Subjective Image Quality of Lateral Cephalometric Radiographs With and Without Application of a Prediction Model

Gang LI[1], Hans Verheij[1], Paul van der Stelt[1], Robert Speller[2], Jenny Griffiths[2], Marinos Metaxas[2], Gary Royle[2], Fotis Psomadellis[3], Renato Turchetta[4], Andrea Fant[4], Sergios Theodoridis[5], Harris Georgiou[5], Joar Østby[6], Helene Schulerud[6], Frixos Triantis[7], Nikolaos Manthos[7], Renato Longo[8], Christian Venanzi[8]

Objective: *A prediction model was developed to simulate an underexposed radiograph to that which is optimally exposed. The objective of the study was to evaluate if radiographic landmarks were equally observed in lateral cephalometric radiographs processed with and without the prediction model.*
Methods: *Using a digital imaging system (Orthopantomograph® OC-100D), test radiographs of a human skull phantom covered with simulated soft tissue were obtained using different exposure settings. The optimal radiograph was subsequently established. The under-exposed raw data radiographs were then processed in two sets. In one set, the radiographs were first simulated from the optimally exposed raw data radiograph using the prediction model and then processed with the default settings of the proprietary software that was used to control the imaging system used. In the second set, the radiographs were processed only with the default settings of the proprietary software. Two monitors were employed to simultaneously display the radiographs. Six observers subjectively compared the fourteen most frequently used landmarks on both radiographs.*
Results: *Compared with the non-predicted radiographs, in the predicted radiographs subjective impression of the radiographic landmarks was more frequently considered the same or better than the optimal radiographs. The difference was statistically significant.*
Conclusion: *The subjective impression of the landmarks in the predicted radiographs is better than that in the non-predicted radiographs.*
Key words: *cephalometry, dental radiography, digital dental radiography, image processing, radiography*

1 Department of Oral and Maxillofacial Radiology, ACTA, Amsterdam, The Netherlands.
2 Department of Medical Physics and Biomedical Engineering, University College London, London, UK.
3 Manager of ANCO S.A. development team, Athens, Greece.
4 Rutherford Appleton Laboratory, CCLRC, Oxford, UK.
5 Department of Informatics and Telecommunications, University of Athens, Athens, Greece.
6 Division of Electronics and Cybernetics, SINTEF, Oslo, Norway.
7 Physics Department, University of Ioannina, Ioannina, Greece.
8 Medical Physics Group, University of Trieste, Trieste, Italy.

Corresponding author: (current address) Dr Gang LI, Department of Oral and Maxillofacial Radiology, Peking University School and Hospital of Stomatology, #22 Zhongguancun Nadajie, Haidian District, Beijing 100081, P.R. China. Tel: 86-10-62179977 ext 2323; Fax: 86-10-62173402.
This study was supported by EU-contract NMP2-CT-2003-505593.

The basic principle for dental radiographic examination is ALARA (As Low As Reasonably Achievable) to the patient dose[1]. This indicates that patient exposure should be kept as low as possible while producing a radiograph of sufficient quality for diagnosis. This is especially important in young people and adolescents, as risks from x-ray radiation may be higher for these patients[2]. Although radiation exposure has been reduced through the use of rare-earth intensifying screens[3], different collimator shapes and digital imaging systems[4-7], this could be improved by adaptively exposing tissues or organs that are of interest to the radiologist.

Recently, a project named I-ImaS (Intelligent Imaging Sensors) was funded by the European Commission under the Sixth Framework Programme[6]. This project aims to design and develop a new generation of intelligent imaging sensor, which allows adaptive exposure of a radiograph so that the region of high information content within a patient is investigated most closely, whilst the remaining regions of low interest are recorded with the minimum amount of radiation. The adaptive procedure is accomplished by arrays of sensors that provide real-time data analysis during radiograph acquisition, i.e. reading data from the scout scan to give real-time feedback control to the x-ray source and the scanning system for the second scan[8-10], and thus allows optimisation of the recorded information whilst minimising the radiation dose or duration of examination.

To prove the principle of the I-ImaS project, dental cephalography was selected as one of the medical applications. A prediction model was developed for real-time adaptive exposure of cephalometric radiographs[11]. With this model, an under-exposed radiograph can be simulated from a radiograph that is exposed at an optimal condition.

The aim of the present study was to evaluate the effectiveness of the prediction model. This was done by comparing subjectively the radiographic quality of the landmarks shown in the cephalometric radiographs.

Material and Methods

Test radiographs

The test radiographs were exposed with a dry human skull covered with simulated soft tissue. The x-ray unit was an Orthopantomograph® OC-100D (Instrumentarium Imaging, Tuusula, Finland), which has a nominal spot size of 0.5 mm, an aluminium filter of 2.5 mm and a CCD sensor with pixel size 90 × 90 µm. To follow the principle of ALARA, radiographs were only exposed at 85 kVp. This was also because the x-ray unit only allowed certain kV-mA-sec combinations. The exposure alternatives are shown in Table 1. During the exposing procedure, the skull phantom was kept at the same position and four radiographs from each setting were exposed randomly to obtain reliable radiographs. Subsequently, the radiographs were exported in raw format with the proprietary software CliniView 5.1 (Instrumentarium Imaging) that was used to control the imaging system.

A prerequisite for applying the prediction model is to determine a radiograph that is optimally exposed so that the underexposed radiographs could be simulated. In the present study, the radiographs exposed at 85 kVp, 12 mA and 20 sec were considered optimal. This was decided by following the recommendations from the manufacturer, considering the size of the human skull and the consensus reached by a panel of dental radiologists.

The radiographs obtained at the exposure settings indicated in Table 1 as underexposed were then considered underexposed and predicted as a raw radiograph with the prediction model. To display the radiograph in the same way as it is displayed in practice, the predicted radiographs were transferred back to the proprietary software CliniView 5.1, and further processed with its default settings. To study the effectiveness of the prediction model, the underexposed radiographs processed only with the default settings of the proprietary software were also evaluated. This set of radiographs will be referred to as non-predicted radiographs hereafter. Example radiographs are shown in Fig 1.

The radiographs (predicted, non-predicted and optimally exposed) were subsequently randomised and displayed simultaneously on two monitors in such a way that when one predicted or non-predicted radiograph was displayed on one monitor, the optimal radiograph was displayed on the other. There was a one in two chance of displaying the optimal and the predicted or non-predicted radiographs on each monitor. To avoid possible effects from different graphics cards, the two monitors were run from one computer. Both monitors were 20-inch Philips Brilliance 200P TFT monitors (Philips, Eindhoven, The Netherlands) and were bought at the same time. The resolution was 1600 × 1200 pixels.

Viewing

The viewing took place in a room with dimmed light. Six dentists who were experienced in lateral cephalometric

Table 1 Exposure alternatives used to expose radiographs

Radiographs	kV	mA	Second
Under-exposed	85	3.2, 4.0, 5.0, 10.0	8.0
Under-exposed	85	12.0	8.0, 10.0, 12.5, 16.0
Optimal	85	12.0	20.0

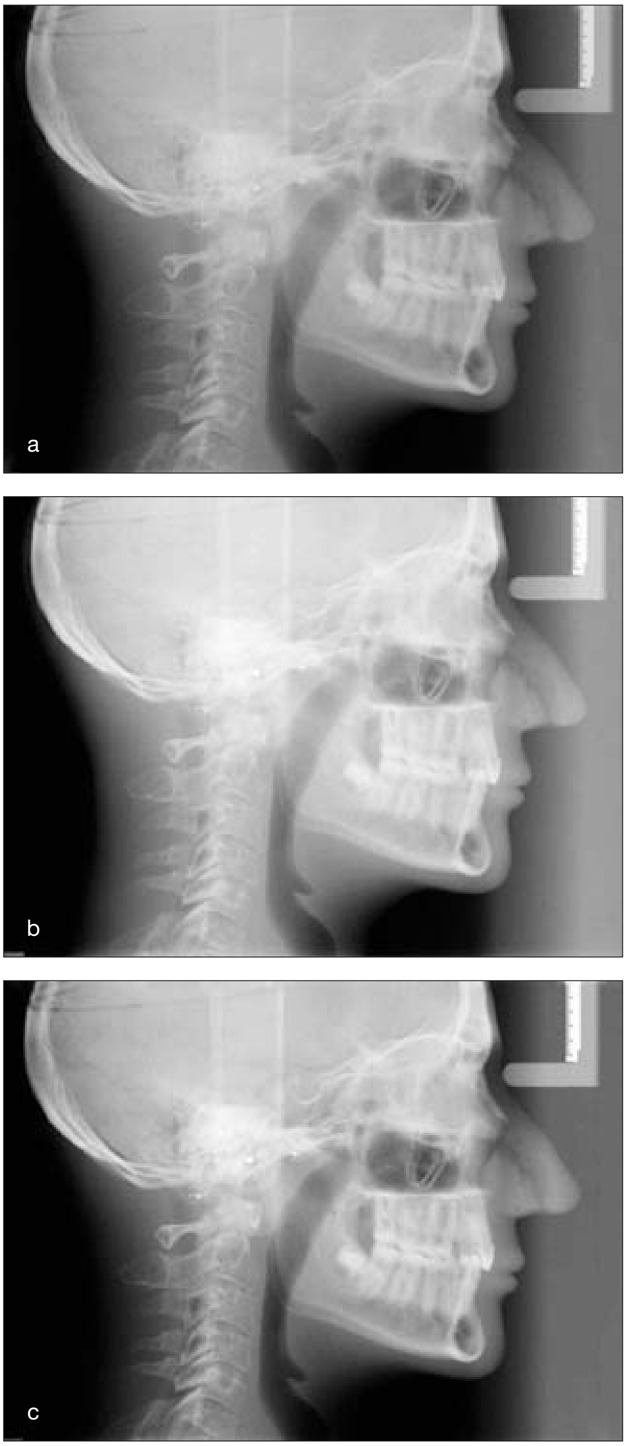

Fig 1 Examples of predicted radiograph (a), non-predicted radiograph (b) and optimal radiograph (c).

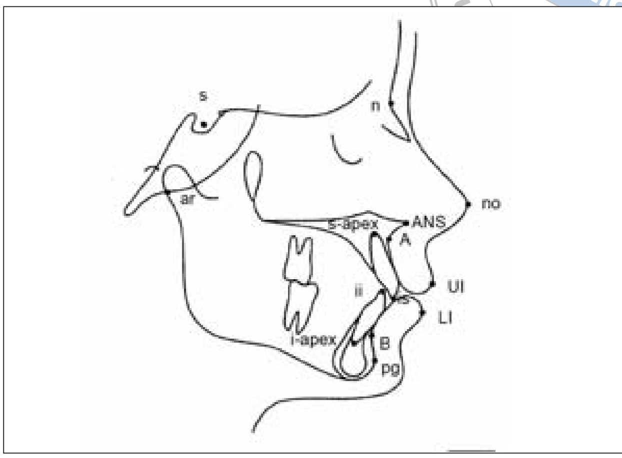

Fig 2 The landmarks used in the study were sella (s), nasion (n), anterior nasal spine (ANS), subspinale (A), supramentale (B), incisor edge superior (is), incisor edge inferior (ii), pogonion (pg), articulare (ar), soft tissue nose (no), upper lip (UI), lower lip (LI), apex of the maxillary incisor (s-apex), apex of the mandibular incisor (i-apex).

radiographs evaluated all radiographs by giving their subjective opinion on the 14 landmarks shown in Fig 2. The rating scale was to indicate whether each landmark was more visible or the same on the right or left monitor. Prior to viewing, brightness and contrast of both monitors were calibrated by two of the investigators using the SMPTE test pattern that is included in the Emago® v.4.0 software (Oral Diagnostic System, Amsterdam, The Netherlands). Additional adjustment of brightness and contrast by the observer was not allowed. To display the radiographs, the software package ACDSee v3.0 (ACD Systems International, British Columbia, Canada) was used. Owing to the size of the cephalometric radiographs (2988 × 2052 pixels), only 50% of each radiograph could be displayed at one time.

To evaluate the effect of the prediction model on the radiographic density, the Emago® v.4.0 software was used to measure the mean density in each test radiograph.

Statistical analysis

Multivariate analysis for discrete data was used for the statistical analysis. The dependent variable was rating scale and the independent variables were exposures. Student *t* test was used to analyse both radiographic density and the frequency of landmarks evaluated in the predicted and non-predicted radiographs ($P < 0.05$ was considered significant).

Results

Figure 3 shows the frequency of landmarks giving the same or better radiographic appearance as those in optimally exposed radiographs. There was a significant difference between the predicted and the non-predicted radiographs ($P < 0.0001$).

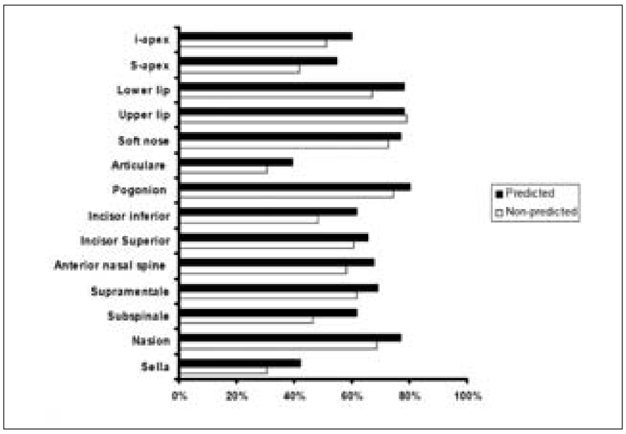

Fig 3 The frequency considering landmarks optimally viewed in the predicted and non-predicted radiographs.

The mean radiographic densities and the standard deviations were 126.7 ± 6.5, 144.2 ± 12.3 and 121.6 ± 0.5 for the predicted, the non-predicted and the optimal radiographs, respectively. There were significant differences between the predicted and the non-predicted radiographs ($P < 0.0001$), between the predicted and the optimal radiographs ($P = 0.023$), and between the non-predicted and the optimal radiographs ($P < 0.0001$).

When studying the effect of exposure, significant differences were found for all landmarks at all exposure settings except for nasion ($P = 0.2192$) and pogonion ($P = 0.0520$). This indicates that recording nasion and pogonion with sensors may not be influenced by exposure.

Discussion

To adaptively expose radiographs seems a promising method to meet the requirement that the dose to the patient is kept as low as possible while producing radiographs with sufficient diagnostic information. Adaptive exposure has been developed in a prototype I-ImaS imaging sensor system. As described above, the new sensor system needs real-time data analysis to provide the exposure feedbacks. To perform this, a prediction model was developed[11]. With this model, an underexposed radiograph could be simulated from the radiograph exposed at an optimal condition, and the exposure parameters for the second scan were subsequently determined. Thus, the subjective image quality of the predicted radiograph should be convinced.

It was previously reported that an extremely underexposed cephalometric radiograph could still provide comparable diagnostic quality with respect to landmark recognition, but the authors agreed that the radiograph quality was poor and the observers had to spend more time locating landmarks[12]. It was confirmed in the present study that the subjective impression of the landmarks is closely related to the exposure that was used for the radiographs, except for the nasion and pogonion landmarks. The subjective image quality of the nasion and the pogonion was not influenced by the exposure, which may be because they are characterised by cortical bone and not superimposed by other anatomical structures.

The standard deviation of radiographic density was smaller in the predicted than in the non-predicted radiographs, but larger than that in the optimal radiographs. If the standard deviation is considered a representation of quantum noise in the radiograph, this implies that the noise in the predicted radiographs was reduced, but was not as low as that in the optimal radiograph. This may explain why the radiographic landmarks were better viewed in the predicted radiographs, but not as clear as those in the optimal radiographs.

In the present study, only half of each radiograph was displayed. This may have an effect on the spatial and contrast resolution of the radiograph displayed. However, this would not have affected the subjective judgment when direct comparisons were made.

The present study shows that the overall subjective impression of the radiographic landmarks is better in the predicted than in the non-predicted radiographs. Over 60% of the evaluations in 11 out of 14 landmarks in the predicted radiographs had the same image quality as in the optimal radiographs, and only 7 landmarks were in agreement with the non-predicted radiographs. Generally, the portrayal of soft tissue, i.e. nose and lower and upper lips, was considered better than the portrayal of the hard tissue. This is logical because the soft tissue has low density and will not be affected as much by decreased exposure. Regarding the hard tissue, over 80% of the evaluations reported the imaging of the pogonion as optimal, and only about 40% of the evaluations considered sella and articulare to be optimal in the predicted radiographs. For the non-predicted radiographs, the percentages for these landmarks are even lower. This may be because the sella and the articulare are points with a large degree of superimposition from other structures.

Although the observers stated that they could recognise all landmarks in the radiographs, in the present study they were only required to indicate their subjective opinions when the landmarks were compared, i.e. whether the predicted or the non-predicted radiographs showed the same image quality as the optimal radiographs. The present study indicates that the subjective impression of the landmarks is approaching the optimal quality more in the predicted than in the non-predicted radiographs.

Conclusion

The subjective impression of the landmarks in the predicted radiographs is better than that in the non-predicted radiographs.

Acknowledgement

The authors wish to express their sincere thanks to all observers.

References

1. Radiation protection 136. European guidelines on radiation protection in dental radiology. The safe use of radiographs in dental practice. European commission, Luxembourg, 2004.
2. Maillie HD, Gilda JE. Radiation-induced cancer risk in radiographic cephalometry. Oral Surg Oral Med Oral Pathol 1993;75:631-637.
3. Halse A, Hedin M. May fast screen-film combinations be used for cephalometry? Br J Orthod 1978;5:189-192.
4. Gijbels F, Sanderink G, Wyatt J, Van Dam J, Nowak B, Jacobs R. Radiation doses of collimated vs non-collimated cephalometric exposures. Dentomaxillofac Radiol 2003;32:128-133.
5. Svenson B, Sjöholm B, Jonsson B. Reduction of absorbed doses to the thyroid gland in orthodontic treatment planning by reducing the area of irradiation. Swed Dent J 2004;28:137-147.
6. Gijbels F, Serhal CB, Willems G, Bosmans H, Sanderink G, Persoons M, Jacobs R. Diagnostic yield of conventional and digital cephalometric images: a human cadaver study. Dentomaxillofac Radiol 2001;30:101-105.
7. 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 2004;197:145-152.
8. Speller RD, Royle GJ, Griffiths JA, et al. Intelligent Imaging Sensors: System development and preliminary results. In: International Workshop Digital Mammography 2006, 2006.
9. Fant A, Gasiorek P, Turchetta R, Avset B, Bergamaschi A, Cavouras D. I-ImaS: A 1.5 D sensor for high resolution scanning. Nucl Instrum Methods Phys Res A 2007;573:27-29.
10. Longo R, Asimidis A, Cavouras D, et al. A scanning system for intelligent imaging: I-ImaS. Proceedings of the SPIE 2007;6510:65100M.
11. Li G, Verheij H, van der Stelt PF. NMP2-CT-2003-505593 Intelligent imaging sensor for industry, health & security. Final report on Radiograph Analysis and Signature Extraction for Dental Imaging. Deliverable 8 for the European Commission, March 2005.
12. Näslund EB, Møystad A, Larheim TA, Øgaard B, Kruger M. Cephalometric analysis with digital storage phosphor radiographs: extreme low-exposure radiographs with and without postprocessing noise reduction. Am J Orthod Dentofacial Orthop 2003;124:190-197.