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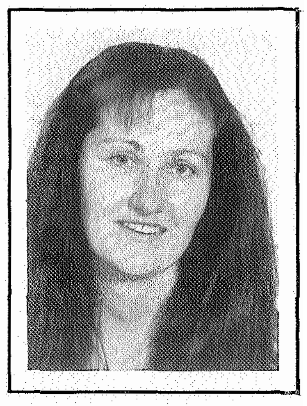

Cephalometric landmark identification error

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Abstract: The study found that each landmark exhibited a characteristic pattern of error, varying in the different planes of space. The method of registration used was the Protocol Standard Film Register Punch and compatible register pins which affords the accurate registration used in the printing industry. Differences between the magnitude of error of some of the landmarks used in previous studies and the present study are discussed. It may be concluded that the twenty two landmarks investigated have envelopes of error characteristic of each point, as indicated in the representative illustrations. These envelopes of error apparently are influenced by the precision of the definition of the point and features of each cephalograph in the region in which the point lies.

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INTRODUCTION

Since the first discussions of cephalometric changes due to growth and treatment were published, the orthodontic literature has been replete with cephalometric analyses, cross-sectional and longitudinal studies of growth change in varied groups, and assessments of change due to the various treatment modalities.

In reviewing this literature, it becomes apparent that the change in relationship of the various craniofacial landmarks due to growth and treatment are generally expressed in small numbers of degrees or millimetres. While such figures may be statistically significant over a large sample or population, the clinician is not only interested in group trends but also the application of such findings to the individual. Landmark identification error is a central issue in assessing the reproducibility and sensitivity of any cephalometric study. It is unreasonable to measure individual variation from a cephalometric norm in tenths of a millimetre if the cephalographic landmarks upon which it is based cannot be identified with a degree of certainty within tens of millimetres. The present study was undertaken to provide a basis for assessment of cephalographic landmarks used in orthodontic diagnosis and treatment assessment.

LITERATURE REVIEW

Measurements made on lateral cephalographs, like all other measurements are subject to errors. These may be classified into two general categories:

1. **Projection errors**. These are errors inherent in the physical system used to produce the lateral cephalograph. They include such considerations as the production of the x-rays, the geometry of image production, film variables and patient variables.
2. **Tracing errors**. These are errors occurring in the assessment and application of lateral cephalographs. They relate to measurement error, landmark identification error and the relationship of such errors to the manner of application of measurements.

The findings of Gravely and Murray Benzies (1974), Halse and Hedin (1978) and McWilliam and Welander (1978) suggested that film quality was not of significance in landmark identification error. Gravely and Murray Benzies (1974) suggested that the quality of cephalographs was subjective, with clarity often varying from one site to another on any one film.

The method used to register and orientate consecutive landmark location determinations varies between studies and is dependent upon the system used to record the coordinates of each landmark. However, these systems are almost uniformly based upon a pinhole method.

Probably the best documented of these methods was that used by Baumrind and Frantz (1971). In this study a transparent plastic template having four needle-point perforations in a rectangular configuration was placed over each cephalograph. The four points were registered by perforating the film using a fine sewing needle in a dental broach holder. When the film was traced, the four registration points were recorded using a fine pencil. McWilliam (1982) has described a similar system in which four indentations were made in each cephalograph. Many other authors (Richardson, 1966; Broch, Slagsvold and Røsler, 1981; Stabrun and Danielson, 1982) have used one, two or three pinholes to register tracings or direct point plots from radiographs.

In the case of Baumrind and Frantz (1971) the four registration points were superimposed using a "least squares best fit" program. In the majority of studies, however, a single point was used as the origin and the second point (and the third point if used) was applied to establishing the X and Y axes.

Once the landmarks of duplicate tracings are superimposed using the fiducial points, the coordinates may be orientated relative to any chosen plane of reference. Baumrind and Frantz (1971) orientated points relative to a horizontal sella-nasion plane, Richardson (1966) and Stabrun and Danielson (1982) orientated points so that the x-axis was approximately parallel to the Frankfort plane.

The literature related to landmark identification is remarkably consistent. Authors such as Baumrind and Frantz (1971) and Broch (1981) agree that the problems of landmark identification error may be **related to certain features** including:

1. The *curvature of the line* upon which the landmark is positioned. A sharp curve of small radius, as of the incisal

edge of the upper incisor, gives a far better delineation of landmark position than does a shallow curve of greater radius, as in gonion.

2. *Contrast*, as it is easier to identify a landmark in a high contrast area.

3. *'Noise'*, as landmark identification is made difficult in those areas where superimposition of other structures interferes with clarity.

4. *Definition of the point* is important as a weak definition leaves a wider margin of disagreement in interpretation between operators.

Since the first observations of Richardson (1966), later authors including Baumrind and Frantz (1971), Midtgard, Björk and Linder-Aronson (1974), Broch, Slagsvold and Røsler (1981), Stabrun and Danielson (1982), Cohen (1984) have investigated numerous landmarks utilised for cephalometric analysis. Although magnitudes of error vary from study to study with different methods employed, agreement has been reached that the distribution of error for a given landmark is characteristic for that landmark and will show different distribution in different planes of space. For this reason, when X and Y axes are used, error is not necessarily the same in both directions for each landmark.

MATERIALS AND METHODS

Twenty lateral cephalographs were used in the study, chosen at random from the records of patients treated in the Orthodontic Department of the Royal Dental Hospital of Melbourne. All cephalographs were taken using a standardised technique based upon that of Broadbent (1931). The equipment used provided a twelve percent magnification of midsagittal structures. Selection was not influenced by sex or malocclusion type.

Prior to tracing the lateral cephalographs, the radiographs and tracing acetate film were punched using a Protocol Standard Film Register Punch (Model no. 149/104)* in the following manner:

Step 1. A master cephalograph was selected and marked to enable its future identification. The radiograph was placed on the punch platform and positioned so that the three round pin punches closest to the rectangular slot punch lay beneath the lower border of the radiograph *Figure 1*.The film was punched and removed from the platform.

Step 2. The lower border of each cephalograph and sheet of tracing acetate film was then individually punched in a manner similar to that of the master cephalograph utilising the lateral guide to produce a similar configuration of punch holes. This gave a pattern of three round pin holes at the lower border of each lateral cephalograph or sheet of tracing acetate *Figure 2*.

Step 3. The master cephalograph was again placed on the platform of the pin punch. Three 6.35mm. diameter, 3mm. flattened profile round register pins were placed in the pin holes previously punched in the lower border of the radiograph. The radiograph was then positioned so that the upper border lay above the punching heads and the three round pin holes opposed each other *Figure 3*. The master cephalograph was taped to the platform in this position to ensure its stability. The master cephalograph was punched in this position. The lateral guide was removed so that film variation did not influence punching procedures. It was found that the radiographs were not right-angled rectangular and presence of a lateral guide at this stage distorted the position of the second line of pin holes.

Step 4. In turn each individual cephalograph or acetate film was placed over the three register pins in the master cephalograph and settled under its own weight to prevent

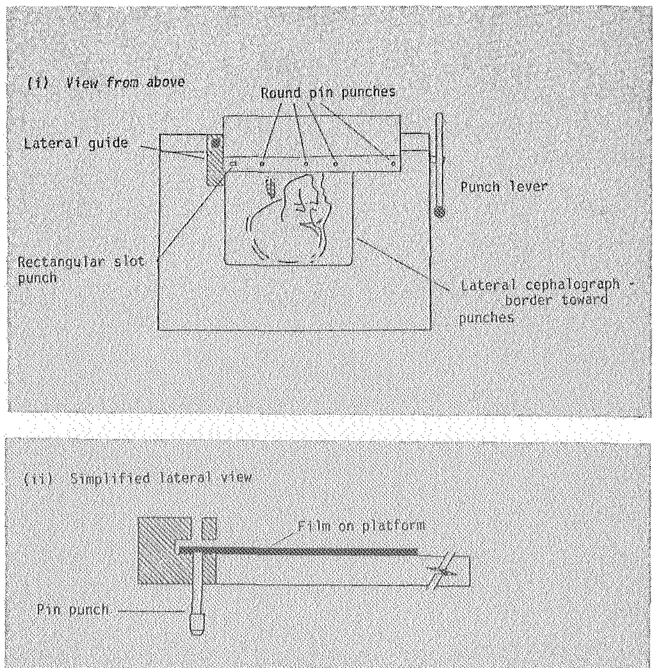


Figure 1 : Punching the master lateral cephalograph.

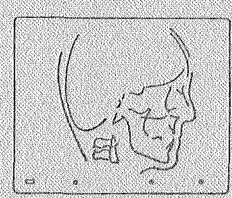


Figure 2 : Lateral cephalograph showing initial punch holes.

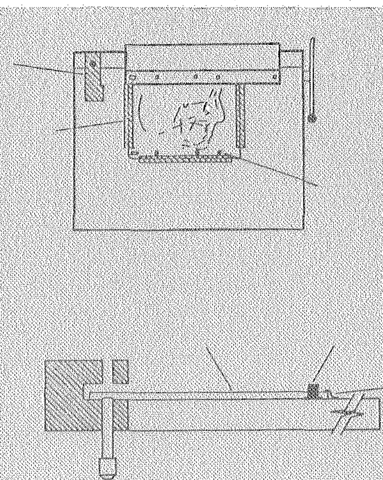


Figure 3 : Master cephalograph positioned with register pins for second punching.

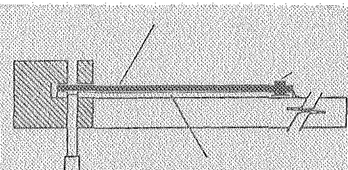


Figure 4 : Lateral cephalograph or tracing acetate film registered for second punching.

distortion. The cephalograph or acetate film was punched and then removed without disturbing the register pins *Figure 4*.

This procedure provided the series of twenty lateral cephalographs and 100 sheets of acetate film in accurate register to a tolerance of less than 0.01mm..

In order to provide stability of registration, the lateral cephalographs and tracing acetate film were mounted on an aluminium plate with six fixed register pins. The plate had a window cut in its centre enabling its use during both tracing and digitising procedures.

Each of the twenty cephalographs were traced on five occasions each separated by a one month interval.

All tracings were performed with cephalograph and tracing acetate film registered over the six register pins of the aluminium plate. They were carried out under uniform conditions in a dark room on a radiograph viewer with fluorescent lighting. Tracings were performed on 0.089mm. (0.0035") double-matte acetate tracing film using a 0.5mm. HB pencil.

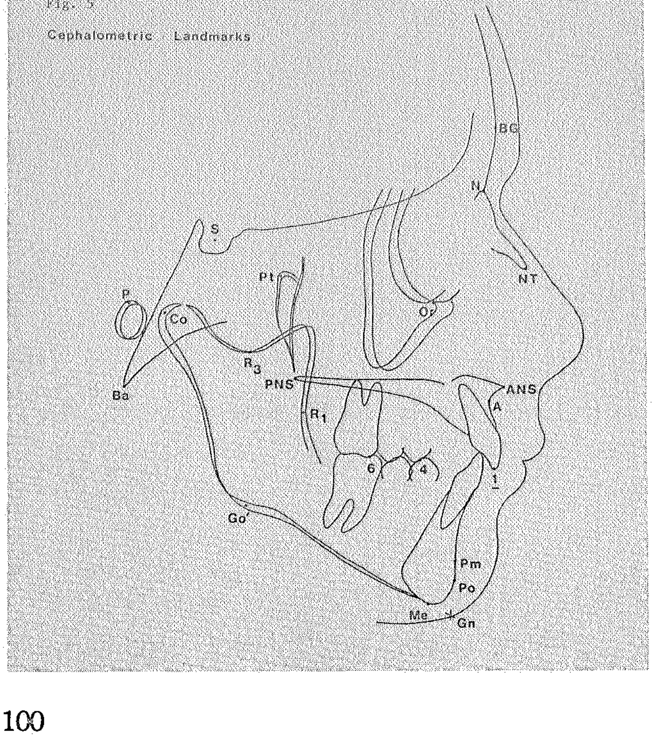
In order to more accurately establish antero-posterior and vertical relationships in Frankfort relation during landmark identification, each tracing was placed over a 2.0 × 2.0mm. grid with Frankfort plane horizontal. Landmarks were marked in pencil.

In all, fourteen single point landmarks and seven bilateral landmarks were identified on each tracing. A further single landmark, gnathion, was established using the coordinates of the facial and mandibular planes.

The following cephalometric landmarks (*Figure 5*) were identified on each tracing:

(a) **Single points**
1. Nasion (N) : most anterior point of the nasofrontal suture in the mid-sagittal plane.
2. Sella (S) : the centre of sella turcica (hypophyseal fossa) determined by inspection.
3. Basion (Ba) : the lowest point on the anterior margin of foramen magnum in the mid-sagittal plane.
4. Anterior Nasal Spine (ANS) : the most anterior point on the median process of the maxillae at the lower margin of the anterior aperture of the nose.
5. Posterior Nasal Spine (PNS) : the most posterior point on the median process at the posterior border of the palatine bones.
6. Point A (A) : the deepest point on the curve of the anterior surface of the maxilla in the mid-sagittal plane between the anterior nasal spine and the alveolar process.

Fig. 5
Cephalometric Landmarks



7. Pogonion (Po) : the most anterior point on the symphysis of the mandible in the mid-sagittal plane when viewed in Frankfort relation.
8. Menton (Me) : the most inferior point on the symphysis of the mandible in the mid-sagittal plane when viewed in Frankfort relation.
9. Suprapogonion (Pm) : the point of inflexion in the anterior contour of the symphysis of the mandible between Pogonion and B Point.
10. Upper Central Incisor Tip (1) : the point at the incisive edge of the more labially positioned maxillary central incisor.
11. Molar Occlusal Point (6) : average of the points of occlusion of the mesiobuccal cusps of the first permanent molars in the left and right sides.
12. Premolar Occlusal Point (4) : average of the points of occlusion of the most anterior premolar or deciduous molar on the left and right sides.
13. Bony Glabella (BG) : the most anterior point on the facial surface of the frontal bone in the mid-sagittal plane when viewed in Frankfort relation.
14. Nasal Bone Tip (NT) : the most anterior inferior point on the nasal bone in the mid-sagittal plane when viewed in Frankfort relation.

(b) **Bilateral points**
1. Porion (P) : most superior point of the external acoustic meatus at the point of intersection with Frankfort plane.
2. Orbitale (Or) : the most inferior point of the inferior margin of the orbit at the point of intersection with Frankfort plane.
3. Pterygoid Point (Pt) : the intersection of the inferior border of foramen rotundum with the posterior wall of the pterygomaxillary fossa.
4. Condylion (Co) : the most posterior superior point on the head of the mandibular condyle when viewed in Frankfort relation.
5. Ramus Concavity (R^1) : the deepest point on the anterior curve of the mandibular ramus when viewed in Frankfort relation.
6. Sigmoid Notch (R^3) : the deepest point on the curvature of the sigmoid notch when viewed in Frankfort relation.
7. Gonial Intersect (Go') : the point at which the mandibular plane, a line drawn through menton tangent to the lower border of the mandibular ramus, is contiguous to the lower border of the mandibular ramus.

(c) **Constructed point:**
Gnathion (Gn) : the intersection of the facial plane (N-Po) with the mandibular plane (Go'-Me).

Figure 5 shows the abovementioned points. For clarity the average of bilateral points is represented.

Measurement of landmark locations was performed using a computerised system comprising a Tektronix 4051 Desktop Computer†*, connected to a Tektronix Interactive Digital Plotter 4662†*, a Summagraphic ID Digitiser‡ and Dataroyal IPS - 5000- A Printer§. The aluminium plate was fixed to the graphic tablet of the digitiser.

Each tracing was in turn registered on the six register pins. Connection to the desktop computer enabled immediate display of all points as they were digitised to permit visual confirmation. The five tracings of each lateral cephalograph were digitised consecutively. In order that the five sets of x and y coordinates for each landmark could be accurately registered, not only was the register plate held fixed, but also a single input of the X and Y origin was made at the lower left corner of the "window". This single origin combined with the accurate pin-register system permitted ease of comparison of coordinates. All landmarks were digitised using an optical cursor with 2x magnification. Landmarks were identified by using an appropriate 'menu' on the graphic tablet.

† Tektronix Incorporated, Beaverton, Oregon 97077

Following visual confirmation of all points the program provided a hard copy of the x and y coordinates for each of the single point landmarks, provided an average x and y coordinate for bilateral points and calculated the coordinates of gnathion.

The coordinates of the 22 landmarks from the 100 tracings were processed utilising a Fortran program on the VAX computer system of the University of Melbourne.

The sets of coordinates for each landmark over each series of five tracings for a single cephalograph were used to give a mean pair of coordinates for each landmark for each of the 20 cephalographs. The deviation of each x and y coordinate from the cephalograph's mean was then computed to give a series of 100 deviations for each landmark investigated.

For each of the 22 landmarks, the deviations from the cephalograph's mean were analysed to give the standard deviation and standard error of the mean. The X-axis and Y-axis deviations were considered separately, as well as combined to give a non-vectorial assessment of error magnitude. The following estimates of parameters were used in the statistical analysis of landmark identification error:

S.D.$_X$: standard deviation on the X-axis =

$$\sqrt{\frac{\Sigma d_x^2}{N(k-1)}}$$

S.D.$_Y$: standard deviation on the Y-axis =

$$\sqrt{\frac{\Sigma d_y^2}{N(k-1)}}$$

S.D.$_T$: standard deviation =

$$\sqrt{\frac{\Sigma(d_x^2 + d_y^2}{N(k-1)}}$$

$$\sqrt{\frac{\Sigma d_T^2}{N(k-1)}}$$

S.E.M.: standard error of the mean=

$$\frac{S.D._T}{\sqrt{N}}$$

where:

d_x = deviation of the x coordinate for a given landmark on a given tracing from the cephalograph's mean for that landmark.

d_y = deviation of the y coordinate for a given landmark on a given tracing from the cephalograph's mean for that landmark.

d_T = non-vectorial deviation of a given landmark on a given tracing from the cephalograph's mean for that landmark, such that d_T =

$$\sqrt{(d_x^2 + d_y^2}$$

N = number of cephalographs in the error estimation = 20

K = number of tracings per cephalograph = 5

RESULTS

The results of the analysis of landmark identification error are shown in *Table 1*. Each of the twenty two cephalometric landmarks investigated has been listed in the first column of the table in order of increasing magnitude of error distribution, as indicated by the

Cephalometric Landmark	1 SD_T (mm)	2 SD_X (mm)	3 A (mm)	4 SD_Y (mm)	5 B (mm)	6 S.E.M. (mm)
Upper central incisor tip(1)	0.31	0.22	5	0.23	2	0.14
Sella (S)	0.38	0.28	6	0.26	5	0.17
Menton (Me)	0.41	0.38	9	0.15	1	0.18
Orbitale (Or)	0.51	0.43	10	0.28	6	0.22
Molar occlusion point (6)	0.51	0.45	11	0.28	3	0.22
Pogonion (Po)	0.53	0.15	1	0.51	9	0.23
Suprapogonion (Pm)	0.58	0.19	3	0.55	10	0.25
Nasion (N)	0.65	0.21	4	0.61	14	0.28
Nasal bone tip(NT)	0.65	0.34	8	0.57	12	0.29
Point A (A)	0.75	0.31	7	0.68	15	0.33
Anterior nasal spine (ANS)	0.92	0.82	15	0.41	8	0.40
Gnathion (Gn)	1.04	1.00	19	0.26	4	0.45
Bony glabella (BG)	1.05	0.17	2	1.04	20	0.46
Pterygoid point (Pt)	1.17	0.55	13	1.03	18	0.51
Porion (P)	1.27	0.98	18	0.81	16	0.56
Condylion (Co)	1.34	0.85	16	1.03	19	0.59
Sigmoid notch (R^3)	1.35	0.96	17	0.95	17	0.59
Posterior nasal spine (PNS)	1.35	1.29	20	0.40	7	0.59
Ramus concavity (R^1)	1.43	0.53	12	1.33	21	0.63
Basion (Ba)	1.52	0.67	14	1.34	22	0.67
Gonial intersect (Go)	1.61	1.51	21	0.56	11	0.71
Premolar occlusal point(4)	2.09	2.01	22	0.56	13	0.92

1. Standard deviation of total error in millimetres (S.D.^{T})
2. Standard deviation of error on the X-axis in millimetres (S.D.^{X})
3. Rank order, in increasing magnitude of error, of standard deviation on the X-axis
4. Standard deviation of error on the Y-axis in millimetres (S.D.^{Y})
5. Rank order, in increasing magnitude of error, of standard deviation on the Y-axis
6. Standard error of the mean, in millimetres (S.E.M.)

Table 1. Estimation of landmark identification error

standard deviation of the total error (S.D.$_T$). The spread of error along the X-axis was indicated by the standard deviation of the x coordinates (S.D.$_X$) as shown in the second column of the table. *Column A* indicates the rank order of the x coordinate error distribution in order of increasing distribution of error. The standard deviation of the y coordinates (S.D.$_Y$) indicated the spread of error along the Y-axis. These values are given in the fifth column of *Table 1* while the sixth column, B, gives the rank order of the y coordinate error distribution in order of increasing distributions of error.

The mean value for each landmark over the five tracings for each lateral cephalograph was assumed to represent the true landmark position or the population mean if an infinite number of tracings were made. In fact, the mean for each landmark on each lateral cephalograph was the best estimate and may not have been situated at the true origin of the error distribution. For this reason, the error in estimating the true mean has been given, equal to the standard deviation of the total error divided by the square root of the number of best estimates of the mean made throughout the total estimation (S.D.$_T$/$\sqrt{20}$). This value, the standard error of the mean (S.E.M.) is shown in the final column of *Table 1*.

In addition representative 100-point scattergrams for the cephalometric landmarks have been depicted in *Figure 6*. This shows the pattern of distribution for each point along the X and Y axes.

DISCUSSION

The method of registration used in the investigation was based upon that used in the graphics and printing industry for the preparation of film in accurate register for lithography, gravure, flexography and plastic letterpress printing. Due to the extremely small tolerances afforded by use of the Protocol Standard Film Register Punch and compatible register pins, any error in recording the location of a point on a tracing if it were digitised a number of times would be attributable to the level of accuracy of the digitiser, rather than the combination of registration error and digitising error, at the level of accuracy discussed (± 0.1mm.).

The use of a pin register system rather than other methods of film and tracing registration currently described in the literature had a number of advantages.

The greatest advantage in using a register pin punched system was the accuracy obtained in registering each film or tracing to a single point origin. Although the techniques of Broch (1981), Stabrun and Danielson (1982), Baumrind and Frantz (1971) and McWilliam (1982) necessitated digitising two or four registration points giving a measurable error in superimposition, the method employed in the present study necessitated digitising one point only when superimposing the five separate tracings for each cephalograph in the error analysis.

An additional advantage in using the register pin system was apparent during tracing procedures. In the usual tracing technique, the tracing acetate is held in position by adhesive tape and three margins are left free so that the acetate film may be lifted and the cephalograph viewed directly when locating difficult landmarks. This technique offers little stability to the relation of tracing acetate to cephalograph during tracing. The alternative is to tape a greater number of tracing acetate margins to the cephalograph. Not only does this then prevent direct viewing of the cephalograph but also introduces a possible further error due to distortion of the tracing acetate film in this taped position. Similarly, during digitising procedures, the tracing acetate may move if inadequately held to the graphic tablet or be distorted in being taped to the graphic tablet. In contrast the register pin system holds the tracing acetate in a fixed position relative to the cephalograph throughout the tracing procedure. The seating of the cephalograph and tracing film under their own weight, in register with the master cephalograph during second punching procedures, ensured that neither was distorted in this fixed position. If it was desired, one margin of the tracing acetate could be temporarily freed from the register pins so that the film could be viewed directly during landmark location. Further, the tracing acetate continued to be held in an identical position during digitising procedures.

Use of tracings enabled cephalometric outlines to be orientated relative to Frankfort horizontal when landmarks were marked. Although points may be chosen on a cephalograph or tracing with excellent reproducibility as shown by a small standard deviation of error, this reproducibility does not necessarily confer a similar degree of validity. Since the majority of landmarks utilised were to be chosen with the cephalograph in Frankfort relation, it was thought that greater validity in landmark identification would be afforded by orientating the tracings in this relation during marking procedures, over a 2.0 x 2.0mm. grid. In this way Frankfort relation was firmly established rather than relying on a visual assessment of the Frankfort plane on the film or tracing.

The results of the landmark identification error analysis confirmed many of the findings of previous studies. Agreement was found with Richardson (1966), Baumrind and Frantz (1971), Broch et al (1981), Stabrun and Danielson (1982) and Cohen (1984), that the envelope of error for each landmark was characteristic of the landmark showing differences in X and Y axis distribution of error.

The studies of Broch et al (1981), Stabrun and Danielson (1982) and Cohen (1984) generally showed smaller standard deviations of error than those found in the present study. This was possibly attributable to the use of two tracings per film rather than superimposition of means of error obtained over five tracings then recording deviations from these. It is important to note that ranges of error were not notably different from these. It is important to note that ranges of error were not notably different from that predicted using standard deviation of error in the present study.

The most directly comparable study with the present investigation was that of Baumrind and Frantz (1971). A number of findings were similar in both investigations. Like Baumrind and Frantz (1971) the upper central incisor tip, sella and menton featured as more readily identifiable landmarks with small error distributions on both the X and Y axes. Similarly gonial intersect in the present study and gonion in the study of Baumrind and Frantz (1971) figured as points with larger error distributions. However, unlike gonion which may vary wildly in both the X and Y directions, gonial intersect which is defined by a tangent to the gonial angle showed little variation in the Y direction. A notable difference between the two studies was found in the degree of variation shown in porion location. This is attributable to the two different definitions used in locating this point. Baumrind and Frantz (1971) used machine porion, a point located by use of the ear rod, while the present study used true porion, located on the external acoustic meatus.

Generally the standard deviations of error displayed in the present investigation were smaller than those in the study of Baumrind and Frantz (1971), with a range of standard deviations of total error in the present study of 0.31 to 2.09mm. as compared to the range of 0.50 to 5.21mm.. This difference in landmark identification error would have been predominantly attributable to the methods used in the two studies. Baumrind and Frantz (1971) used five sets of tracings of twenty cephalographs prepared by five independent operators trained in the same criteria of landmark identification, while the present study used five set of tracings of twenty cephalographs prepared by a single operator. Differences in magnitude of error distribution are attributable to differences in correlation between tracings of five operators and tracings of one operator on five occasions. It would appear that the bias of one operator gives greater consistency in landmark location than does the varied interpretation of even a single definition of a landmark amongst a number of operators.

SUMMARY AND CONCLUSIONS

The study investigated landmark identification error in identifying 22 cephalometric points on twenty lateral cephalographs chosen at random from the files of the Orthodontic Department, Royal Dental Hospital of Melbourne. Each film was traced on five occasions separated by an interval of one month.

The text describes the method used to superimpose tracings during tracing and digitising procedures. This method was based upon that used in the printing industry and utilised a pin punch register system.

Errors in landmark identification were given in the X and Y directions using an orientation where Frankfort plane was approximated to the X-axis and as a total magnitude of error. Scattergrams were used to visually depict these errors.

In agreement with earlier studies, it was found that each landmark exhibited a characteristic pattern of error, varying in the different planes of space. Differences between the magnitude of error of some of the landmarks used in previous studies and the present study were discussed.

It may be concluded that the twenty two landmarks investigated have envelopes of error characteristic of each point. These envelopes of error apparently are influenced by the precision of the definition of the point and features of each cephalograph in the region in which the point lies.

‡ Summagraphics Corporation, Fairfield, Connecticut 06430
§ Dataroyal Incorporated, Nashua, New Hampshire 03051

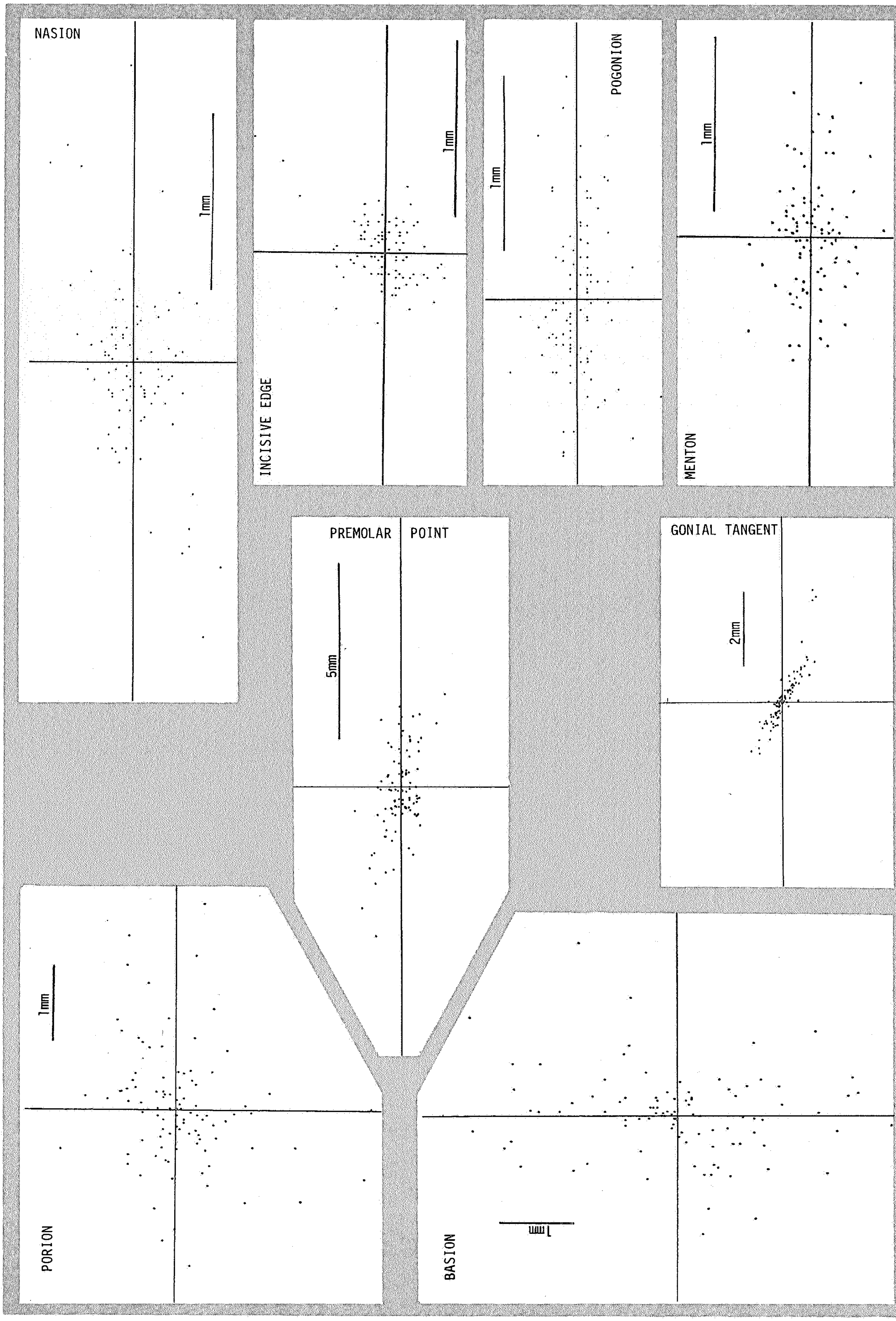


Figure 6. Representative scattergrams of various labelled landmarks.

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