Quantitative Evaluation of Patient Movement during Simulated Acquisition of Cephalometric Radiographs

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The objective of this study was to perform the quantitative three-dimensional analysis of the patients' movements at the different time points during the simulated acquisition of cephalometric radiographs. Fifty-three subjects (32 men, 21 women) were divided into four groups according to their age (Group 1: 9–12, Group 2: 13–19, Group 3: 20–25, and Group 4: 26–30 years old). The experiment (Exp) consisted in providing the subjects with three different kinds of verbal instructions as follows; Exp 1: they were simply instructed not to move, Exp 2: detailed instructions were provided, and Exp 3: they were specifically instructed to clench their molars. The amount of their movement during the 20 s of the cephalometric X-ray exposure was measured using an optical marker and tracker. The maximum movement was analyzed three-dimensionally at 0.5, 2, 5, 10, 15, and 20 s. There was minimal vibrating movement every 0.3–0.5 s and relatively large movement every 3–5 s. The youngest group showed the largest amount of movement among the four age groups, and their movement was more significant in the up and down direction ($p < 0.05$). There was no significant difference in the amount of movement according to the instructions. The longer exposure time showed the larger amount of the movement. Children can show the significant movements during X-ray taking, and the longer exposure time can also result in the larger movement during acquisition of cephalometric radiographs. Therefore, the shorter exposure time is recommended in order to improve image quality.

KEY WORDS: Digital radiography, evaluation studies, image blurring, movement, cephalometry

INTRODUCTION

Digital radiography in dentistry has many advantages such as ease of storage and transmission, ability to control the brightness and contrast, and other image enhancement capabilities, lower exposure rate, and automatic cephalometric

analysis.^{1,2} Digital radiographic systems can be divided into the computerized radiography (CR) and digital radiography (DR) according to the image acquisition method.³ CR system uses an image plate (photostimulable phosphor plate) and a CR reader and requires scanning procedure of the plate before the image can be visualized on the computer monitor.^{4–6} The size of the image plates and the basic method for X-ray taking are practically the same as for the conventional film. On the other hand, the DR system acquires the radiographic images using several types of sensors such as the charge coupled device (CCD), complementary metal-oxide semiconductor (CMOS), and flat panel.³ CCD/CMOS sensors can only cover a small area due to the sensor size limitation; therefore, it can be used for

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periapical radiography while flat panel detectors can cover a large area such as the chest.⁷

Digital radiography including both CR and DR systems is also used for cephalometric radiography. In order to take a digital cephalometric radiograph, the CR image can be acquired with the same method used for conventional film radiography; however, in the case of DR system using CCD/CMOS sensors, two special methods have been developed to overcome the sensor size limitations. One method involves the use of an image intensifier in order to demagnify the image which can then be covered by the small sensor. The other method uses a slit type of X-ray beam and sensor.⁸ With this method, the cephalometric radiograph can be taken by horizontally or vertically moving the combination of a thin CCD array and the X-ray source to cover the patient's head. This type of equipment requires longer exposure time compared to the conventional film method.^{9,10} Unfortunately, the longer exposure time can result in the image distortion due to the patients' swallowing, breathing, and unexpected movement. Patient movement during X-ray exposure can be one of the factors that cause image blurring¹¹; therefore, an effort not to move should be made to avoid it.

There were studies on the cephalometric analysis comparing between the conventional and digital radiographs using CR images,¹² scanned images of conventional films,^{13,14} and a slit-beam type machine with a skull,¹⁵ a cadaver,¹⁶ or a phantom.⁹ Although there were a few studies using the slit-beam type of cephalometric equipment,^{17,18} they did not consider the possibility of the image distortion due to the patients' movements. Therefore, this study was performed to record and quantitatively analyze the amount of the patients' movements at the different time points during the simulated acquisition of the digital cephalometric radiographs.

MATERIALS AND METHODS

Fifty-three volunteers participated in this study. Their age ranged from 9 to 30 years (mean age was 20 years old) and consisted of 32 males and 21 females. The study protocol was explained to them in detail, and informed consent was obtained. The participants were not exposed to X-rays. Instead, the procedure to take a cephalometric radiograph was simulated. The subjects were divided into four

groups according to their age as follows: Group 1: 9 to 12 years old (mean age: 11, three males and five females), Group 2: 13 to 19 years old (mean age: 17, 12 males and seven females), Group 3: 20 to 25 years old (mean age: 22, 12 males and seven females), and Group 4: 26 to 30 years old (mean age: 28, nine males and four females).

The exposure times for cephalometric X-ray equipments using film, CR, and DR radiography were investigated through the manufacturers' brochures and their websites. According to our investigation, the exposure time ranged from 0.1 to 4.0 s for film or CCD with intensifier and from 4.5 to 23 s for slit-beam type of equipments. Therefore, the simulated exposure times were determined as 0.5, 2, 5, 10, 15, and 20 s in this study.

Quantitative Evaluation of Movement

The volunteers were positioned at the cephalometric X-ray equipment (Orthophos XG5 DS®, Sirona, Bensheim, Germany) in the same way as that used in clinical settings (Fig. 1). Their movements were recorded using a set of optical tracker and marker (Polaris Vicra System, Northern Digital Inc., Waterloo, Canada). Briefly, the optical tracker is an equipment for motion capture, which can identify the three-dimensional positions of the optical sensors or markers using an ultra-red

Fig 1. The subject positions at the digital lateral cephalometric X-ray equipment (Orthophos XG5®, Sirona, Bensheim, Germany). The optical marker is attached to the subject's chin.

camera and the distance error is under 0.25 mm.^{19,20} The optical marker was attached to the volunteers' chin area using a chin cap (Fig. 1), and the optical tracker and marker were set up to record the subjects' movements. Movements were recorded every 0.05 s for over 20 s using the optical tracker (Fig. 2).

Three types of instructions were given to the subjects. The first one (Exp 1) was that the subjects were simply instructed not to move during the exposure time. The second one (Exp 2) was providing very detailed instructions that they should pay attention not to move, not to swallow their saliva, and to breathe very softly. The third one (Exp 3) was asking them to clench their molars and hold continuously. The procedures according to the instructions for each subject were performed with at least 1 week interval.

Data Acquisition

Three-dimensional position of the optical marker was acquired on the *X*, *Y*, and *Z* axes. The position on *X* axis was that of the optical marker in the left or right direction (a negative (−) value meant left side and a positive (+) value meant right side), *Y* axis was the optical marker in the up or down direction (negative (−) value was up, positive (+) value was down), and *Z* axis meant front and back (negative (−) value was front, positive (+) value was back). The position was

Fig 2. Optical tracker (Polaris Vicra System, Northern Digital, Waterloo, Canada).

recorded every 0.05 s, and then the relative position to the initial point was calculated in the unit of millimeters.

The amount of the maximum movement was calculated on the *X*, *Y*, and *Z* axes during the previously selected exposure times (0 to 0.5, 2, 5, 10, 15, and 20 s). The amount of the movement was defined as the distance between the minimum negative and maximum positive values on each axis.

Statistical Analysis

Individual subjects provided multiple repeated observations of their movements at each exposure time (0.5, 2, 5, 10, 15, and 20) according to the type of the instructions given to them (Exp 1, 2, and 3), and according to the reference axes (*X*, *Y*, and *Z* axes). Therefore, linear mixed model analysis was used because these serial measurements were “correlated” or “clustered” according to the individual subjects. Statistical analyses were carried out using PROC MIXED (SAS 9.1, SAS Institute, Cary, NC, USA). Bonferroni adjustment was used to compare multiple mean differences. Values were considered significant when $p < 0.05$.

RESULTS

The subjects' movements presented various patterns during the exposure time such as continuous increase, minimal vibration near the initial position, or increase and decrease periodically. Subpanels a and b of Figure 3 are the examples of subjects' movements on the *X*, *Y*, and *Z* axes showing the largest movement and the smallest movement for 20 s, respectively. All subjects including these examples showed minimal vibration every about 0.3–0.5 s and a relatively larger movement every about 3–5 s.

There was no statistical significance between genders ($p > 0.05$). Tables 1, 2, 3, 4, 5, and 6 show all datasets using pooled data without division by gender. Regarding the age group, group 1 showed the largest amount of movements among all of the groups ($p < 0.05$). Group 2 also showed larger movements compared to groups 3 and 4; however, there was no statistical significance ($p > 0.05$). Regarding the amount of the movements according to the axes, the movement on the *Y* axis was the

Fig 3. The actual movement of a subject on the X, Y, and Z axes for 20 s. a The largest movement, b the smallest movement.

largest, followed by that on the Z axis. The movement on the X axis was the smallest ($p < 0.05$). Figure 4 shows the comparison of the movements on the axes between group 1 (under 12 years old) and the other groups (over 13 years

old). On this comparison, group 1 showed the larger movement compared to the other groups significantly.

In regards to the experiments (Exps) which consisted in providing the subjects with different

Table 1. The Maximum Movements (in mm) within 0.5 s

Group	Exp	X	Y	Z
1	1	0.67	1.02	1.26
	2	0.82	1.16	1.29
	3	1.16	1.93	1.54
2	1	0.87	0.66	0.77
	2	0.60	0.88	0.85
	3	0.64	0.64	0.62
3	1	0.42	0.71	0.54
	2	0.59	0.55	0.55
	3	0.45	0.66	0.56
4	1	0.39	0.48	0.49
	2	0.39	0.48	0.39
	3	0.40	0.51	0.46

Group 1: 9–12, group 2: 13–19, group 3: 20–25, group 4: 26–30 years old. Exps 1, 2, and 3: the different instructions provided

Table 2. The Maximum Movements (in mm) within 2 s

Group	Exp	X	Y	Z
1	1	1.41	2.52	2.21
	2	1.98	2.73	2.77
	3	2.46	5.59	4.09
2	1	1.37	1.46	1.29
	2	1.24	1.62	1.60
	3	1.37	1.66	1.69
3	1	1.02	1.54	1.35
	2	0.97	1.15	1.06
	3	0.87	1.44	1.25
4	1	0.86	1.15	1.24
	2	0.76	0.90	0.72
	3	0.83	1.12	0.94

Group 1: 9–12, group 2: 13–19, group 3: 20–25, group 4: 26–30 years old. Exps 1, 2, and 3: the different instructions provided

Table 3. The Maximum Movements (in mm) within 5 s

Group	Exp	X	Y	Z
1	1	2.25	5.73	4.07
	2	3.33	5.04	4.31
	3	3.22	6.78	5.01
2	1	1.84	2.43	2.14
	2	1.68	2.27	2.10
	3	2.14	3.03	2.82
3	1	1.54	2.12	1.74
	2	1.39	1.55	1.55
	3	1.34	2.00	1.61
4	1	1.62	2.28	2.03
	2	1.11	1.59	1.22
	3	1.21	1.82	1.30

Group 1: 9–12, group 2: 13–19, group 3: 20–25, group 4: 26–30 years old. Exps 1, 2, and 3: the different instructions provided

Table 5. The Maximum Movements (in mm) within 15 s

Group	Exp	X	Y	Z
1	1	4.20	10.65	7.88
	2	9.04	8.93	8.27
	3	5.41	13.63	9.40
2	1	2.40	4.07	3.61
	2	2.19	3.45	3.11
	3	3.08	5.26	4.30
3	1	2.08	3.76	2.53
	2	1.82	2.39	1.99
	3	1.94	2.93	2.33
4	1	2.28	3.77	2.61
	2	1.63	2.50	1.88
	3	1.76	3.19	2.12

Group 1: 9–12, group 2: 13–19, group 3: 20–25, group 4: 26–30 years old. Exps 1, 2, and 3: the different instructions provided

types of instructions, there was no statistical significance. Therefore, the data of the three experiments were pooled and analyzed sequentially. Regarding the exposure time, the amounts of movements increased with longer exposure time, and the proportion of the increase was larger in group 1 compared to the other groups ($p < 0.05$; Fig. 5).

DISCUSSION

Radiologists encounter unsharp X-ray images due to patient's movement even with short exposure times. This study was performed to

evaluate the expected patient movement during exposure times used in cephalometric radiography.

The exposure time for a cephalometric radiograph is clinically determined based on the desired diagnostic quality, the patient's physique, the equipment capacity, the type of film and intensifying screen, and the acceptable amount of image noise in film radiography and digital images using CR machine. On the other hand, in case of the slit-beam type of digital cephalometric X-ray machine, the exposure time is predetermined based on the machine. In other words, the exposure time is the moving time of the slit beam and the receptor. The exposure time varies depending on the equipment used; therefore, the simulated exposure times

Table 4. The Maximum Movements (in mm) Within 10 s

Group	Exp	X	Y	Z
1	1	3.94	8.54	5.86
	2	8.88	8.69	7.43
	3	4.16	9.01	6.17
2	1	2.14	3.28	3.12
	2	1.94	2.95	2.59
	3	2.64	4.21	3.57
3	1	1.88	3.02	2.20
	2	1.73	2.02	1.81
	3	1.73	2.62	1.99
4	1	1.96	3.36	2.45
	2	1.39	2.19	1.54
	3	1.48	2.72	1.93

Group 1: 9–12, group 2: 13–19, group 3: 20–25, group 4: 26–30 years old. Exps 1, 2, and 3: the different instructions provided

Table 6. The Maximum Movements (in mm) within 20 s

Group	Exp	X	Y	Z
1	1	6.48	13.18	9.34
	2	9.58	9.54	9.03
	3	5.49	15.53	11.32
2	1	2.62	4.27	3.71
	2	2.34	3.88	3.50
	3	3.32	5.90	4.54
3	1	2.17	4.16	2.72
	2	1.93	2.81	2.21
	3	2.17	3.18	2.48
4	1	2.41	4.24	2.76
	2	1.82	2.83	2.06
	3	1.83	3.59	2.31

Group 1: 9–12, group 2: 13–19, group 3: 20–25, group 4: 26–30 years old. Exps 1, 2, and 3: the different instructions provided

Fig 4. The movements on the axes of group 1 (under 12 years old) and the pooled data of other groups (over 13 years old). Group 1 shows significantly larger movement.

of 0.5, 2, 5, 10, 15, and 20 s were selected in our study considering the manufactures' instructions and common exposure times used in clinical settings.

The results showed minimal periodic vibration about every 0.3–0.5 s. This type of movement was

observed in all of the subjects including those that showed the least amount of movement; therefore, this type of movement appears to be related to involuntary movement such as the cardiac pulse. The relatively large periodic movement was observed about every 3–5 s and was thought to be due to their breathing even though they were instructed not to move during the exposure time. The movement on the left to right direction was smallest compared to other directions. This could be explained by the use of the cephalostat which is positioned in both ear canals and prevents the rotating movement to the left and right sides.

Our results showed that the youngest subjects showed the largest amount of movement. Even during the shortest exposure time of 0.5 s, their mean value of the movement was over 1 mm. This result suggests that the younger patients have a greater chance of needing retakes of cephalometric radiographs even when they were exposed with the short exposure time. This phenomenon may be due to the shorter attention span commonly seen in

Fig 5. The amount of the subjects' movements. The youngest group shows larger increasing proportion of the movements compared to other groups.

children; therefore, whenever the exposure time as short as possible should always be applied for the pediatric radiographic examinations. In this respect, the slit-beam type of X-ray equipment is not recommended for the pediatric patients because of the long exposure time.

Patients are usually instructed not to move during radiographic examinations to ensure good image quality. More detailed instructions are expected to decrease the chance of the patient's movement; however, our results showed no significant difference according to the types of the instructions. It is possible that the previous experiences of the radiographic exams may have had an effect in the lack of difference between experiments. People who had the experience taking radiographs might understand the procedure, and they might be more mindful not to move even when they were instructed simply.

The amount of the patients' movements is shown in Table 1 and Figure 5. The longer exposure time resulted in greater movement. Although dentists and radiologists might predict these results, this study showed that the real amount of the movement was measured according to the exposure time. In case of the conventional film/screen combination or CR type of equipment, patient's movement can cause image unsharpness; therefore, the need for a retake could be easily determined. However, in case of the slit-beam type of X-ray machine, patient's movement might not result in the image unsharpness but instead more prominent step-ladder type of artifacts on the cortical outline or angle change artifacts could be seen when the movement was continuous. Motion artifacts could not be detected on the radiographs in some cases particularly if the patient moved little, slowly, or continuously. Considering these results, a shorter exposure time is also recommended.

The main limitation of this study was that the process of taking a cephalometric radiograph was simulated but the real image was not acquired. Therefore, the amount of the maximum movement was measured on each axis three-dimensionally, but the real movement on the radiographs could not be acquired. Actually, the measurement of movement on lateral and frontal radiographs and the real-time movement during the exposure time would be useful when evaluating of the true measuring error on the cephalometric analysis and should be included in future studies. Another

limitation is that the optical marker was attached to the subject's chin; therefore, these results indicated chin movement only. Nevertheless, these results were useful since some landmarks used in cephalometric analysis were located in the mandible. Additionally, the process recording the patient's movement may also be useful for other X-ray equipment with long exposure time such as cone beam computed tomography.

CONCLUSION

The longer exposure time can result in the larger movement during acquisition of cephalometric radiographs. Patient's movement was more significant in children; therefore, a shorter exposure time is recommended in order to get a good quality of image and the slit beam type of cephalometric equipment is not recommended for pediatric patients.

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REFERENCES

1. Vandre RH, Webber RL: Future trends in dental radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 80:471–480, 1995
2. Wenzel A, Grondahl HG: Direct digital radiography in the dental office. *Int Dent J* 45:27–34, 1995
3. Sanderink GC, Miles DA: Intraoral detectors. CCD, CMOS TFT, and other devices. *Dent Clin North Am* 44:249–255, 2000
4. Parks ET, Williamson GF: Digital radiography: an overview. *J Cont Dent Pract* 4:23–39, 2002
5. Hildebolt CF, Couture RA, Whiting BR: Dental photo-stimulable phosphor radiography. *Dent Clin North Am* 44:273–297, 2000
6. Kashima I: Computed radiography with photostimulable phosphor in oral and maxillofacial radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 80:577–598, 1995
7. Schaefer-Prokop C, Uffmann M, Eisenhuber E, Prokop M: Digital Radiography of the Chest: Detector Techniques and Performance Parameters. *J Thorac Imaging* 18:124–137, 2003
8. Mupparapu M, Binder RE, Cummins JM, Feldman CA, Cappelli MA, Matheson PB: Implementation of a Digital Radiographic Image Acquisition and Retrieval System

(DRIARS) using a wireless network in an orthodontic department. *J Contemp Dent Pract* 9:115–123, 2008

9. Wenger NA, Tewson DH, McDonald F: Direct digital lateral cephalometry: the effects of JPEG compression on image quality. *Med Eng Phys* 28:560–567, 2006

10. Gijbels F, Sanderink G, Wyatt J, Van Dam J, Nowak B, Jacobs R: Radiation doses of indirect and direct digital cephalometric radiography. *Br Dent J* 197:149–152, 2004

11. Li T, Schreibmann E, Yang Y, Xing L: Motion correction for improved target localization with on-board cone-beam computed tomography. *Phys Med Biol* 51:253–267, 2006

12. Geelen W, Wenzel A, Gotfredsen E, Kruger M, Hansson LG: Reproducibility of cephalometric landmarks on conventional film, hardcopy, and monitor-displayed images obtained by the storage phosphor technique. *Eur J Orthod* 20:331–340, 1998

13. Sayinsu K, Isik F, Trakyalı G, Arun T: An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. *Eur J Orthod* 29:105–108, 2007

14. Bruntz LQ, Palomo JM, Baden S, Hans MG: A comparison of scanned lateral cephalograms with corresponding

original radiographs. *Am J Orthod Dentofacial Orthop* 130:340–348, 2006

15. Schulze RK, Gloede MB, Doll GM: Landmark identification on direct digital versus film-based cephalometric radiographs: a human skull study. *Am J Orthod Dentofacial Orthop* 122:635–642, 2002

16. Gijbels F, Bou Serhal C, Willems G, Bosmans H, Sanderink G, Persoons M, Jacobs R: Diagnostic yield of conventional and digital cephalometric images: a human cadaver study. *Dentomaxillofac Radiol* 30:101–105, 2001

17. Celik E, Polat-Ozsoy O, Toygar Memikoglu TU: Comparison of cephalometric measurements with digital versus conventional cephalometric analysis. *Eur J Orthod* 31:241–246, 2009

18. You M, Li X, Wang H, Zhang J, Wu H, Liu Y, Miao J, Zhu Z: Morphological variety of the soft palate in normal individuals: a digital cephalometric study. *Dentomaxillofac Radiol* 37:344–349, 2008

19. Otake Y: Real-time mandibular movement analysis system using four-dimensional cranial bone model. *Syst Comp Jpn* 37:1216–1226, 2006

20. Wilson EM, Green JR: The development of jaw motion for mastication. *Early Hum Dev* 85:303–311, 2009