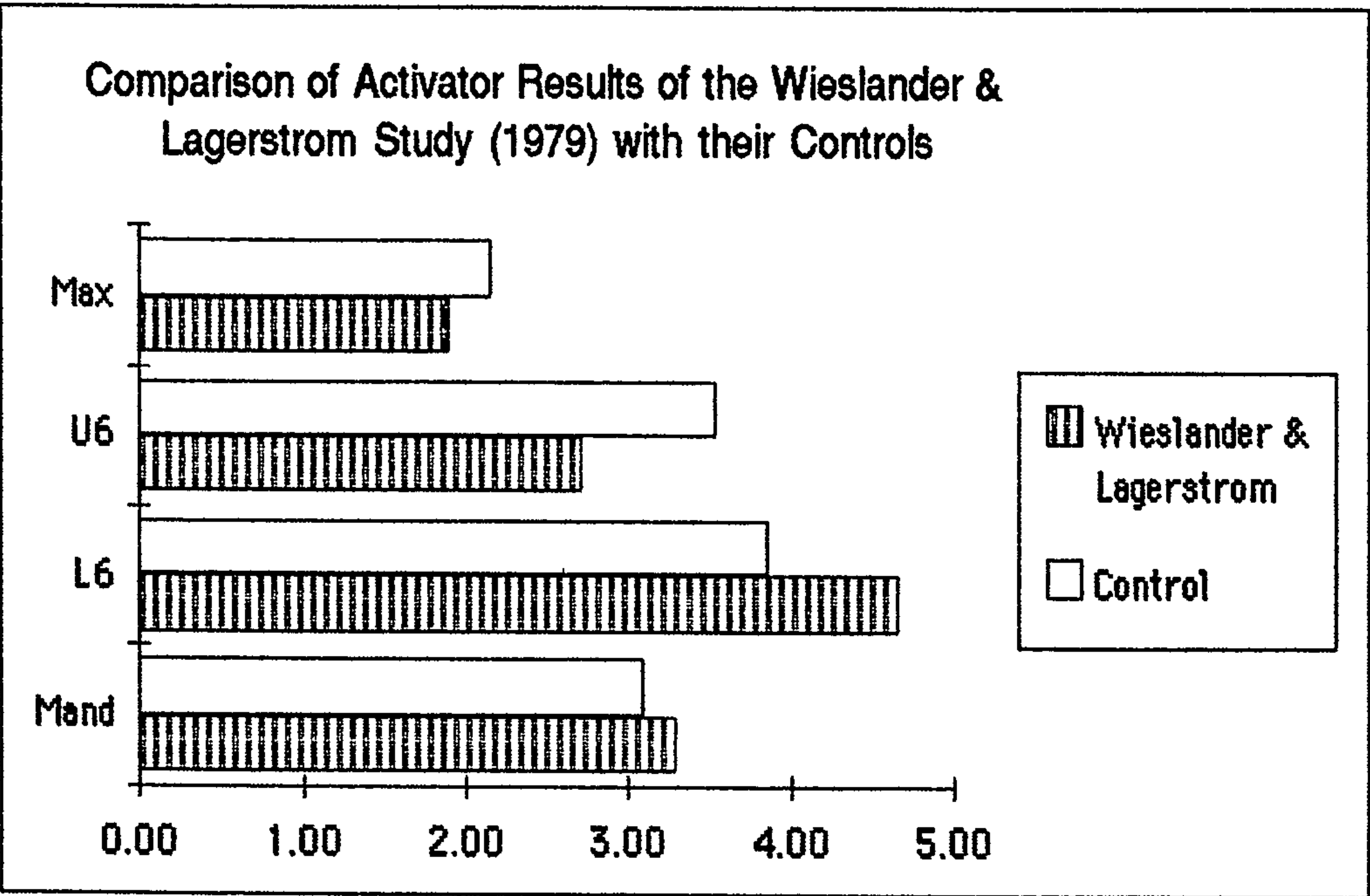
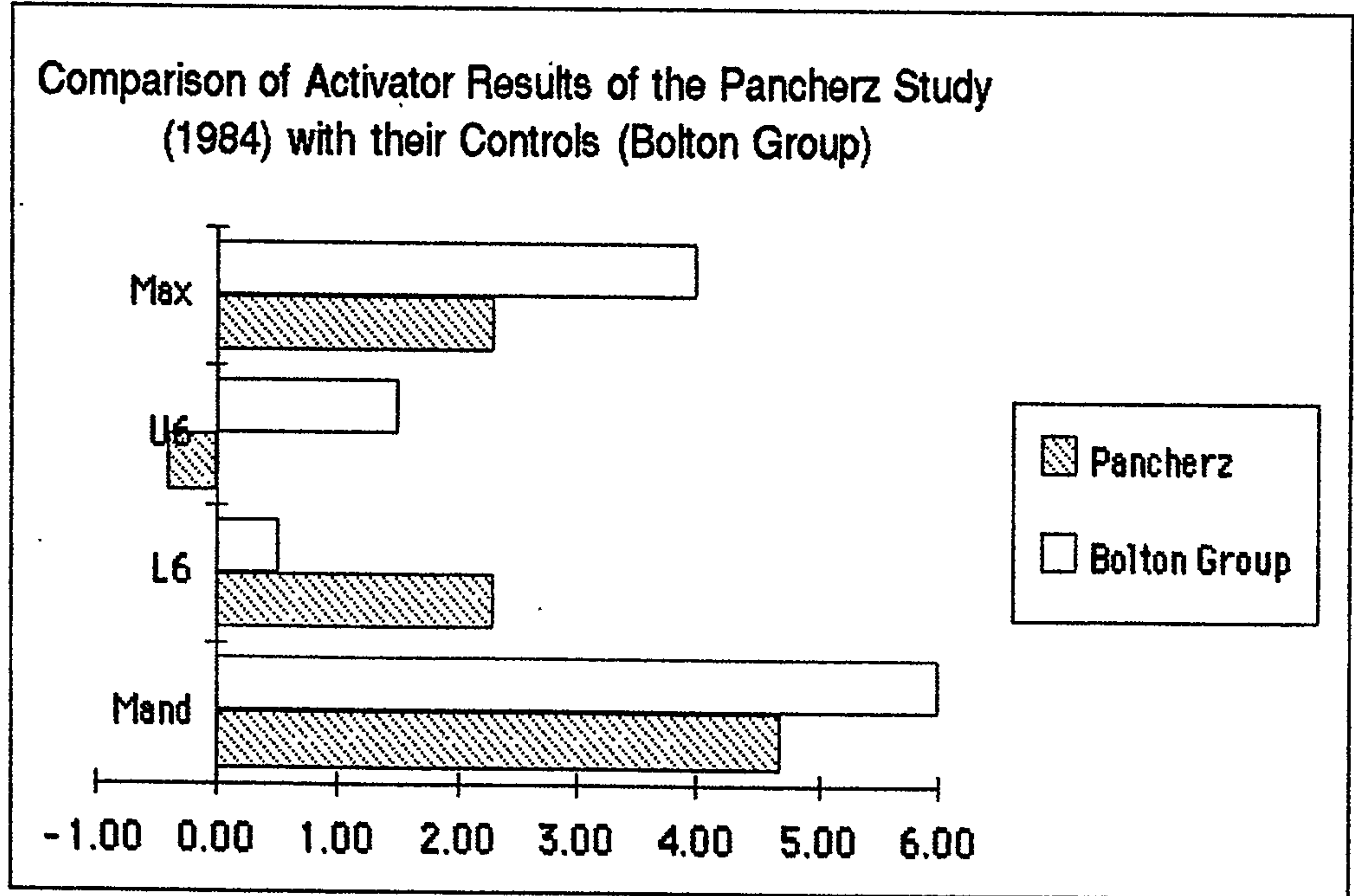


Fig. 11



The results of the various studies done on functional treatment show variability, with authors claiming different treatment effects. However, in spite of the differences, there exists a trend in the results.

The upper molar showed the greatest variability in change, but overall, the trend showed that its normal forward migration was inhibited, resulting in a relative distal movement.

The lower molar, generally, moved forward, but it did not move significantly more mesially than normal mesial migration.

The maxilla in activator-treated patients showed a slight forward movement, but a net restricting effect on the maxilla was exhibited, by a reduction in its normal forward growth.

There was a significant amount of mandibular growth, but it was not significantly more than normal growth.

10. SUMMARY AND CONCLUSIONS

10.1 RELIABILITY OF JOHNSTON'S METHOD OF SUPERIMPOSITION

The results demonstrate that the methodology is reliable. The analysis of variance test (ANOVA) for multiple comparisons, found the measurements of upper molar change (U6), lower molar change (L6), maxillary change (Max), mandibular change (Mand), and apical base change (ABCH), revealed no significant differences between the five sets of measurements at the 0.05 confidence level. The measurements for total molar change (6/6), however, were found to be unreliable, and could not be used. Johnston's method of double-checking the direct measurements of 6/6 with a derived value, may have contributed to the errors, and should be deleted from the method.

The standard deviations of the measurements obtained were found to be lower than those of other methods of cephalometric superimposition, as reported by Baumrind et al (1976), Houston and Lee (1985), and Buschang et al (1986).

The standard deviations for upper molar change (U6), and lower molar change (L6), being closer to the plane of reference (maxilla), were found to be lower than those of maxillary change (Max) and mandibular change (Mand). This agrees with the findings of Baumrind et al (1976), Pancherz and Hansen (1984), and Houston and Lee (1985) where the structures further away from the reference plane experienced greater rotational error.

It may be argued that this test was maybe a little biased as only one operator was involved in carrying out all the procedures. In all the other studies mentioned, the methods were tested with more than one operator, and inter-operator variability could have contributed to the larger errors found (Richardson, 1981; Savage et al, 1987). Savara et al (1966), however, found that the intra- and inter-operator variability was similar.

Still, it has demonstrated that the method is reliable, and a follow-up study can later be carried out to check its reliability with more than one operator.

10.2 ACTIVATOR TREATMENT CHANGES

In this sample, the Class II correction was obtained by:

1. Inhibition of forward migration of the upper molar.

The upper molar more or less did not move (mean change -0.24 mm.), which indicated an inhibitory effect on the normal mesial migration of the dentition.

2. Mesial migration of the lower molars (mean change 1.26 mm.).

It is not clear whether the normal mesial migration was significantly affected by the activator treatment.

3. Slight restriction of forward maxillary growth (mean change -1.41 mm.).

Although the net effect was a forward growth of the maxilla, the activator exhibited a slight restricting effect on the maxilla, by restricting its normal forward growth (Pancherz, 1984).

4. Normal growth of the mandible (mean change 3.92 mm.).

The mandibular growth obtained was not significantly more than can be expected from normal growth.

In conclusion, the activator treatment effects were mainly dentoalveolar. There was a slight orthopedic effect on the maxilla, but no significant mandibular growth was observed, above that which can be expected from normal growth.

The findings here support the reports of Creekmore and Radney (1983), and Gianelly et al (1984), who found that, in the correction of Class II malocclusion with activator treatment, the orthopedic component was approximately 30%, and the orthodontic component 70%.

The treatment results of this sample, as in other samples before (Creekmore and Radney, 1983; Gianelly et al, 1984; Vargervik and Harvold, 1985; Derringer, 1990; Lagerstrom et al, 1990), showed large variation, meaning that one can select individual cases to prove or disprove almost any point. Pooling these data and reporting mean changes would present a very unrepresentative picture of the effect of the appliance and the individual patient responses, which ranged from poor to excellent.

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E. APPENDICES

I. STATISTICAL FORMULAE

(Brunning and Kintz, 1977)

I.1 ANALYSIS OF VARIANCE (ANOVA) - MULTIPLE COMPARISONS TEST

The question to be resolved is whether the difference among the five sets of measurements is statistically significant or whether it is one that could occur by chance. The comparison is made on the basis of the variance within each group and among the five groups. The null hypothesis says that there is no difference among the five sets of measurements, i.e.,

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5.$$

Further, if the hypothesis is true, the means of the five groups will be close together and the variance between the groups will approximate the variance for the distribution of all scores from their individual means; if the hypothesis is false, the converse will apply.

Total sum of squares (SS_T):

$$SS_T = \sum X^2 - (\sum X)^2/N$$

Where X is each individual measurement in the entire series of measurements for the 5 groups, and N is the total number of measures in all 5 groups. The term $(\sum X)^2/N$ is called a correction factor (C.T.).

Between groups sum of squares (SS_B):

$$SS_B = \sum\{(\sum X_k)^2/N_k\} - C.T.$$

where,

$$\sum\{(\sum X_k)^2/N_k\} = (\sum X_1)^2/N_1 + (\sum X_2)^2/N_2 + (\sum X_3)^2/N_3 + (\sum X_4)^2/N_4 + (\sum X_5)^2/N_5$$

and k = number of groups

Within groups sum of squares (SS_W):

$$SS_W = \sum\{(\sum X_s)^2/N_s\} - C.T.$$

where,

$$\sum\{(\sum X_s)^2/N_s\} = (\sum X_1)^2/N_1 + (\sum X_2)^2/N_2 + \dots + (\sum X_{14})^2/N_{14} + (\sum X_{15})^2/N_{15}$$

and S is the number of subjects in each group.

Error-term sum of squares:

$$SS_{Error} = SS_T - SS_W - SS_B$$

The degrees of freedom:

$$df_B = k - 1; (k = \text{number of groups})$$

$$df_W = S - 1; (S = \text{number of subjects in each group})$$

$$df_T = N - 1; (N = \text{total number of measures})$$

$$df_{error} = N - k - S$$

Mean square:

$$MS_B = SS_B/df_B$$

$$MS_{Error} = SS_{Error}/df_{Error}$$

F statistic:

$$F = MS_B / MS_{Error}$$

The calculations are presented in a summary table, as follows:

Source	SS	df	MS	F
Total	SS _T	df _T		
Within groups	SS _w	df _w		
Between groups	SS _B	df _B	SS _B /df _B	MS _B /MS _{Error}
Error	SS _{Error}	df _{Error}	SS _{Error} /df _{Error}	

1.2 THE T-TEST FOR A DIFFERENCE BETWEEN A SAMPLE MEAN AND THE POPULATION MEAN

The formula:

$$t = \frac{\bar{X} - m}{\sqrt{\frac{\sum X^2 - \frac{(\sum X)^2}{N}}{N(N - 1)}}$$

- where, $\bar{X}$ = the mean of the sample.
- m = the mean of the population.
- $\sum X^2$ = the sum of the squared score values.
- $(\sum X)^2$ = the square of the sum of all the scores.
- N = the number of scores used in the analysis.

The degrees of freedom = $N - 1$

I.3 THE TEST FOR A DIFFERENCE BETWEEN TWO INDEPENDENT MEANS

The formula:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sum X_1^2 - \frac{(\sum X_1)^2}{N_1} + \sum X_2^2 - \frac{(\sum X_2)^2}{N_2}}{(N_1 + N_2) - 2} \cdot \frac{1}{N_1} + \frac{1}{N_2}}}$$

where, $\bar{X}_1$ = the mean of the first group of scores.

$\bar{X}_2$ = the mean of the second group of scores.

$\sum X_1^2$ = the sum of the squared values of the first group.

$\sum X_2^2$ = the sum of the squared values of the second group.

$(\sum X_1)^2$ = the square of the sum of the scores in the first group.

$(\sum X_2)^2$ = the square of the sum of the scores in the second group.

N_1 = the number of scores in the first group.

N_2 = the number of scores in the second group.

The degrees of freedom = $(N_1 + N_2) - 2$

II. SUMMARIES OF DATA

Table 11: Method Error (Maxilla)

Patient\Measures	1st	2nd	3rd	4th	5th	S.D.
CC	-1.90	-2.11	-1.39	-1.39	-1.80	0.32
VS	-0.55	-0.81	-0.94	-0.24	-0.81	0.28
KM	-6.67	-5.43	-6.34	-5.81	-6.16	0.48
RH	-2.19	-2.47	-1.55	-2.10	-1.90	0.34
ML	-0.47	0.00	-0.32	-0.67	-0.47	0.25
SB	-2.40	-1.94	-2.38	-2.28	-2.38	0.19
AF	-2.52	-1.85	-1.83	-2.07	-2.01	0.28
DO	-3.41	-2.90	-1.96	-2.36	-3.16	0.59
NL	0.00	0.00	0.00	0.00	-0.36	0.16
NP	-0.42	-0.93	-0.19	-0.52	0.00	0.35
MD	1.01	-1.14	-0.94	-0.71	-1.38	0.95
LP	-2.05	-1.27	-1.37	-1.12	-1.29	0.36
BC	-1.65	-1.22	-1.12	-1.24	-0.89	0.28
GG	-1.33	-1.69	-1.45	-1.83	-1.18	0.26
KS	-2.74	-2.51	-2.18	-1.67	-2.42	0.41
						Mean 0.37

Table 12: Method Error (Mandible)

Patient\Measures	1st	2nd	3rd	4th	5th	S.D.
CC	4.25	4.57	4.19	3.88	4.38	0.25
VS	1.66	1.83	1.64	1.88	1.50	0.15
KM	8.99	7.72	8.38	8.06	8.62	0.49
RH	5.17	5.70	4.93	5.22	5.12	0.29
ML	4.12	4.03	4.01	3.70	3.75	0.19
SB	4.82	4.93	5.33	5.26	5.21	0.22
AF	7.61	6.92	7.02	7.11	6.96	0.28
DO	4.92	5.29	3.40	3.54	4.48	0.83
NL	1.96	1.46	1.94	1.52	1.83	0.24
NP	0.90	1.29	0.71	0.52	0.00	0.48
MD	7.48	7.59	7.29	7.16	7.81	0.25
LP	2.05	1.82	1.37	2.01	2.70	0.48
BC	4.25	3.75	3.73	3.92	3.89	0.21
GG	5.49	5.69	5.88	6.01	5.46	0.24
KS	4.41	3.53	3.58	3.00	4.44	0.62
						Mean 0.35

Table 13: Method Error (Upper Molar)

Patient\Measures	1st	2nd	3rd	4th	5th	S.D.
CC	0.71	0.32	0.49	0.19	0.76	0.25
VS	0.00	0.00	0.26	0.00	0.25	0.14
KM	-1.38	-0.61	-1.40	-1.29	-1.11	0.33
RH	0.37	0.77	0.44	0.51	0.42	0.16
ML	0.72	0.68	0.80	0.68	0.94	0.11
SB	0.81	0.85	0.95	0.57	0.89	0.15
AF	-0.85	-0.66	-0.51	-0.84	-0.77	0.14
DO	1.29	0.83	0.88	0.82	1.14	0.21
NL	-1.96	-1.54	-1.84	-1.57	-1.63	0.18
NP	1.02	1.01	1.24	0.97	1.14	0.11
MD	-0.66	-1.53	-0.88	-0.86	-0.99	0.33
LP	0.66	0.45	0.51	0.74	-0.10	0.33
BC	1.02	1.52	1.13	0.96	0.80	0.27
GG	-2.64	-2.74	-2.78	-2.81	-2.71	0.07
KS	0.00	1.09	0.00	0.32	0.00	0.47
						Mean 0.22

Table 14: Method Error (Lower Molar)

Patient\Measures	1st	2nd	3rd	4th	5th	S.D.
CC	0.78	0.87	1.24	0.74	0.86	0.20
VS	1.68	2.01	1.65	1.88	2.43	0.32
KM	3.86	3.11	3.65	3.60	3.51	0.28
RH	0.80	0.56	0.49	0.78	0.54	0.14
ML	0.10	0.00	0.00	0.75	0.41	0.33
SB	0.78	0.72	0.30	1.09	0.75	0.28
AF	0.00	0.00	0.00	0.00	0.17	0.08
DO	1.63	1.17	2.12	1.77	1.68	0.34
NL	1.16	1.24	0.88	1.21	1.32	0.17
NP	1.68	1.38	1.40	1.93	1.64	0.23
MD	0.00	0.41	0.17	0.63	0.18	0.24
LP	1.41	1.08	1.45	1.01	1.02	0.22
BC	1.52	1.14	1.34	0.86	0.44	0.42
GG	2.95	3.15	3.39	3.51	3.58	0.26
KS	2.47	2.45	2.6	2.54	1.96	0.26
						Mean 0.25

Table 15: Method Error (Apical Base Change)

Patient\Measures	1st	2nd	3rd	4th	5th	S.D.
CC	2.35	2.46	2.80	2.49	2.58	0.17
VS	1.11	1.02	0.70	1.64	0.69	0.39
KM	2.32	2.18	2.04	2.25	2.46	0.16
RH	2.98	3.23	3.38	3.12	3.22	0.15
ML	3.65	4.03	3.69	3.03	3.28	0.39
SB	2.42	2.99	2.95	2.98	2.83	0.24
AF	5.09	5.07	5.19	5.04	4.95	0.09
DO	1.51	2.39	1.44	1.18	1.32	0.48
NL	1.96	1.46	1.94	1.52	1.47	0.26
NP	0.48	0.36	0.52	0.00	0.00	0.26
MD	6.47	6.45	6.35	6.45	6.43	0.05
LP	0.00	0.55	0.00	0.89	1.41	0.60
BC	2.60	2.53	2.61	2.68	3.00	0.18
GG	4.16	4.00	4.43	4.18	4.28	0.16
KS	1.67	1.02	1.40	1.33	2.02	0.38
						Mean 0.26

Table 16: Maxillary Change

Patient	Mean	SD
DTs	-1.52	0.47
VSp	-0.78	0.57
AS	1.11	0.37
KW	-0.88	0.09
LG	-0.88	0.01
SKz	-1.24	0.45
MG	-2.93	0.39
CJ	-1.54	0.70
BH	-2.81	0.54
RFC	-0.75	0.21
KD	-0.66	0.01
AFm	0.00	0.00
DN	-0.63	0.04
BM	-1.92	0.05
VSp	-1.27	0.35
JM	-1.19	0.92
DTu	0.00	0.00
PF	0.35	0.49
AT	-1.91	0.16
MLe	-4.36	0.18
ER	-1.48	0.18
CC	-1.72	0.32
VS	-0.67	0.28
KM	-6.08	0.48
RH	-2.04	0.34
ML	-0.39	0.25
SB	-2.28	0.19
AF	-2.06	0.28
DO	-2.76	0.59
NL	-0.07	0.16
NP	-0.41	0.35
MD	-0.63	0.95
LP	-1.42	0.36
BC	-1.22	0.28
GG	-1.50	0.26
KS	-2.30	0.41
Mean	-1.41	
SD	1.32	

Table 17: Mandibular Change

Patient	Mean	SD
DTs	1.52	0.47
VSp	4.39	0.45
AS	1.11	0.37
KW	4.23	0.45
LG	2.82	0.16
SKz	5.31	0.30
MG	5.47	0.62
CJ	2.42	0.55
BH	6.51	0.25
RFC	3.94	0.42
KD	4.42	0.10
AFm	2.74	0.63
DN	2.66	0.35
BM	5.32	0.08
VSp	3.77	0.30
JM	2.80	0.52
DTu	0.00	0.00
PF	1.61	0.30
AT	3.37	0.23
MLe	7.68	0.37
ER	3.67	0.09
CC	4.25	0.25
VS	1.70	0.15
KM	8.35	0.49
RH	5.23	0.29
ML	3.92	0.19
SB	5.11	0.22
AF	7.12	0.28
DO	4.33	0.83
NL	1.74	0.24
NP	0.68	0.48
MD	7.47	0.25
LP	1.99	0.48
BC	3.91	0.21
GG	5.71	0.24
KS	3.79	0.62
Mean	3.92	
SD	2.02	

Table 18: Upper Molar Change (U6)

Patient	Mean	SD
DTs	1.94	0.08
VSp	-0.21	0.29
AS	-0.88	0.06
KW	1.25	0.08
LG	-0.49	0.21
SKz	0.01	0.35
MG	-5.35	0.01
CJ	0.53	0.74
BH	-3.73	0.21
RFC	-1.14	0.66
KD	0.74	0.22
AFm	0.94	0.28
DN	0.20	0.28
BM	0.63	0.08
VSp	-0.88	0.43
JM	-2.41	0.07
DTu	2.60	0.65
PF	0.02	0.46
AT	0.40	0.57
MLe	-2.00	0.57
ER	0.00	0.00
CC	0.49	0.25
VS	0.10	0.14
KM	-1.16	0.33
RH	0.50	0.16
ML	0.76	0.11
SB	0.81	0.15
AF	-0.73	0.14
DO	0.99	0.21
NL	-1.71	0.18
NP	1.08	0.11
MD	-0.98	0.33
LP	0.45	0.33
BC	1.09	0.27
GG	-2.74	0.07
KS	0.28	0.47
Mean SD	-0.24 1.57	

Table 19: Lower Molar Change (L6)

Patient	Mean	SD
DTs	0.29	0.40
VSp	0.17	0.23
AS	1.62	0.03
KW	1.66	0.04
LG	1.45	0.11
SKz	1.65	0.28
MG	0.88	0.14
CJ	1.31	0.40
BH	2.37	0.45
RFC	0.80	0.18
KD	0.07	0.09
AFm	1.30	0.11
DN	1.88	0.21
BM	1.12	0.00
VSp	1.25	0.01
JM	1.66	0.16
DTu	1.51	0.61
PF	1.51	0.21
AT	1.90	0.13
MLe	0.39	0.40
ER	0.00	0.00
CC	0.90	0.20
VS	1.93	0.32
KM	3.55	0.28
RH	0.63	0.14
ML	0.25	0.33
SB	0.73	0.28
AF	0.03	0.08
DO	1.67	0.34
NL	1.16	0.17
NP	1.61	0.23
MD	0.28	0.24
LP	1.19	0.22
BC	1.06	0.42
GG	3.32	0.26
KS	2.40	0.26
Mean SD	1.26 0.84	

Table 20: Apical Base Change

Patient	Mean	SD
DTs	0.00	0.00
VSp	3.61	0.11
AS	0.00	0.00
KW	3.35	0.35
LG	1.94	0.17
SKz	4.08	0.74
MG	2.54	0.23
CJ	0.89	1.25
BH	3.70	0.28
RFC	3.19	0.63
KD	3.76	0.11
AFm	2.74	0.63
DN	2.03	0.30
BM	3.40	0.13
VSp	2.51	0.05
JM	1.61	0.40
DTu	0.00	0.00
PF	1.26	0.18
AT	1.46	0.40
MLe	3.32	0.20
ER	2.19	0.09
CC	2.54	0.17
VS	1.03	0.39
KM	2.25	0.16
RH	3.19	0.15
ML	3.54	0.39
SB	2.83	0.24
AF	5.07	0.09
DO	1.57	0.48
NL	1.67	0.26
NP	0.27	0.26
MD	6.43	0.05
LP	0.57	0.60
BC	2.68	0.18
GG	4.21	0.16
KS	1.49	0.38
Mean	2.41	
SD	1.46	

Table 21: Sample Data

Patient (n=36)	Sex	Age at start of treatment	Treatment Duration (months)	Duration between Cephalograms (months)
DTs	M	9 yr 0 mth	8	13
DTu	M	13 yr 6 mth	7	8
PH	F	11 yr 8 mth	4	6
AT	F	11 yr 11 mth	7	8
MLe	M	12 yr 9 mth	14	20
JM	M	11 yr 10 mth	6	8
VSh	F	13 yr 9 mth	9	10
BM	F	13 yr 4 mth	6	8
DN	M	11 yr 6 mth	9	10
AFm	F	11 yr 9 mth	8	9
KD	F	10 yr 9 mth	7	9
RFC	M	12 yr 7 mth	9	11
AS	F	12 yr 6 mth	5	7
VSp	F	11 yr 10 mth	11	11
KW	F	13 yr 3 mth	6	7
LG	F	12 yr 10 mth	9	11
SKz	F	11 yr 6 mth	12	14
MG	M	11 yr 10 mth	25	25
CJ	M	12 yr 7 mth	8	10
BH	F	9 yr 8 mth	32	34
ER	F	10 yr 4 mth	4	7
CC	F	11 yr 0 mth	12	12
VS	F	12 yr 3 mth	8	14
KM	F	12 yr 9 mth	8	18
RH	F	12 yr 2 mth	9	11
ML	M	13 yr 6 mth	8	9
SB	F	13 yr 0 mth	7	17
AF	F	11 yr 5 mth	12	16
DO	F	11 yr 10 mth	14	16
NL	F	13 yr 9 mth	6	16
NP	F	12 yr 1 mth	8	10
MD	M	13 yr 3 mth	10	14
LP	F	12 yr 0 mth	9	10
BC	M	12 yr 4 mth	11	13
GG	F	12 yr 2 mth	15	17
KS	F	12 yr 10 mth	18	18
Mean		12 yr 2 mth	10.03	12.69
SD		12.90 mth	5.54	5.63