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Reproducibility of lateral cephalometric landmarks on conventional radiographs and spatial frequency-processed digital images

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ABSTRACT

Purpose : Computed radiography (CR) has been used in cephalometric radiography and many studies have been carried out to improve image quality using various digital enhancement and filtering techniques. During CR image acquisition, the frequency rank and type affect to the image quality. The aim of this study was to compare the diagnostic quality of conventional cephalometric radiographs to those of computed radiography.

Materials and Methods : The diagnostic quality of conventional cephalometric radiographs (M0) and their digital image counterparts were compared, and at the same time, six modalities (M1-M6) of spatial frequency-processed digital images were compared by evaluating the reproducibility of 23 cephalometric landmark locations. Reproducibility was defined as an observer's deviation (in mm) from the mean between all observers.

Results and Conclusion : In comparison with the conventional cephalometric radiograph (M0), M1 showed statistically significant differences in 8 locations, M2 in 9, M3 12, M4 in 7, M5 in 12, and M6 showed significant differences in 14 of 23 landmark locations ($p < 0.05$). The number of reproducible landmarks that each modality possesses were 7 in M6, 6 in M5, 5 in M3, 4 in M4, 3 in M2, 2 in M1, and 1 location in M0. The image modality that observers selected as having the best image quality was M5. ***(Korean J Oral Maxillofac Radiol 2002; 32 : 213-9)***

KEY WORDS : cephalometry; radiographic image enhancement; image processing; reproducibility of results

Most radiologists agree that the future of radiology would be digital and digital images now are of great importance for the medical and dental applications. In contrast to conventional radiography, digital radiography produces images by numerically processing radiograms. Digital imaging has several potential advantages[1-3] over traditional radiography. These include elimination of chemical processing and darkroom, reduced exposure to radiation for patients, archiving, transmission, and enhancement of images,[4] and the possibility of automated cephalometric analysis.[5-7] In digital radiography, we can improve diagnostic quality of digital images using various algorithms. In digital radiography, a method in which x-ray digital images are obtained on a flat imaging plate with photostimulable phosphor is referred to as computed radiography. In 1983, Fuji computed radiography introduced imaging plate system with photostimulable phosphor screen to medical application. This system uses conventional radiographic equipment but, instead of x-ray film, a detector imaging plate is placed in the holding cassette. The image plate stores the energy from the radiation as a latent image. This latent image is released, pixel by pixel, in a digital format.

The development of cephalometrics has led to a growing need for exact location of landmarks to improve quantitative studies of craniofacial growth, evaluation of treatment effects, and diagnostic classification of cases. During the 1980s and early 1990s research into the application of digital technologies to lateral cephalometric radiography emerged. It has been claimed by Rossmann and Wiley[8] that interpretation of radiographic images is dependent on radiologic knowledge, pattern recognition, and physical image quality. It seems logical to believe that cephalometric images with a high image quality would provide the best conditions for accurate landmark identification. But, McWilliam and Welander[9] found that there would appear to be other more important factors than physical image quality involved in the reliability of landmark identifi-

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cation. Björk[10] has described three reasons for error of method in cephalometric measurement studies and those are differences in projection between two films of the same individual, differences caused by variation of the positioning of the landmarks, and errors in the reading process. Baumrind and Frantz[11] found that the factors influencing accurate identification were quoted as distinctness of structural detail, noise from adjacent structures due to superimposition of conflicting anatomical details, and conceptual judgement, a factor which is largely based on the past experience and radiological knowledge of the observer. They also studied the side effects of uncertain landmark identification and found these errors were significant when transmitted to angular and linear measurements.

Döler et al.[12] showed an improvement in image quality of digital cephalograms when using various digital enhancement and filtering techniques. Macri and Wenzel[13] studied about the reliability of landmark recording on film and digital lateral cephalograms, but the digital image was recorded with the video camera. More recently, Geelen et al.[14] found that among conventional film, hardcopy and monitor-displayed images, there was no unequivocal trend that one modality was always the best.

In addition, there have been several studies[15-17] which evaluated reliability of landmark locations in digital imaging cephalometry. But they used image processing procedure 'properly' under subjective decision not any objective criteria.

The aims of this study were therefore to compare the reproducibility of cephalometric landmarks on six modalities of spatial frequency-processed digital images, to find out the most desirable setting of spatial frequency type and rank, and to compare those digital image modalities with conventional radiographs.

Materials and Methods

1. Sample

The sample consisted of 10 randomly selected adults (9 men and 1 woman). The gender, the type of occlusion, and the skeletal pattern were not taken into consideration in the study design. The subjects were aged between 25 and 35 years. All subjects were exposed to two kinds of radiographic lateral head examinations and resultant radiographs were 10 sheets of conventional radiographs and 60 sheets of image processed digital radiographs.

2. The radiographic recording methods

The radiographic examinations were taken with the subjects in the fixed head position in the cephalostat without any head movement during the two times of exposures of a conventional film and a digital image. Radiographs were exposed with a Asahi CX-90 SP (Japan) cephalometric machine for 0.4 sec at 74 kVp and 20 mA. At first 10 × 12-inch Agfa Ortho type film combined with Curix screen was exposed and then 10 × 12-inch Fuji imaging plate was exposed.

Conventional radiographs were developed in a Kodak model M7B processor. Imaging plate cassette was inserted into the image reader (Fuji computed radiography FCR 5000) and then spatial frequency-modifying image processing was performed and finally film was automatically output to the laser imager (Fuji medical laser imager FL-IM D). Digital image processing was undertaken with the CRT image console varying frequency rank and frequency type. Six kinds of spatial frequency-processed digital image modalities were obtained and each of them was as follows;

Modality	M1	M2	M3	M4	M5	M6
Frequency rank	5	5	7	7	9	9
Frequency type	T	F	T	F	T	F

And conventional cephalometric radiograph was defined as M0.

3. Landmark definition and sampling

Twenty-three commonly used skeletal, dental and soft tissue cephalometric landmarks[18] (Table 1) were selected. Two fiducial lines were used to construct coordinate reference lines and they met at right angles. The intersection was used as an origin for calculating x- and y- co-ordinates. Five observers recorded the 23 landmarks on the images from the seven image modalities in the 10 subjects. Those observers were five orthodontists who had orthodontic clinical experiences of more than five years. Prior to the registrations, the observers were calibrated with respect to the definition of the landmarks. The 10 conventional radiographs and 60 digital images were coded and presented to the observers in a random order. Landmark identification was performed in a dimmed tracing room. Landmarks were recorded on an 8 × 10-inch sheet of 0.003-inch matte, acetate tracing paper with 0.3 mm sharp pencil. Digital sampling was performed with the use of scanner (Hewlett Packard Scanjet 5200C) and specially designed computerized program for landmark sampling. Landmark sampling was performed with a mouse-controlled cursor in combination with the program. The program was designed to measure up to 0.01 mm. Five registrations on each of the 70 images were superimposed with fiducial lines. For each of seven modalities, the ten five-point scattergrams for each landmark were superimposed with their origin and axis in common.

This yielded a set of twenty-three 50-point scattergrams for each modality, representing the dispersion of the errors around the best estimate for that landmark. In addition, after completing registrations, ten series of each subject's modalities were revealed and then the observers were asked to select one modality of radiographs they preferred the most as having the best image quality.

Table 1. Reference points used in the cephalometric study

1. Sella; the point representing the midpoint of the pituitary fossa
2. Porion; the superior point of the external auditory meatus (bilateral)
3. Articulare; the point of intersection of the images of the posterior border of the condylar process of the mandible and the inferior border of the basilar part of the occipital bone (bilateral)
4. Basion; the median point of the anterior margin of the foramen magnum
5. Nasion; the most anterior point of the frontonasal suture in the median plane
6. Orbitale; the lowest point in the inferior margin of the orbit, midpoint between right and left images (bilateral)
7. ANS; the tip of the bony anterior nasal spine, in the median plane
8. PNS; the intersection of the continuation of the anterior wall of the pterygopalatine fossa and the floor of the nose, marking the dorsal limit of the maxilla
9. A point; the point at the deepest midline concavity on the maxilla between the anterior nasal spine and prosthion
10. B point; the point at the deepest midline concavity on the mandibular symphysis between infradentale and pogonion
11. Pogonion; the most anterior point of the bony chin in the median plane
12. Menton; the most inferior midline point on the mandibular symphysis
13. U1 apex; the incisal apex of the maxillary central incisor
14. U1 edge; the incisal edge of the most protruded maxillary central incisor
15. L1 edge; the incisal edge of the most protruded mandibular central incisor
16. L1 apex; the incisal apex of the mandibular central incisor
17. M 6; the tip of the mesiobuccal cusp of the maxillary first permanent molar
18. Glabella; the most prominent point in the midsagittal plane of forehead
19. sNasion; the point of the deepest concavity of the soft tissue contour of the root of the nose
20. Nose tip; the most prominent point on the soft tissue contour of the nose
21. UL; the median point in the upper margin of the upper membranous lip
22. LL; the median point in the lower margin of the lower membranous lip
23. sPogonion; the most prominent point on the soft tissue contour of the chin

4. Data treatment

For each landmark in each of 7 modalities, the mean x- and y-coordinates between five observers were calculated, leading to the best estimate for that particular landmark in a given image. The differences between the mean coordinates for each landmark were calculated as the distance in millimeters, named 'the deviation from the mean'. The deviation from the mean was used as the variable determining reproducibility for each landmark. The means and standard deviations were calculated per modality for each landmark. The smaller the deviation in millimeters, the higher the reproducibility.

Statistical comparison between the seven modalities were performed using a analysis of variance (ANOVA) for each landmark and Duncan's multiple range test for variables. All differences were considered statistically significant at $p < 0.05$.

Fig. 1. M0 Conventional lateral cephalometric radiograph is seen.

Fig. 2. M1 Digital lateral cephalometric radiograph is seen.

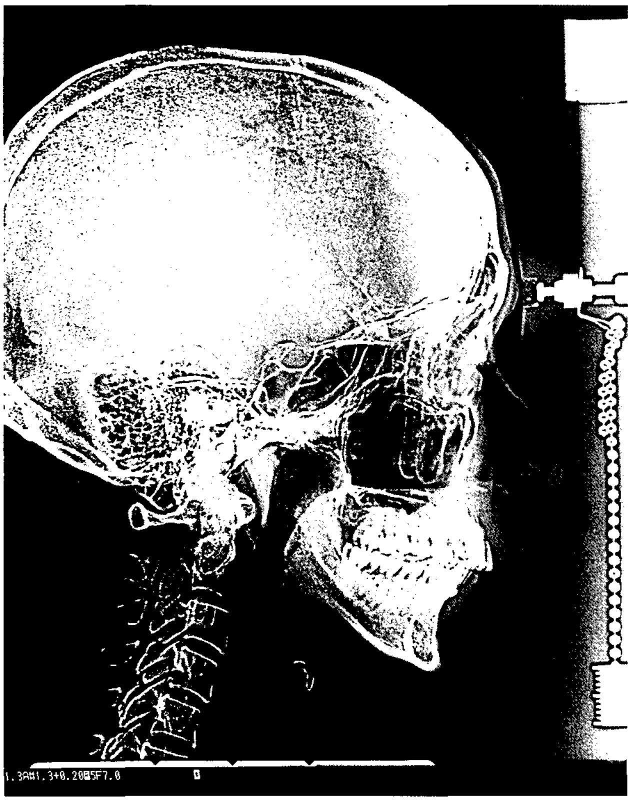

Fig. 3. M2 Digital lateral cephalometric radiograph is seen.

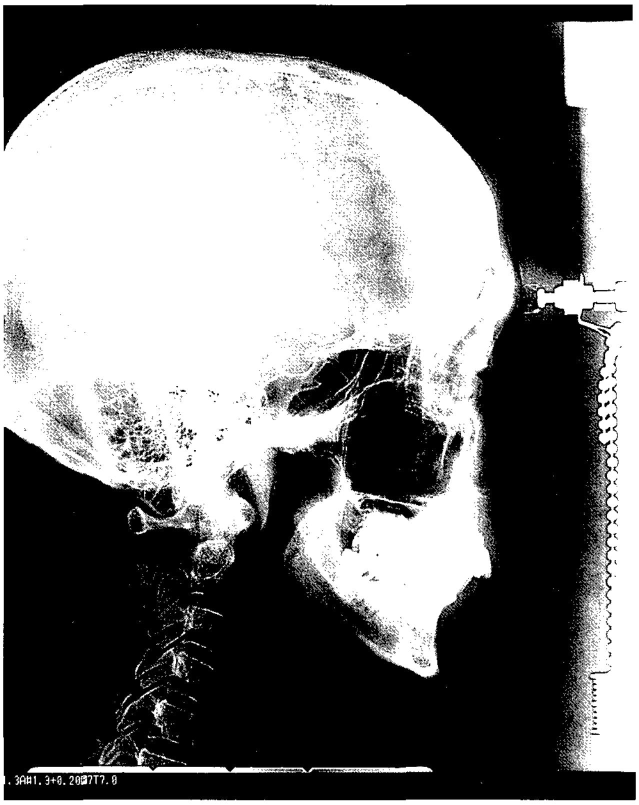

Fig. 4. M3 Digital lateral cephalometric radiograph is seen.

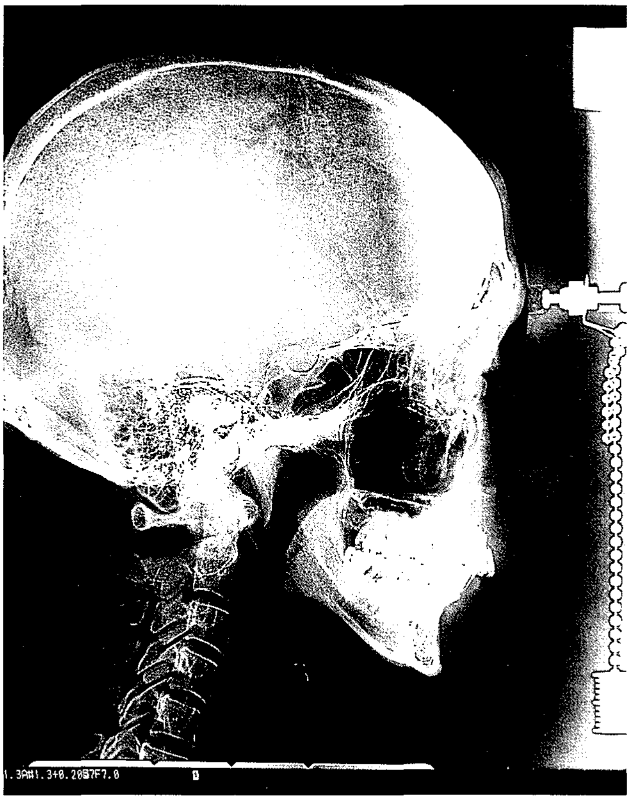

Fig. 5. M4 Digital lateral cephalometric radiograph is seen.

Fig. 6. M5 Digital lateral cephalometric radiograph is seen.

Fig. 7. M6 Digital lateral cephalometric radiograph is seen.

Table 2. The deviation from the mean in millimeters for each modality as an average between observers for each landmark

Modality	M0		M1		M2		M3		M4		M5		M6	
Landmark	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Sella														
Porion	0.47	0.24	0.35*	0.22	0.38	0.25	0.35*	0.17	0.39	0.20	0.40	0.21	0.44	0.20
Articulare	1.10	0.64	1.30	0.90	1.00	0.65	0.76*	0.50	0.84	0.68	0.72*	0.59	0.81*	0.44
Basion	0.64	0.40	0.62	0.44	0.50*	0.32	0.48*	0.31	0.52	0.44	0.36*	0.27	0.43*	0.35
Nasion	0.78	0.51	0.61	0.59	0.68	0.53	0.64	0.45	0.68	0.45	0.67	0.58	0.57*	0.51
Orbitale	0.66	0.49	0.53	0.33	0.67	0.44	0.46*	0.34	0.55	0.45	0.47*	0.38	0.65	0.78
ANS	0.83	0.56	0.73	0.45	0.62*	0.42	0.70	0.46	0.70	0.44	0.78	0.57	0.53*	0.33
PNS	0.90	0.58	0.75	0.50	0.83	0.66	0.85	0.69	1.15	0.88	0.87	0.64	0.73	0.73
A point	0.63	0.41	0.47*	0.43	0.62	0.51	0.52	0.48	0.42*	0.29	0.49*	0.43	0.57	0.52
B point	0.83	0.59	0.82	0.49	0.90	0.68	0.85	0.78	1.00	0.75	0.92	0.65	0.76	0.50
Pogonion	0.69	0.40	0.66	0.38	0.60	0.40	0.49*	0.27	0.54*	0.31	0.48*	0.28	0.52*	0.27
Menton	0.69	0.37	0.56	0.33	0.68	0.53	0.53*	0.30	0.67	0.61	0.50*	0.33	0.61	0.39
U1 apex	0.68	0.40	0.56	0.35	0.59	0.48	0.66	0.46	0.62	0.41	0.62	0.44	0.53*	0.37
U1 edge	1.05	0.61	0.87	0.62	0.82*	0.56	0.90	0.52	0.92	0.50	1.19	0.62	0.96	0.51
L1 edge	0.36	0.22	0.23*	0.12	0.23*	0.13	0.28*	0.27	0.31	0.24	0.23*	0.19	0.20*	0.12
L1 apex	0.39	0.27	0.33	0.19	0.34	0.30	0.36	0.28	0.37	0.36	0.33	0.27	0.28*	0.19
M 6	0.93	0.59	1.09	0.62	0.98	0.63	1.23*	0.72	1.31*	0.89	1.14	0.65	1.16	0.79
Glabella	0.66	0.41	0.73	0.64	0.74	0.52	0.83	0.71	0.59	0.36	0.63	0.39	0.69	0.46
sNasion	0.84	0.53	0.66	0.46	0.63*	0.34	0.70	0.41	0.65	0.43	0.68	0.41	0.53*	0.31
Nose tip	0.98	0.58	0.54*	0.31	0.55*	0.34	0.52*	0.31	0.63*	0.41	0.60*	0.44	0.42*	0.32
UL	0.73	0.63	0.41*	0.24	0.36*	0.20	0.38*	0.25	0.34*	0.22	0.42*	0.32	0.37*	0.26
LL	0.53	0.34	0.41*	0.22	0.46*	0.27	0.42*	0.27	0.35*	0.20	0.33*	0.18	0.39*	0.27
	0.59	0.30	0.36*	0.22	0.37*	0.22	0.43*	0.25	0.39*	0.26	0.42*	0.23	0.42*	0.28
	0.67	0.38	0.47*	0.31	0.44	0.28	0.56	0.48	0.56	0.35	0.36*	0.21	0.48*	0.30
sPogonion														

* : statistically significant difference compared with conventional radiograph (M0) ($n = 50$)

Results

Table 2 describes the deviation from the mean in millimeters for each modality as an average between observers for each landmark. All modalities of digital images were compared with conventional radiograph (M0) each other and the statistical significance was measured separately ($p < 0.05$). So in comparison with the conventional cephalometric radiograph (M0), M1 showed statistically significant differences in 8 locations, M2 showed in 9, M3 showed in 12, M4 showed in 7, M5 showed in 12, and M6 showed in 14 of 23 landmark locations ($p < 0.05$).

By Duncan's Multiple Range Test for variables, the numbers of landmarks that each modality has as the most reproducible locations were 7 in M6, 6 in M5, 5 in M3, 4 in M4, 3 in M2, 2 in M1, and 1 location in M0 ($p < 0.05$). The image modality which observers selected as having the best image quality was M5. Four observers selected M5 and one observer selected M3.

Discussion

Computed radiography units specialize in digital image acquisition, image processing and archiving. We can process the image as desired on the screen, and the original is always retained. The computer is responsible for archiving. In this study, we laid stress on the image processing. The quality of a digital image is strongly dependent on the spatial resolution, the relationship of the gray level values of the pixels to the optical density of the radiograph and the image display. We can control those critical factors by adjusting post-processing.

There are several factors we can modify to obtain high quality images. Those are gradation processing, spatial frequency processing, subtraction, dynamic range control processing, tomographic artifact suppression and so on. Many studies have been performed to compare the reliability of conventional radiography and digital radiography. And they used proper processing under their subjective judgement to optimize image quality. To make more objective decision for optimized quality images, we modified spatial frequency rank in combination with frequency type. The frequency rank can be ranged from 0 to 9. And as the frequency rank increases, the more detailed images can be observed. If we want to observe the outline of a large structure, soft tissue or kidney, we should decrease the frequency rank. The frequency type means curve for nonlinear unsharp mask. Fujita et al.[19] found that the detail visibility of linearly enhanced images, especially in low-density areas, was superior to that of nonlinearly enhanced images, although the presence of more artifacts and more noise was noted in linearly enhanced images. And in this study, frequency type F made the linearly enhanced images. On the contrary, frequency type T made the nonlinearly enhanced images to reduce the enhancement of low-density area.

As this study reflects, the modality which the observer subjectively selected as having the best image quality was not identical to the modality with the highest reproducibility, although it is doubtful whether this statistical significance has clinically significant influence on the outcome of the cephalometric analysis. Most orthodontists are accustomed to the conventional analogue radiograph and the digital image of higher frequency rank is close to it. We think this is why most observers in this study selected modality 5 (M5) which has the highest frequency rank and less noise.

We believe that if the environment the observer undertook registration was not dimmed as an ordinary clinical room, the digital image would be superior to conventional film as far as the soft tissue locations concerned because of the digital image's wide dynamic range. Through digital image processing, it was possible to trace most cephalometric anatomic structures with ease, more promptly and without any hesitation. But the landmark which is bilaterally present or superimposed by the adjacent structures was not so clear whether it is conventional radiograph or higher quality digital image, which supported Baumrind and Frantz's identification.[11]

Midtgård et al.[20] found that an interval of one month between two registrations did not significantly affect the reproducibility of the landmarks examined. Richardson[21] had two judges register cephalometric landmarks, lines, and angles on ten cephalograms with an interval of one week. He found that ordinary cranial landmarks have a margin of error of less than 1 mm. Houston[22] concluded that although more replications will reduce random errors still further, it is questionable whether it is cost effective except in special circumstances, and it is essential that the quest for precision should not obscure the dubious validity of some cephalometric landmarks and measurements. We did not request the observers to repeat the registrations of landmarks. Instead we focused on the calibration of observers with respect to the definition of landmarks to reduce the method errors.[23,24]

In recent years, several cephalometric studies using the hardcopy display of the storage phosphor technique have been published, especially in relation to radiation dose. Naslund et al.[25] concluded that a dose reduction of 75% does not effect the localization of anatomical landmarks in lateral cephalograms obtained with computed radiography. Eppley[26] found that on the digital hardcopies, both soft and hard tissue landmarks were equally well localized, independent of the radiation dose. Even though we made every effort to minimize the errors[22] in this study, we used no radiation reduction to the subjects, but the same radiation exposure as in the conventional radiography was used, which should be considered seriously beforehand.

Further investigations should be undertaken to the area of other extraoral radiographies using these variable digital image processing procedures. The future of radiology would be the age of digital radiography. So to know how to use this new technology would be the power for exact diagnosis.

If we are able to use these various kinds of digital image processing procedures proficiently and choose the most proper image with an exact eye, this would certainly help us for our digital diagnostic future.

References

1. Kashima I. Computed radiography with photostimulable phosphor in oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995; 80: 577-98.
2. Forsyth DB, Shaw WC. Digital imaging of cephalometric radiography, part 1: Advantages and limitations of digital imaging. Angle Orthod 1996; 66: 37-42.
3. Kim EK. Digital x-ray imaging in dentistry. J Korean Oral Maxillofac Radiol 1999; 29: 387-96.
4. Jackson P, Dickson G. Digital image processing of cephalometric radiographs; a preliminary report. Br J Orthod 1985; 12: 122-32.
5. Darryl N, Mackay F. Reliability of cephalometric analysis using manual and interactive computer methods. Br J Orthod 1991; 18: 105-9.
6. Forsyth DB, Davis DN. Assessment of an automated cephalometric analysis system. Eur J Orthod 1996; 18: 471-8.
7. Rudolph DJ. Automatic computerized identification of cephalometric landmarks. Am J Orthod Dentofacial Orthop 1998; 113: 173-9.
8. Rossmann K, Wiley BE. The central problem in the study of radiographic image quality. Radiology 1970; 96: 113-25.
9. McWilliam J, Welander U. The effect of image quality on the identification of cephalometric landmarks. Angle Orthod 1978; 48: 49-56.
10. Björk A, Solow B. Measurements on radiographs. J Dent Res 1962; 41: 672-83.
11. Baumrind S, Frantz R. The reliability of head film measurements. Am J Orthod 1971; 60: 111-27.
12. Döler W, Steinhofel N, Jäger A. Digital image processing techniques for cephalometric analysis. Comput Biol Med 1991; 21: 23-33.
13. Macri V, Wenzel A. Reliability of landmark recording on film and digital lateral cephalograms. Eur J Orthod 1993; 15: 137-48.
14. Geelen W, Wenzel E, Gotfredsen M. Reproducibility of cephalometric landmarks on conventional film, hardcopy, and monitor-displayed images obtained by the storage phosphor technique. Eur J Orthod 1998; 20: 331-40.
15. Sagner T, Storr I. Diagnostic image quality in comparison of conventional and digital cephalometric radiographs. Dentomaxillofac Radiol 1998; 27: S1, S26, A27.
16. Forsyth DB, Shaw WC. Digital imaging of cephalometric radiography, part 2: Image quality. Angle Orthod 1996; 66: 43-50.
17. Kim HD. The reliability of cephalometric landmarks in conventional radiography and digital radiography. J Korean Oral Maxillofac Radiol 1997; 27: 99-105.
18. Athanasios E. Orthodontic cephalometry. Mosby-Wolfe; 1995. p.21-62, 221-40.
19. Fujita M, Kodera Y, Ogawa M, Tanimoto K, Sunayashiki T, Wada T et al. Digital image processing of dentomaxillofacial radiographs. Oral Surg Oral Med Oral Pathol 1987; 64: 485-93.
20. Midtgård J, Björk G, Linder-Aronson S. Reproducibility of cephalometric landmarks and errors of measurements of cephalometric cranial distances. Angle Orthod 1974; 44: 56-62.
21. Richardson A. An investigation into the reproducibility of some points, planes and lines used in cephalometric analysis. Am J Orthod 1966; 52: 637-51.
22. Houston W. The analysis of errors in orthodontic measurements. Am J Orthod 1983; 83: 382-9.
23. Cheon SD. Method errors in digital lateral cephalometry. J Korean Oral Maxillofac Radiol 1997; 27: 105-15.
24. Cooke MS, Wei SHY. Cephalometric errors: a comparison between repeat measurements and retaken radiographs. Austral Dent J 1991; 36: 38-43.
25. Naslund EB, Kruger M. Analysis of low-dose digital lateral cephalometric radiographs. Dentomaxillofac Radiol 1998; 27: 136-9.
26. Eppley BL. Computerized digital enhancement in craniofacial cephalometric radiography. J Oral Maxillofac Surg 1991; 49: 1038-43.