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Scientific Section

Phosphor-stimulated Computed Cephalometry: Reliability of Landmark Identification

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Abstract. *The aim of this randomized, controlled, prospective study was to determine the reliability of computed lateral cephalometry (Fuji® Medical Systems, Tokyo, Japan) in terms of landmark identification compared to conventional lateral cephalometry (CAWO®, Schrobenhausen, Germany).*

To assess the reliability of landmark identification on lateral cephalographs, 20 computed images, taken at 30 per cent reduced radiation (70 kV, 15 mA, 0·35 s) were compared to 20 conventional images (70 kV, 15 mA, 0·5 s). The 40 lateral cephalographs were taken from 20 orthodontic patients at immediate post-treatment and 1 year after retention. The order and type of imaging was randomized. Five orthodontists identified eight skeletal, four dental and five soft tissue landmarks on each of the 40 films. The error of identification was analysed in the XY Cartesian co-ordinate following digitization.

Skeletal landmarks exhibited characteristic dispersion with respect to the Cartesian co-ordinates. Root apices were more variable than crown tips. Soft tissue landmarks were more consistent in the X co-ordinate. Two-way ANOVA shows that there is no significant difference between the two imaging systems in both co-ordinates ($P > 0{\cdot}05$).

Moreover, the differences are generally small ($< 0{\cdot}5$ mm), and are unlikely to be of clinical significance. Most of the variables attained statistical power of at least 0·8 in the X-co-ordinate while only the dental landmarks achieved statistical power of at least 0·78 in the Y-co-ordinate.

Based on the results of the study:

(1) computed lateral cephalographs can be taken at 30 per cent radiation reduction, compared to conventional lateral cephalograph;
(2) each anatomical landmark exhibits its characteristic dispersion of error in both the Cartesian co-ordinates;
(3) there is no trend between the two imaging systems, with equivocal result, and none of the landmarks attained statistical significance when both raters and imaging systems are considered as factorial variables;
(4) the random error of raters in landmark identification after replicate tracing was highlighted and needs to be taken into consideration in all studies involving landmark identification.

Index words: Computed Radiography, Phosphor Stimulated, Randomized Prospective Study.

Refereed Paper

Introduction

Computerized cephalometry

Clinical cephalometry has been accepted as a routine requirement for modern orthodontics. Some of the applications of it include: diagnosis, treatment planning, monitor treatment progress and comparison of treatment results. Since the advent of the cephalostat (Broadbent, 1931), the conventional method of image capturing has remained largely unchanged. The process involves the emission of luminescence from the intensifying screen, which will then expose the silver-halide emulsion on the radiographic film. Recent attempts to improve image quality have led to the adoption of the rare earth intensifying screen, filter screen, soft tissue wedge and wide latitude film (Tyndall *et al.*, 1988).

The rapid advances made in the field of computer technology and image processing have given rise to the possibility of computerized cephalometry. The basic algorithm includes: image capturing, digitisation, display, analysis and hard copy production. With regard to image capturing, the process may be direct or indirect (Forsyth *et al.*, 1996). The indirect method involves the conversion of a hard copy radiographic image on film to digital form (Jackson *et al.*, 1985; Cohen and Linney, 1986). This is achieved with a digitizing tablet or a video camera and frame grabber. The alternative method involves the direct conversion of data from the incident radiation to digital form for display. Currently, there are two main methods of attaining this. The first involves the same principle as conventional radiography, except that the luminescence from the intensifying screen is received by a charged couple diode (CCD) camera (May *et al.*, 1995). The analog information is then digitized and then available for display. The entire process is continuous and the display can be viewed within seconds from the start of the radiation exposure.

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The second method, known as storage phosphor computed radiography was first reported by Sonada *et al*. (1983). With incident radiation, the energy is captured within the crystals of barium fluorohalide. This energy is released, with a passing scanning helium neon laser. The process is termed photostimulated luminescence (Tateno *et al*., 1987). The fluorescent blue light is amplified, converted to a time series electrical signal, digitized and processed for optimal display. A second passing laser scan removes all traces of residual energy within the crystal lattice and the imaging plate is then reusable.

Reliability of landmark identification

The process of cephalometry involves the identification of numerous anatomical landmarks for clinical or research purposes. The errors of identification of conventional cephalograph have been well investigated (Hatton and Grainger, 1958; Baumrind and Frantz, 1971a,b; Mitgard *et al*., 1974; Houston, 1983; Houston *et al*., 1986; Sandler, 1988; Stirrups, 1989). Baumrind and Frantz (1971a) reported large variation in the magnitude and configuration of the envelope of error for the 16 anatomical landmarks studied. They recommended replication of landmark estimate to reduce these errors. Stirrups (1989) found that the use of rare-earth screen/film combination did not significantly affect the reproducibility of selected landmark identification. The radiation requirement was 20 per cent less compared to conventional barium–strontium sulphate screen/film combination.

Houston (1982) showed that computerized cephalometry is more reliable than manual tracing on acetate paper. Macri and Wenzel (1993) compared the reliability of landmark identification in indirectly captured digital image, of varying quality, on computer display with those on radiographic films. They found that the low resolution of the computer image resulted in greater identification error. Digital processing of the computer image improves the reproducibility of the better quality radiographs but not those of the poor quality ones. Similar findings were reported by Cohen and Linney (1986) and Jackson *et al*. (1985).

In an attempt to quantify and analyse the effect of identification error on the reliability of identification and measurement of landmarks, several statistical analyses have been devised (Bjork, 1947; Chebib *et al*., 1973; Houston, 1983). Battagel (1993) compared several statistical analyses on cephalometric error. The author recommended that all reported results should be interpreted in relation to the measurement error.

Aim

To date, the available data on computed cephalometry are derived from in-vitro (Calderazzi *et al*., 1992; Foong and Lim, in press), and uncontrolled studies (Seki and Okano, 1993). As such, the aim of this comparative, controlled clinical study was to determine the reliability of computed lateral cephalometry in terms of landmark identification compared to conventional lateral cephalometry.

Materials and Methods

Sample

All the materials available for the current study were obtained from the Orthodontic Department, Government Dental Clinic, Singapore. In order to ensure that growth changes would not confound the identification of landmarks, 20 orthodontic patients (15 females and five males) at completion of treatment were selected based on the following criteria:

1. 16 years or above to reduce the effect of growth.
2. Class I malocclusion to minimize abnormal growth changes.
3. No cone-cutting of the soft tissue profile.

The immediate post-treatment lateral cephalographs of 10 patients were taken with a conventional film/screen system (Cawo®, Schrobenhausen, Germany), while the other cohort of 10 lateral cephalographs were taken with the phosphor imaging plates (Fuji® Medical Systems, Tokyo, Japan). The order of selection for the type of imaging was randomized. The same X-ray unit set at 90 kV was used throughout the study (W105, Gendex®, General Electric, Milwaukee, U.S.A.). The focal to subject distance was fixed at 150 cm and the subject to cassette distance was fixed at 15 cm.

An earlier study comparing computed and conventional image quality of lateral cephalographs (Foong and Lim, in press), found that the radiation requirement varies with the anatomical landmarks. With the exception of sella which was superimposed by an artefact peculiar to the phantom head used in the study, the radiation requirement was, on average, 30 per cent less for the computed system. For the current study, the radiation dosage for the conventional system was set 7·5 mAs, while that for the computed system was set at 30 per cent less or 5·25 mAs.

The 20 patients were systematically reviewed at 3-monthly intervals. At 1 year post-treatment, a second series of lateral cephalographs were taken. The type of imaging selected for the patients was reversed, i.e. conventional if computed system was used at immediate post-treatment and vice versa.

Mode of registration of anatomical landmarks

A rubber template with four pinhead-sized perforations was used for consistent superimposition. The location of four pin perforations formed a rectangle with a dimension of 22 × 16 cm. The localizing of acetate paper over the lateral cephalograph was secured with four pins passing through the acetate paper and cephalograph into the template perforations.

Five orthodontists with at least 5 years of clinical experience were shown a standard lateral cephalometric line tracing. The 17 anatomical landmarks selected for the study were clearly marked out, together with their respective definitions (Table 1). The anatomical landmarks on the 40 cephalographs were identified consecutively with a red felt pen (0·1 mm diameter pen tip) on the localized acetate paper. All raters were blind to the type and order of imaging, as the randomly selected cephalographs were placed on an X-ray viewer with the extraneous area

TABLE 1 *Definition of anatomical landmark*

Landmark	Definition
Skeletal	
Sella	Concentric center of the pituitary fossa
Nasion	Junction of the frontal and nasal bone in the sagittal plane. Recognized by a radiolucent slit or a change in contour
Orbitale	Lowest border of the bony orbit
A point	The deepest concavity on the anterior border of the maxilla
B point	The deepest concavity on the anterior border of the mandible
Anterior nasal spine	The tip of the bony spicule at the anterior end of the maxilla
Posterior nasal spine	The tip of bony spicule at the posterior end of the maxilla
Pogonion	The most anterior border of the mandibular synphysis
Dental	
Upper incisal crown tip	The incisal edge of the most proclined upper central incisor
Upper incisor root tip	The root tip corresponding to the upper incisal crown tip
Lower incisal crown tip	The incisal edge of the most proclined lower incisor
Lower incisor root tip	The root tip corresponding to the lower incisal crown tip
Soft tissues	
Glabella	The most anterior border of the forehead
Nasal	The most anterior point on the nose
Upper lip	The most anterior point on the upper lip
Lower lip	The most anterior point on the lower lip
Chin	The most anterior point on the chin

blocked off by black paper. The identification was carried out at ambient light condition. There was no time limit for the identification. A total of 6800 (five operators × 40 films × two treatment time × 17 landmarks) registrations were made.

All the landmark registrations on the acetate papers were then digitized (Logitec 510-MK II, Kanto. Denshi Corporation, Tokyo, Japan) by the first author and the XY Cartesian co-ordinates of each individual landmark computed and stored. The pen cursor had a tip diameter of 0·1 mm. The acetate paper was localized on the digitizer tablet with the four pins passing through the same perforations of the acetate paper into the template.

Statistical analysis

The mean and standard deviation of all the 17 variables in both Cartesian co-ordinates were computed. The reliability of landmark identification was determined by the following equation:

$$\Sigma \sqrt{\frac{(x - x)^2}{n}}$$

where x is the co-ordinate value in X or Y axis, x is the mean co-ordinate value for the landmark in either X or Y axis, and n is the number of determination.

Two-way analysis of variance was used to determine the inter- and intra-group effects of types of imaging (computed and conventional) and raters (five orthodontists who identified the landmarks). One-way analysis of variance was used to determine the effect of raters and imaging types alone. The F-values were obtained for each of the variables and the significance level determined. Multiple t-tests were not used, as it may produce a false positive result due to random error.

Error consideration

Two main areas of error can confound the final result. They are landmark registration and operators' error. To determine the random error involved in digitizing and superimposition of images, an acetate paper with four pin-sized dots, widely dispersed on it was used. The dots were digitized in a circular manner, i.e. starting with the first dot, followed by the second and so on until each dot had been digitized five times by the first author. The same acetate paper was removed and relocalized, and the digitization process repeated four times. To determine the systematic and random error of the five orthodontists, four cephalographs were randomly selected, and each of the operators was requested to identify the landmarks on each of the cephalographs. The process was repeated three times, in a randomised order. All statistical analyses were done with the software Statistical Package for Social Science (SPSS Inc, Chicago, USA). Statistical power was computed based on the method suggested by Gore and Altman (1982). The minimum difference of clinical significance was 0·5 mm.

Results

The mean and standard deviations of the error of identification in the X co-ordinate are presented in Table 2 while those in the Y co-ordinate are in Table 3. There is no statistical significance ($P>0{\cdot}05$), in both co-ordinates when both the raters and imaging types are considered as the factorial variables. The tabulated statistical finding is based on one way analysis of variance, with imaging type as the factorial variable.

Skeletal

In both co-ordinates, there is no clear trend between the two types of imaging. In the X co-ordinate (Table 2), conventional radiography scores better in five out of the eight variables. Sella ($P<0{\cdot}05$) is more reliable with conventional radiography and B point ($P<0{\cdot}01$) performs better with computed radiography. However, the differences are of small magnitude (<0·5 mm), and are unlikely to reach clinical significance. Variables with mean error greater than 1 mm are: orbitale, anterior nasal spine and posterior nasal spine for both systems, and A point for computed radiography.

In the Y co-ordinate (Table 3), conventional radiography performs better than computed radiography in seven out of the eight variables. Only pogonion attains statistical significance ($P<0{\cdot}05$) with conventional radiography being more reliable. Similarly, the differences are of small magnitude (<0·5 mm). Variables with mean error greater than 1 mm include orbitale, A point, B point,

TABLE 2 *Summary statistics for computed and conventional image in the* X *co-ordinate*

	Computed radiography *X* co-ordinate			Conventional radiography *X* co-ordinate			
Anatomic Landmark	Mean	SD	Range	Mean	SD	Range	*F* values
Skeletal							
Sella	0·37	0·28	1·32	0·23	0·15	0·54	7·09*
Nasion	0·19	0·16	0·84	0·23	0·23	1·22	2·35
Orbitale	1·60	1·20	4·26	1·11	0·84	4·02	2·17
A point	1·03	1·02	5·18	0·82	0·72	3·18	0·83
B point	0·34	0·36	1·78	0·64	0·59	2·52	7·03**
Pogonion	0·22	0·18	0·72	0·21	0·14	0·55	0·01
Anterior nasal spine	1·25	0·50	5·44	1·16	1·32	5·40	0·01
Posterior nasal spine	1·17	1·01	3·42	1·50	1·76	8·44	1·37
Dental							
Upper incisal crown tip	0·18	0·11	0·40	0·12	0·09	0·30	4·38*
Upper incisal root tip	0·52	0·52	2·10	0·85	0·86	4·56	2·37
Lower incisal crown tip	0·21	0·17	0·64	0·18	0·13	0·42	0·03
Lower incisal root tip	0·50	0·40	1·42	0·90	0·56	1·88	10·81**
Soft tissues							
Glabella	0·22	0·23	1·08	0·18	0·15	0·72	0·56
Nasal	0·17	0·16	0·56	0·67	1·51	6·39	3·56
Upper lip	0·26	0·34	1·94	0·16	0·10	0·52	2·48
Lower lip	0·24	0·31	1·68	0·16	0·16	0·76	0·13
Chin	0·26	0·34	1·84	0·37	0·36	1·94	1·15

*$P<0·05$; **$P<0·01$.

TABLE 3 *Summary statistics for computed and conventional image in the* Y *co-ordinate*

	Computed radiography *Y* co-ordinate			Conventional radiography *Y* co-ordinate			
Anatomic Landmark	Mean	SD	Range	Mean	SD	Range	*F* values
Skeletal							
Sella	0·25	0·18	0·62	0·21	0·23	0·94	0·70
Nasion	0·58	0·73	3·42	0·44	0·35	1·48	1·44
Orbitale	1·59	0·89	3·78	1·22	1·25	6·10	1·91
A point	1·24	1·08	3·60	0·92	0·88	3·96	3·07
B point	1·50	1·56	7·34	1·72	1·41	5·84	1·43
Pogonion	1·15	1·14	4·10	0·68	0·67	3·48	4·98*
Anterior nasal spine	1·00	1·72	8·08	0·65	0·70	3·04	1·12
Posterior nasal spine	0·56	0·96	4·98	0·41	0·43	1·76	0·22
Dental							
Upper incisal crown tip	0·14	0·12	0·62	0·26	0·20	0·86	7·33*
Upper incisal root tip	0·72	0·56	3·06	0·54	0·61	2·48	1·89
Lower incisal crown tip	0·22	0·16	0·52	0·23	0·18	0·62	0·01
Lower incisal root tip	0·69	0·56	2·42	0·92	0·68	2·28	2·34
Soft tissues							
Glabella	1·91	1·54	5·85	1·67	1·47	5·16	0·34
Nasal	0·52	0·33	1·34	0·82	1·02	5·84	2·29
Upper lip	1·04	1·40	5·18	0·60	0·49	1·76	3·24
Lower lip	0·57	0·71	3·74	1·04	1·01	4·40	4·13*
Chin	1·15	1·16	4·68	0·90	0·75	2·92	0·84

*$P<0·05$; **$P<0·01$.

pogonion, and anterior nasal spine for computed radiography; orbitale and B point for conventional radiography. Reliability of landmark identification in both co-ordinates varies with the landmarks. Nasion, orbitale, A point, B point, and pogonion are more reliable in the *X* co-ordinate. Sella, anterior nasal spine, and posterior nasal spine are more reliable in the *Y* co-ordinate.

Dental

In both co-ordinates, localization of crown tip is less consistent than root tip. In the *X*-co-ordinate, computed radiography scores better for root tip localization, while conventional radiography scores better for crown tip localization (Table 2). Upper incisal crown tip ($P<0·05$) and lower incisal root tip ($P<0.01$) reach statistical significance. In the Y co-ordinate, there is a slight tendency for more consistent crown tip localization for computed radiography (Table 3). Only upper incisal crown tip reaches statistical significance ($P<0.01$). Similarly, the differences between the two systems are of small magnitude (<0·4 mm for X co-ordinate and <0·3 mm for Y co-ordinate).

Soft tissues

The level of mean errors are generally similar for the two imaging systems, in both the co-ordinates. Outlier values account for the high range for the nasal spine (conventional radiography). The only statistical significance is for lower lip ($P<0.05$) in the Y co-ordinate. The differences are of small magnitude (<0·5 mm for X co-ordinate and <0·54 mm for Y co-ordinate). Reliability of all the landmarks is greater in the X co-ordinate.

Error analysis

The maximum random error of digitization and superimposition is 0·2 mm. For replicate identification of landmarks, most of the mean random errors of the raters are less than 1 mm, with the exception of glabella (1·26 mm) and chin (1·03 mm) in the Y co-ordinate (Table 4). One-way analysis, with raters as the factorial variable shows no statistical difference ($P>0.05$). The mean dispersion of error, for replicate landmark identification (Table 4) is close to the mean error incurred in the actual identification of landmarks of the 40 radiographic films (Tables 2 and 3).

In the X co-ordinate, all the anatomical landmarks attained statistical power of at least 0·8, except orbitale, A point, anterior nasal spine and posterior nasal spine. In the Y co-ordinate, the dental landmarks achieved statistical power of at least 0·78. The majority of the skeletal and soft tissue landmarks are below this level.

Discussion

Radiation requirement

The study showed that image quality produced by computed radiography is comparable to conventional radiography, despite the reduction of radiation dosage of 30 per cent. The result concurred with most reported studies on computed radiography both in the field of Medicine (Akita, 1991; Hansell, 1991; Peter *et al.*, 1991; Carr *et al.*, 1992; Kaimimura, 1992; Razavi *et al.*, 1992; Theate *et al.*, 1992; Wahlmann and Ruppentahl, 1992; Miyazaki, 1993), as well as in the field of Lateral Cephalometry (Calderazzi *et al.*, 1992; Seki and Okano, 1993). The reported reduced radiation requirement of the computed radiographic system ranges from 10 to 90 per cent.

This reduction is possible because computed radiography utilizes an automatic sensitivity and image range setting mechanism that can anticipate the amount of luminescence from the imaging plate by first prereading the information recorded on the imaging plate with a passing laser beam. A histogram analysis of the extracted information is performed to determine the sensitivity of the image recorder, fine-tuning it to produce optimal output (Takahashi *et al.*, 1984).

Calderrazi *et al*. (1992) compared teleradiographs of a skull and reported a reduced radiation requirement and a reduced number of repeats for computed radiography. Seki and Okano (1993), conducted a comparative study on 40 orthodontic patients and found that there was no

TABLE 4 *Summary statistics for error in the* XY *co-ordinates*

	Error X co-ordinate			Error Y co-ordinate		
Anatomic Landmark	Mean	SD	Range	Mean	SD	Range
Skeletal						
Sella	0·25	0·20	0·98	0·19	0·18	1·00
Nasion	0·22	0·21	1·18	0·29	0·25	1·20
Orbitale	0·59	0·54	2·58	0·54	0·51	3·34
A point	0·58	0·56	2·90	0·65	0·51	2·18
B point	0·38	0·39	1·80	0·80	0·72	2·68
Pogonion	0·21	0·20	1·00	0·47	0·40	1·88
Anterior nasal spine	0·74	0·74	3·48	0·42	0·52	3·12
Posterior nasal spine	0·95	0·86	3·30	0·62	0·94	3·80
Dental						
Upper incisal crown tip	0·17	0·14	0·66	0·23	0·16	0·63
Upper incisal root tip	0·45	0·43	1·66	0·30	0·28	1·24
Lower incisal crown tip	0·20	0·17	0·64	0·26	0·25	1·16
Lower incisal root tip	0·48	0·59	2·50	0·76	1·11	4·95
Soft tissues						
Glabella	0·17	0·14	0·68	1·26	0·95	3·92
Nasal	0·17	0·11	0·50	0·55	0·43	1·80
Upper lip	0·34	0·64	2·82	0·58	0·50	2·18
Lower lip	0·44	0·72	2·94	0·81	0·94	3·92
Chin	0·49	0·54	2·70	1·03	0·89	3·70

*$P<0.05$; **$P<0.01$.

TABLE 5 *Standardised difference and statistical power for the computed radiography.* (n = 40, *significance level is 0·05 and the selected relevant clinical difference is 0·5 mm*)

		Computed radiography *X* co-ordinate		Computed radiography *Y* co-ordinate	
Anatomic	Landmark	Standardised difference	Statistical power	Standardised difference	Statistical power
Skeletal					
Sella		1·79	0·99	2·78	0·99
Nasion		3·13	0·99	0·68	0·57
Orbitale		0·42	0·30	0·56	0·44
A point		0·49	0·38	0·46	0·30
B point		1·39	0·99	0·32	0·17
Pogonion		2·78	0·99	0·44	0·30
Anterior nasal spine		0·33	0·19	0·29	0·15
Posterior nasal spine		0·50	0·35	0·52	0·37
Dental					
Upper incisal crown tip		4·55	0·99	4·17	0·99
Upper incisal root tip		0·96	0·85	0·89	0·78
Lower incisal crown tip		2·94	0·99	3·13	0·99
Lower incisal root tip		1·25	0·99	0·89	0·78
Soft tissues					
Glabella		2·17	0·99	0·32	0·17
Nasal		3·13	0·99	1·52	0·99
Upper lip		2·94	0·99	0·36	0·20
Lower lip		1·61	0·99	0·70	0·60
Chin		1·47	0·99	0·43	0·25

significant difference in image quality with radiation reduction of up to 90 per cent. Foong and Lim (in press) however, reported that the radiation requirement varies with the anatomical landmarks, from −77·5 to +45 per cent of the conventional imaging system.

Reliability of landmark identification

It is known that the greatest potential for error lies in the process of landmark identification (Baumrind and Frantz, 1971a). In general, the current study shows that the differences between the two imaging systems are of small magnitude and are unlikely to be of any clinical significance. Due to the rigorous selection criteria of the study: (1) calibration of the five raters who are orthodontists with at least 5 years of clinical experience; (2) cephalographs for comparison are taken from the same patient to ensure similar condition of images; (3) patients are post-menarche to reduce changes in image density due to growth, the dispersion of error of identification is generally smaller than those reported by other authors.

Baumrind and Frantz (1971a) used students as raters. Seki and Okano (1993) used an assortment of raters ranging from radiographers, students and orthodontists. Both studies did not attempt to quantify the inter-raters' variability on the results obtained. The inter-raters' variability contributes to the dispersion of the error and has been shown by the current study to exert a significant effect on the statistical results using two-way analysis of variance. The statistical analysis, with raters and imaging types as factorial variables shows that none of the anatomical variables attained a statistically significant level ($P>0·05$), while one-way analysis of variance, with imaging types as the factorial variable shows some variables attaining statistical significance (Tables 2 and 3).

The current study shows that there is no clear trend between the two imaging systems for skeletal landmarks in both co-ordinates. As expected, sella and nasion are the more reliable landmarks, concurring with other reported studies (Baumrind and Frantz, 1971a; Seki and Okano, 1993). Anatomical landmarks with low radiodensity, e.g. orbitale, A point and those ending in thin taper, e.g. anterior and posterior nasal spine tend to be less reliable (Tables 2 and 3). The identification of A point is more variable for computed radiography. This fact is supported by the earlier study (Foong and Lim, in press) whereby the raters scored it requiring 47 per cent more radiation for attaining diagnostic image quality than conventional radiography. The difficulty of identification is compounded by granularity of the computed image. This is due to increased noise, subsequent to digital enhancement.

Due to the radiopacity and definite sharp bend (in contrast to contour or curve) of the dental landmarks, the localization is more consistent. Root tips are more variable, compared to crown tips. As a radiograph is a two-dimensional representation of a three-dimensional object, the incisal roots overlap one another, creating a composite image, making the localization more difficult.

With regard to soft tissue landmarks, reliability of identification is higher in the *X* co-ordinate, compared to similar landmarks in the *Y* co-ordinate (50–85 per cent reduction of mean error of identification in the *X* co-ordinate). All of the soft tissue landmarks are smooth contour orientated in the *Y* co-ordinate. As such, the random error would be greater in the *Y* co-ordinate because of the inability to define one precise point of identification for the particular landmark, resulting in a dispersion of identification points along the soft tissue contour, irrespective of image quality. Despite this, all five raters agreed that computed radiography produces sharper soft tissue image than conventional radiography. This subjective preference is supported by studies on a phantom skull with soft tissue drape (Calderazzi *et al*., 1992; Foong and Lim, in press).

One of the proposed methods to reduce the effect of random error on landmark identification is to compute the mean of the landmark after replicate tracings (Baumrind and Frantz, 1971a,b) or repeated digitizations (Houston, 1982). This entails more work and time for the clinician. The study shows that triplicate determination offered little over and above single determination (Table 4). This is in contrast to that reported by Gravely and Benzies (1974), who showed that multiple replication may be required to achieve acceptable reliability. This may be due to the fact that the authors chose the average measurement of several tracings as the true value. Compared to the statistical means in the identification of anatomical landmarks for the 20 cephalographs, the mean random error of dispersion for replicate identification ranges widely, from 3 to 275 per cent in the X co-ordinate and 34 to 167 per cent in the Y co-ordinate, with the majority in the 30–60 per cent range. Mcwilliam and Welander (1978) in their study showed that image quality alone does not account for the variability of error seen in landmark identification. They proposed that other factors, such as radiological knowledge, difference in projection, distinctness of structural detail and noise from adjacent structures do exert significant effects. The current study attempts to control all these confounding influences by a strict standardization procedure, including:

1. Follow-up study of all 20 patients.
2. Patients are older than 16 years old at start of study with Class I malocclusion to reduce the effect of growth.
3. The use of the same X-ray unit.
4. All raters are orthodontists with at least 5 years of clinical experience.
5. Calibration of all raters with the use of a standard line tracing of the lateral cephalograph with landmarks marked out together with their respective definitions.
6. Digitization of all landmarks by one person.

Calibration is designed to reduce inter and intra raters disagreement to acceptable levels, as reported in the study by McNicoll and Stirrups (1985). The current study highlights the fact that random error of individual rater and between raters for the identification of landmarks persists even after attempts to minimise it. Depending on the landmark, these effects may be as large as the variance observed in the actual identification of landmarks for cephalometric study. These have not been reported before and need to be taken into account in all studies requiring lateral cephalographs.

Conclusions

Based on the results of the study:

1. Computed lateral cephalographs can be taken at 30 per cent radiation reduction, compared to conventional lateral cephalograph.
2. Each anatomical landmark exhibits its characteristic dispersion of error in both the Cartesian co-ordinates.
3. There is equivocal result, indicating no trend between the two imaging systems. None of the landmarks attained statistical significance when both raters and imaging systems are considered as factorial variables.
4. The random error of raters in landmark identification, even after replicate identifications, was substantial and needs to be taken into consideration in all studies involving landmark identification.

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