Autor
Wissenschaftler
Status
Aktuell
Kategorie
Studie

Quality aspects of digital radiography in general dental practice

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The use of digital radiography in general dental practices has increased during the last decade and is gradually replacing film radiography. Digital radiography has several advantages compared with conventional film radiography. Film and dark-room processing are avoided. This means fewer environmental problem[1]. The absorbed dose to the patient can be lowered substantially with the digital technique[2, 3, 4]. But problems often plague the introduction of a new technical system. It is therefore important to ensure that image quality in dental digital radiographs is constant and high so that diagnostic accuracy is maintained.

Dental digital radiography has been the subject of many studies[5-8]. As a conclusion in the most studies, the digital systems perform at least comparable to or even better than conventional radiography. In Norway, Wenzel and Møystad[9] investigated dentists' experiences and their opinions about digital radiography in a questionnaire study. It concluded that the dentists were of the opinion that digital image quality was subjectively better or equal to film image quality, but the dentists also reported that technical problems were common.

The final link in digital radiography is the monitor. Two main types of monitors are used in dental clinics: liquid crystal display (LCD) which is the most common type, and cathode ray tube (CRT). A standard colour monitor usually has a maximum luminance between 100 and 200 cd/m^2. Brightness and contrast levels can be adjusted on most modern monitors. There are few numbers of studies that have evaluated the monitors' contribution to the final image quality in dental digital radiography[10, 11]. The studies were mostly performed on CRT monitors.

The Swedish Standards Institute (SIS)[12] sets standards for environmental conditions in different working situations. SS-EN 12464-1 includes standards for ambient light (illuminance) in a dental practice. It states that a dental operating room needs about 1000 lux, in other words a very bright light. The American Association of Physicists in Medicine (AAPM)[13] recommends an illuminance of less than 50 lux when monitors with luminance values of 250 cd/cm^2 or lower are used to evaluate digital radiographs. Ambient light reflections on the monitor are also difficult to avoid. Few studies that evaluate the effects of illuminance have been published. Cederberg et al.[14] found that illuminance did not appear to affect the detection of artificial carious lesions. Li et al.[15] found that observers who evaluated radiographs with thin endodontic files in a root canal could determine the lengths of the files more exactly in a room with dimmed light than in a room with ordinary artificial light. To ensure good diagnostic performance when evaluating digital radiographs, establishment of optimal environmental conditions appears to be important.

Aims

The aims of the thesis were to examine:

- the quality of radiographic examinations submitted to the Dental Insurance Office; whether it was adequate and whether there were any differences between radiographic digital and film images taken in general dental practices[Paper I].
- experiences of general practice dentists in digital radiography, particularly regarding quality issues[Paper II].
- performance and use of dental digital radiography[Paper III].
- ambient light in the dental operating room, where digital radiographs are interpreted[Paper III].

- whether ambient light influences the diagnostic accuracy of approximal caries[Paper IV].
- whether monitor brightness and contrast settings influence diagnostic accuracy in approximal caries[Paper IV].

Materials and methods

Paper I

Radiographs (in total 4,863) of 540 randomly selected treatment plans that had been sent by mail from practitioners in Sweden to the Dental Insurance Office in Lund, Sweden, for treatment approval of patients over age 65 years comprised the material of this study. Digital radiographs were submitted on different media, and the type of medium was noted. Digital radiographs that were sent in on disk or CD were evaluated in the same way as they were by the Dental Insurance Office. Digital radiographs were processed to obtain the best image possible. The quality variables density, contrast, unsharpness, angulation and receptor / patient position were rated "acceptable" or "unacceptable" for diagnostics. Two observers evaluated the images. Intra- and inter-observer agreement were also evaluated.

Statistical methods

A chi-square analysis was used to assess whether the observed frequencies differed significantly from those expected. Differences were considered significant if $p \leq 0.05$.

Paper II

All private general practice dentists (n=513) in the southernmost county in Sweden (Skåne) were sent a letter in 2004 asking whether they used digital radiography in their clinics. The response rate was 79 % and 106 dentists replied that they used digital radiography. Together with 33 dentists from the Public Dental Service who also used digital technique, they received a questionnaire about digital radiography.

Paper III

Twenty general practice dentists were randomly selected from the group of dentists who answered the questionnaire[Paper II]. Nineteen were visited at their clinics. Three of the general practice dentists worked in the Public Dental Service and 16 worked in private care. At the visits, illuminance in the operating room where the digital radiographs were interpreted was measured. The monitor used by the dentist was evaluated, and how the dentist used the image processing programs was observed.

Test images from the AAPM[13] were used to check the monitors, and some were used to optimise the brightness and contrast settings of the monitor. Figure 1 illustrates one of the test images.

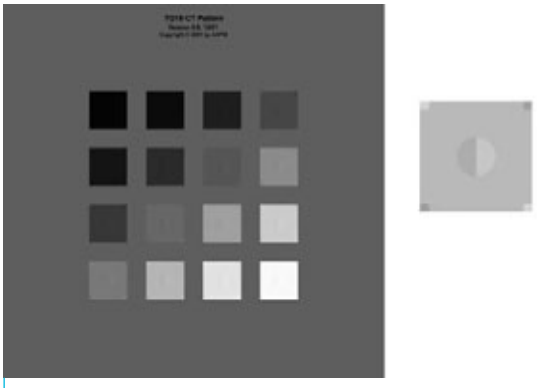

Fig. 1: TG18–CT: Test pattern for visual assessment of light emitted by the display monitor (luminance). An object shaped like a half–moon should be visible inside each square.

A low-contrast phantom in Plexiglas (Fig. 2) was radiographed at the Department of Oral and Maxillofacial Radiology, Malmö University, and the radiograph was compared to a locally exposed image. The number of visible holes was counted after the image had been processed. A high-contrast test phantom (Fig. 3) was also radiographed at the department for use in evaluating high-contrast resolution (line-pairs/mm).

Fig. 2: Low–contrast phantom (seen from the side) with holes of different diameters (range 1.0–4.0 mm) and depths (range 0.5–2.0 mm).

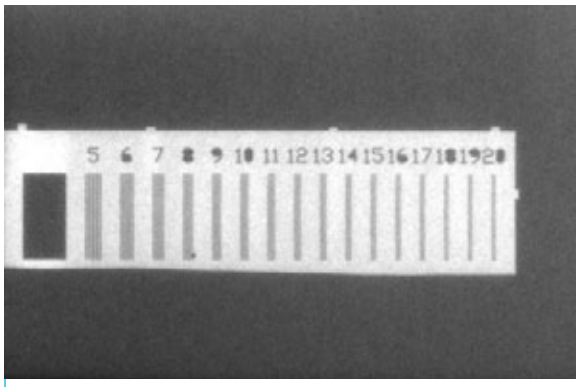

Fig. 3: High-contrast phantom with different numbers of line-pairs/mm.

All images, including test images and radiographs of the two phantoms, were imported to the dentists' computer. The general practice dentists and the two visiting persons evaluated all radiographs of the phantoms. The number of holes in the low-contrast phantom and the number of line-pairs/mm on the high-contrast test phantom that were visible on the monitor were noted. The dentists were allowed to use their image processing programs. After the initial evaluation, monitor brightness and contrast were visually adjusted using the AAPM[13] TG18 test images. The numbers of visible objects were again noted.

Paper IV

One hundred extracted human were included in this study. The teeth were mounted in blocks together with a 1 cm thick plate of Plexiglas to simulate soft tissue, 30 total, were radiographed in a standardised way. All evaluations of the radiographs were made on the same colour monitor (Dell 456, Dell Inc., Round Rock, Texas, USA), which measured 48 cm diagonally. Monitor contrast and brightness were visually adjusted with the aid of the AAPM[13] test images and thereafter locked. Luminance was checked to ensure it was the same before each observation.

Image brightness and contrast were altered in a standardised way using the software Paint Shop Pro 4 (version 4.12 Shareware, Jasc Inc., Eden Prairie, Minnesota, USA). To evaluate how changes corresponded to actual differences in monitor brightness and contrast, test images TG18-LN12-01, -09, and -18 (Fig. 4) were measured on the monitor with a luminance meter (model LS-100, Konica-Minolta, Langenhagen / Hanover, Germany). A brightness change of ± 25 % in Paint Shop mimicked a brightness change of ± 50 % on the monitor while a contrast change of ± 25 % in Paint Shop mimicked a contrast change of ± 6 % on the monitor.

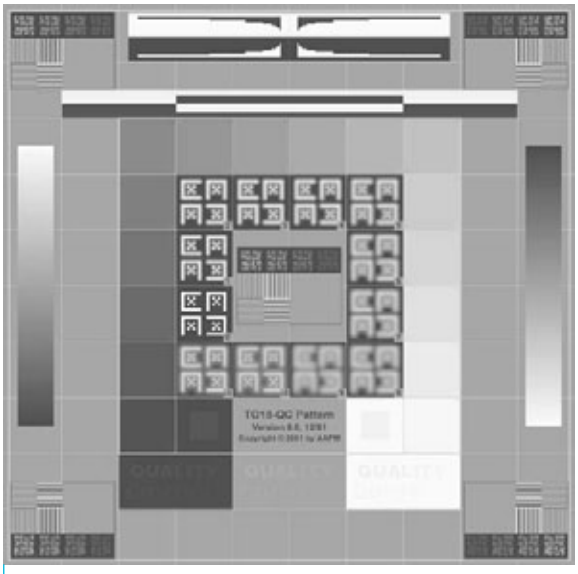

Fig. 4: TG18-QC: Test used to evaluate five different areas visually. The two horizontal arrows indicate smaller differences in contrast as small squares inside bigger squares. The three vertical arrows point to the text "Quality control". The pattern has been contrast enhanced.

Seven observers evaluated the radiographs on two different occasions. The first evaluation was made with an illuminance as close to as possible to, but not exceeding, 50 lux and the second with an illuminance as close as possible to, but not less than, 1000 lux. The observers were asked to record their level of confidence on a 5-point graded scale where 1 was definitely not caries and 5 was definitely caries.

To determine the true condition of the approximal surfaces – whether they were sound or carious – the teeth were histologically examined.

ROC analysis

Observer performance at all monitor settings of brightness and contrast and differences in illuminance were compared using Receiver Operating Characteristic (ROC) curves[16] with the histological evaluation as the gold standard[17].

Statistical analysis

The paired t-test[18] was used to analyse the areas

under each ROC curve with the hypothesis that there were no differences in ability to diagnose carious lesions in a room with an illumination of 50 lux or 1000 lux with different monitor brightness and contrast settings. Differences were considered significant if $p \leq 0.05$.

Results

Paper I

Of the 540 treatment plans sent to the Dental Insurance Office and selected for this study in 2002 150 (28 %) contained radiographic images that were unacceptable for diagnostic evaluation concerning the proposed treatment. The most frequent error was projection errors, for both digital and film radiographs.

Based on errors per image, digital radiographs were unacceptable for diagnosis significantly more often ($p < 0.01$) than film radiographs. Digital radiographs were significantly inferior ($p \leq 0.001$) to film radiographs for all criteria except density.

Paper II

The questionnaire was answered by 130 (94 %) of the general practice dentists who had reported that they worked with digital radiography. Most (92 %) worked with CCD/CMOS sensors and only a few (8 %) used SPS. Most respondents were satisfied with digital radiography. But many dentists (65 %) did experience problems. The most frequently described problem was that the detector did not work. Due to different problems, 35 % of the respondents also used film radiography. Only 40 % replied that any kind of quality control was carried out on their digital system. This was mostly done by technicians from the vendor once or twice a year. The general practice dentists were often unaware of the purpose and type of the quality controls.

Paper III

Nineteen general practice dentists were visited at their clinics; 18 used colour LCD monitors and one a colour CRT monitor. Only six screens were clean. Placement of seven of the monitors was such that ambient light reflected on the screen, even when the power was on.

How well the test images and radiographs of the phantoms could be seen differed greatly between clinics. Brightness and contrast settings on all but one monitor had to be adjusted to improve image quality. The most frequent changes made to improve an image were to decrease brightness and contrast from initial values. Table 1 summarises the evaluation of the test images TG18-AFC (Fig. 5) and TG18-QC (Fig. 6) before and after the monitor was adjusted.

	Number of monitors (n=18)	
Visible test area	**Before calibration**	**After calibration**
TG18-AFC		
4 quadrants	6	11
3 quadrants	10	7
2 quadrants	2	-
TG18-QC		
contrast square, right side	12	17
contrast square, left side	14	18
QC, right side	4	14
QC, middle	8	17
QC, left side	11	14

Tab. 1: Number of monitors on which the test areas in the two test images TG18–AFC and TG18–QC could be seen before and after visual calibration of brightness and contrast (QC = the text "Quality control").

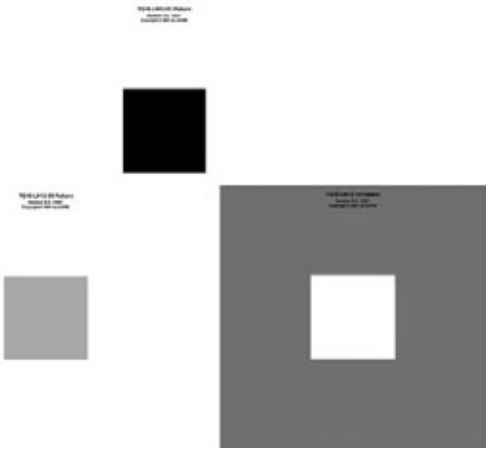

Fig. 5: Test images TG18–LN12–01, –09, –18: Luminance was measured inside each of the quadrants in the middle of the images.

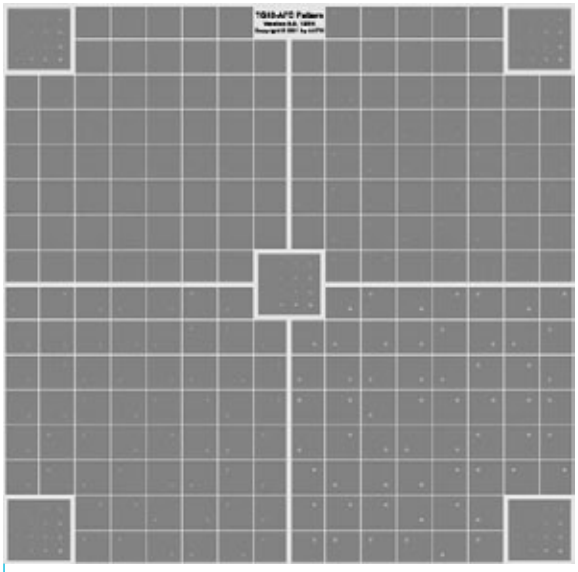

Fig. 6: TG18–AFC: Test pattern for visual assessment of contrast and detail. The image is divided into four quadrants. Inside each quadrant are squares containing small spots. The observer should evaluate in how many of the four quadrants the spots can be seen. The pattern has been contrast enhanced.

Average illuminance in the rooms where the images were being evaluated was 668 lux (range 190 to 1250 lux). The ability to observe the holes in the radiographs of the low-contrast phantom image taken at the clinic decreased as illuminance increased.

Paper IV

The histological examination showed that 100 approximal surfaces of the teeth were sound and 100 had different depths of carious lesions (Tab. 2).

Lesions (grade)	No. of surfaces	Per cent
Sound (0)	100	50.0
Enamel caries (1)	75	37.5
Border of enamel-dentin (2)	14	7.0
Dentin caries (3)	11	5.5

Tab. 2: Results of the histological evaluation of the approximal surfaces of the teeth (in total 100 teeth).

For each monitor brightness and contrast setting, the mean areas under the ROC curves were smaller with an illuminance of 1000 lux.

Differences between observations made in 50 lux and in 1000 lux with an optimally adjusted monitor were significant for all types of carious lesions ($p < 0.01$) and for carious lesions in the dentine ($p < 0.02$). Differences between observations made in the two light levels were also significant for enamel ($p < 0.01$) and for all types of carious lesions ($p < 0.02$) on a monitor with a slightly higher contrast setting (6 %).

Discussion

The overall aim of this thesis was to evaluate the use of dental digital radiography by general practice dentists. The main concern was image quality and its relation to some important factors in the digital systems that affect the making of adequate diagnoses. Different methods were used to measure and evaluate digital image quality and some key technical parameters in the digital technique.

Comparing studies on image quality in general dental practice is difficult. How the criteria for evaluating radiographic image quality is perceived by the observers is also difficult to explain, and the criteria used in different studies is often not comparable. The digital images in paper I showed that the dental staff had trouble placing the detector correctly, regarding both position and angle. The most common error was vertical misalignment[19] concluded that bitewing radiographs were more difficult to position in the vertical direction when CCD sensors were used than SPS plates. The sensor's small size increases the risk of incorrectly positioning the sensor; areas of interest. Such geometric difficulties, combined with a limited understanding of the possibilities and limitations of digital systems, hamper their proper use.

One great advantage of digital radiography compared to conventional film is the lower amount of radiation needed for each exposure when CCD or CMOS sensors are used. Several studies report considerable decreases in dose[4, 20] with digital detectors. Almost all dentists in study II reported that they had decreased exposure time by at least 50 %. At the same time 35 % of the dentists in the study believed that they made more digital than conventional film retakes. The question, then, is how many retakes were made to achieve the same diagnostic accuracy as with film? Does the dentist expose so many more digital than conventional radiographs that the patient receives similar amounts of radia-

tion in both procedures? A Dutch study[21] reported that dentists believed they needed to take more digital radiographs to improve their confidence in their treatment or to improve the accuracy of their diagnosis than they would have needed conventional radiographs. The same study concluded that the dentists believed that the lower doses of radiation used in digital radiography allowed more radiographs to be exposed without an increase in the absorbed dose to the patient in comparison to conventional radiography. From a radiation protection viewpoint, this is an unfortunate assumption and, at least in Sweden, clearly violates the law concerning radiation protection of the patient. Information and knowledge concerning radiation protection and how to produce digital radiographs with good image quality must improve. The studies in this thesis demonstrated that these intentions (year 2007) are far from fulfilled.

Digital image quality depends on several parameters. The monitor is probably one of the weaker links[22]. It seems that most general practice dentists use a standard colour monitor with standard luminance (100 to 200 cd/m^2). The monitors were usually adjusted for viewing standard colour images and text. We studied the effects of different brightness and contrast settings of the monitor[Paper IV] and found that the most accurate diagnosis of carious lesions was made when viewing the radiograph on a monitor that had been optimally adjusted with AAPM[13] test images or that had slightly higher contrast settings.

An issue that should be addressed in the future is whether use of a monitor of higher quality than a standard monitor will affect diagnostic outcome. Another question is whether a calibration standard as given in DICOM part 14 (Digital Imaging and Communications in Medicine)[23] is necessary for a monitor used in dental care. Most monitors in medical radiology are calibrated according to DICOM 1423; the same quality aspects should be applied to the monitors used in dental radiography.

External factors such as ambient light[11, 14] and screen reflections also need to be considered. The hypothesis that bright ambient light in the evaluation room hampers radiographic caries diagnoses was supported in study IV, where the AAPM[13] recommendations were followed. It was found that significantly more accurate caries diagnoses were made in a room with low illuminance. Even though carious lesions in general are difficult to diagnose radiologically[7], study IV showed that, for all of the monitor brightness and contrast settings used, the observers seemed to do better in a room with low illuminance. Studies III and IV conclude that if the dentist chooses to remain in the operating room to view radiographs, the level of light must be low.

These conclusions can be drawn from the studies in this thesis on digital radiography in general dental practice:

- The radiographic documentation accompanying treatment plans sent to the Dental Insurance Office must be improved, and because the quality of digital radiographs was lower than that of conventional radiographs, general practice dentists must improve their knowledge of digital radiography and undergo more training.
- Most general practice dentist respondents were satisfied with the quality of their digital images. But many experienced problems. Less than half of them were aware of the need for routine quality control of their digital system. These results imply that the need for quality control measures and other adjuncts to improve digital image quality is great.
- The ambient light level in the operation room affected the accuracy of approximal caries diagnoses. Accuracy was higher when ambient light levels were low compared with when ambient levels were high. So digital radiographs displayed on a standard monitor should be evaluated in illuminances lower than 50 lux.
- The accuracy of approximal caries diagnoses is higher when monitor brightness and contrast have been set at levels that are optimal for the task. So standardised monitor settings for special tasks such as caries diagnosis need to be determined.

This thesis is a supplement to Swedish Dental Journal 184, 2007.

Papers

This thesis was based on the following papers:

[Paper I] **K. Hellén-Halme, P. M. Johansson, J. Håkansson, A. Petersson:** Image quality of digital and film radiographs in applications sent to the Dental Insurance Office in Sweden for treatment approval. Swed Dent J 2004; 28: 77-84.

[Paper II] **K. Hellén-Halme, M. Rohlin, A. Petersson:** Dental digital radiography. A survey of quality aspects. Swed Dent J 2005; 29: 81-7.

[Paper III] **K. Hellén-Halme, M. Nilsson, A. Petersson:** Digital radiography in general dental practice. A field study. Dentomaxillofac Radiol 2007; 37: 1-7.

[Paper IV] **K. Hellén-Halme, A. Petersson, G. Warfvinge, M. Nilsson:** Effect of ambient light and monitor brightness and contrast settings on the detection of approximal caries in digital radiographs. An in vitro study (accepted to be published Dentomaxillofac Radiol 2007).

The bibliography can be requested from the editorial office.

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update

Guided Surgery

Am 18. und 19. April 2008 findet im Maritim Hotel in Berlin das 13. DENTSPLY Friadent World Symposium 2008 statt. Das wissenschaftliche Programm bietet implantologische Fachvorträge zu aktuellen Themen wie Platform Shifting, Fallbeispiele bewährter und neuer Behandlungskonzepte sowie die Präsentation von Langzeitstudien. Neben dem Besuch der Vorträge wird die Möglichkeit des Erfahrungsaustauschs „Face-to-face" mit Referenten und Spezialisten beispielsweise im Rahmen von Hands-on-Kursen geboten. Neuentwicklungen des Unternehmens wie die stepps® Praxismarketing-Plattform können die Teilnehmer selbst am Computer erproben. Einen besonderen Schwerpunkt wird das Thema Guided Surgery darstellen. Das neue Planungsprogramm EXPERTEASE wird vorgestellt und dessen Anwendung kann ebenfalls vor Ort getestet werden. Zum Abschluss des Symposiums wird an den Veranstaltungsort die mit EXPERTEASE computergestützte Live-OP von Dr. Dr. Michael Stiller aus Berlin übertragen.

Die Teilnahmegebühren betragen für Zahnärzte und Zahntechniker 695,- Euro, für zahnärztliche Assistenzkräfte 200,- Euro, für Universitätsassistenten 250,- Euro und für Studenten 70,- Euro. Deutsche Teilnehmer erhalten bis zu 12 Zertifizierungspunkte gemäß der Punktebewertung der BZÄK und DGZMK.

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