

# The British Journal of Radiology

---

## Review article: Radiation protection in dental radiology\*

K HORNER, FDSRCPS, DRRRCR

Unit of Oral Radiology, University Dental Hospital of Manchester, Higher Cambridge Street, Manchester M15 6FH, UK

### Abstract

Dental radiology represents the most frequent diagnostic radiological investigation in the industrialized world, with over 16 million examinations performed annually in England and Wales alone. Although individual doses and risks are low in dental radiography, the collective dose is not inconsiderable and many examinations are performed in younger age groups. Radiation protection of patients in dental radiology is achieved in three ways: by appropriate selection criteria for patients and equipment, methods of dose limitation and quality assurance procedures. There is a lack of agreed radiographic selection criteria to guide British dentists and this may lead to overuse of certain techniques, principally panoramic radiography. In intraoral radiography the use of fast (E-speed) film and rectangular collimation offer dose reductions of approximately 50% and 60%, respectively. Constant potential X-ray units and rare-earth filtration permit further reductions. In panoramic and cephalometric radiography, improved collimation offers a simple means of dose limitation, while doses can be reduced by up to one-eighth by combining the use of constant potential X-ray units, rare-earth intensifying screens and rare-earth filtration. Lead protection of the abdomen has little relevance to radiation protection; however, thyroid shielding has some value. Concern has been expressed about the poor diagnostic quality of radiographs taken in the general dental services. Consequently a quality assurance programme plays an essential part in dental radiation protection by improving diagnostic yield and limiting repeat examinations.

Analysis of the statistics of the Dental Practice Board of England and Wales [1] over the 1980s demonstrates a steady growth in dental radiology (Figure 1). In 1980 over 11 million dental radiographic examinations were performed; currently the annual figure is approximately 15 million. These figures are limited to National Health Service (NHS) general dental practice in England and Wales, excluding other parts of the kingdom and work carried out in private practices, hospitals and the community service. The true figures for the scale of dental radiology are clearly even greater, but have been estimated to represent approximately 25% of the total

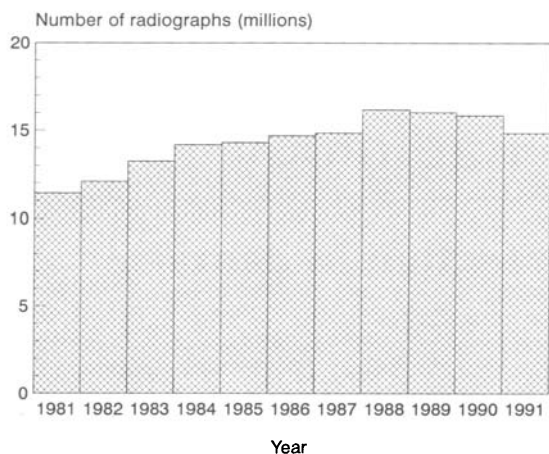
annual frequency of all medical X-ray examinations [2]. Dental radiology almost exclusively comprises plain radiographic examinations, almost 90% of these being simple bitewing or periapical views [1]. Panoramic radiography is the second most common form of examination, with the remainder consisting occlusal, oblique jaw and cephalometric radiography.

Although the numbers of examinations are considerable, the radiation doses in dental radiology are individually very small. In 1983 Wall and Kendall [3] assessed the weighted dose equivalents for typical dental examinations carried out using standard equipment and facilities at the time. They calculated the weighted dose equivalent from a single dental intraoral radiograph to be 10  $\mu$ Sv and that from a panoramic radiographic examination to be 80  $\mu$ Sv. Such dose levels are a fraction of annual background and lower than those received in most medical radiological examinations. Furthermore, Hughes et al [2] estimated that dental radiology

---

*Received 12 November 1993 and in revised form 9 February 1994, accepted 15 February 1994.*

\*This article is based on an invited lecture at Radiation & Oncology '93 (51st Annual Congress of the British Institute of Radiology), Glasgow, 18 May 1993.



**Figure 1.** Numbers of radiographs (panoramic and all other types) taken in general dental practice in England and Wales (1981–1991/2). Data from reference [1].

contributes only a small proportion, around 200 man-Sv, to the total annual collective dose in the UK. Despite this, there are still concerns about dose levels in dental radiology. This is for several reasons. First, unlike medical radiology, where the benefits from diagnostic X-ray examinations may be of great significance to the management of life-threatening conditions, dental radiology is rarely of such immediate and tangible benefit to patients. Secondly, a high proportion of dental radiography is carried out in children and young adults, where the risks from X-ray exposure may be twice as high [4]. Thirdly, and perhaps most disturbingly, there is considerable evidence that many patients are subjected to unnecessarily high radiation doses during dental radiography because of unsatisfactory equipment, outdated techniques and inadequate processing of films in general dental practice. For example, Hewitt et al [5], reporting the results of the National Radiological Protection Board (NRPB) dental monitoring service, stated that for 40% of X-ray sets tested the exposures that were used by the dentists exceeded the optimum, presumably because of routine underdevelopment. Allied to the latter point is the evidence that many dental radiographic examinations result in images of poor or non-diagnostic quality. Rushton [6], in a small survey of periapical radiography in Cheshire, found that 44.5% of films were diagnostically unacceptable due to errors in technique, while Smith et al [7], in a large survey of panoramic radiographs from general dental practices, found 25.9% were entirely non-diagnostic. Clearly, in such cases patients are receiving no benefits from the X-ray examination, and the exposure and risks are unacceptable.

Radiation risk assessment from dental radiography was the subject of a recent excellent review by White [8]. The principal risks are those of cancer induction, notably leukaemia and in susceptible organs in the face and neck such as the thyroid, parotid glands and oesophagus. Estimates of risk are usually derived from studies of

individuals exposed to high doses of radiation, but some studies [9, 10] have associated previous exposure to multiple dental radiographic examinations with a higher incidence of salivary gland and brain tumours.

These points, allied to the scale of use of dental radiography, mean that the need to keep all exposures as low as reasonably practicable is as pertinent to dental as it is to medical radiology. The recent establishment of a Royal College of Radiologists and NRPB Joint Working Party on Dental Radiology is evidence of the concern over radiological practices in dentistry. In this paper the main methods whereby radiation protection of dental patients can be achieved are presented.

### Selection criteria

It is fundamental to the practice of radiation protection that all exposures to ionizing radiation should be clinically justified. Having made the decision to carry out radiography the clinician may then be faced with a choice between several imaging techniques. The type of examination selected should be that which is most likely to produce a high diagnostic yield of significance to treatment while exposing the patient to the lowest practicable dose.

There has been little published work on formalizing selection criteria for dental radiography in the UK. However, in the USA the Department of Health and Human Services established an expert panel to develop such criteria in 1983. Their work culminated in the publication of a strategy for radiological management of patients seeking dental treatment in 1987 [11]. The American panel approached the challenge by categorizing patients according to specific clinical situations, type of visit (new or recall patient), stage of dental development and, in the case of dental caries assessment, the presence of risk factors (e.g. oral hygiene, exposure to fluoride). This introduces a sensitivity to variations in patient needs: for example, in the case of caries assessment the criteria accommodate the likelihood that a bitewing examination in an individual in a "low risk" group may be indicated only once every 3 years, while the time interval may be reduced to every 6 months for a child with "high risk" factors for dental caries.

Inevitably these criteria are appropriate to disease prevalence and incidence in the USA and are influenced by previous accepted practice amongst American dentists. Thus the detailed recommendations may be inappropriate for adoption in the UK. However, the philosophy underlying the development of the selection criteria is commendable and would provide a useful model for this country.

In the UK efforts to produce radiographic selection criteria have been made by specialists such as the British Association of Oral and Maxillofacial Surgeons [12] and the British Endodontic Society [13] and also by individual clinicians [14]. Such developments are welcome, but there is a need to co-ordinate specialist groups and societies, Royal Colleges and professional associations to produce selection criteria that are acceptable to the whole dental profession.

The steady rise in the numbers of panoramic radiographic examinations has already been referred to. Dentists working within the NHS are advised by the Dental Practice Board of England and Wales that: "The Board are of the opinion that the taking of a panoramic radiograph may be appropriate for the examination of a patient new to the practice, or for a patient for whom a comprehensive radiographic examination has not previously been undertaken at the practice" [15]. Although these comments are meant only as guidelines, it is likely that many dentists will perceive them as "selection criteria" and routinely carry out panoramic radiography of any new patient, regardless of clinical indications and the likely diagnostic yield. "Screening" radiography of this kind inevitably leads to unnecessary patient exposure and risk.

The common dental diseases (caries, periodontal disease and periapical pathology) have been shown to be visualized more accurately by intraoral (bitewing and periapical) radiography than by panoramic radiography [16, 17]. However, one study [18] in the UK causes particular concern as it demonstrated that 57% of patients had only a panoramic radiograph taken at their initial examination, and for 50% of these, the main reason for taking the radiograph was caries diagnosis.

Some clinicians attempt to justify the use of screening panoramic radiography on the basis of the detection of "occult" pathology (lesions not associated with symptoms and signs). This stance ignores the prevalence of lesions, the probability of a lesion arising without signs or symptoms, the clinical consequences if a lesion went undetected and, most importantly, the consequences of detection of a lesion on treatment. The detection of occult lesions that do not require treatment does not justify a "screening" examination [11]. Furthermore, the prevalence of unsuspected lesions of major clinical significance is extremely low [19].

The Dental Practice Board also advises that "... a panoramic radiograph could be an aid to examination/diagnosis when considering the need for orthodontic treatment (this normally applying to patients of 8 or 9 years of age, when they can be expected to be into the mixed dentition stage)" [15]. The need to take a panoramic radiograph for an orthodontic assessment of 8 or 9-year-old patients can be questioned when it is remembered that orthodontic treatment may not be carried out until children reach 11–12 years of age. This often means patients undergo a second panoramic examination to update the information on the earlier film. Replacing a practice of screening panoramic radiography for orthodontic purposes at 8 or 9 years with selective radiography at 11 or 12 years has been shown by Hintze et al [20] to identify effectively the vast majority of those in need of orthodontic treatment while excluding those without an orthodontic problem.

As with all radiological examinations, the use of panoramic radiography should be based on specific selection criteria which are likely to result in both a high

and significant diagnostic yield and the minimization of unnecessary exposures [16, 21, 22].

### Methods of dose reduction

#### *X-ray generation*

Until recently, dental X-ray sets in Europe were manufactured to operate at low kilovoltages, at 50 kV or even lower. Such X-ray units are associated with high surface doses and higher kilovoltage units have been manufactured as a means of dose reduction. Currently, British dentists are advised [23] to acquire sets operating at 70 kV, while Swedish legislation permits a minimum of 60 kV. This increase in kilovoltage is a simple way of reducing surface dose. However, the choice of around 70 kV as "ideal", rather than an even higher operating potential, is made for two main reasons. First, although surface dose can be reduced by increasing the kilovoltage of X-ray generation, it is an unreliable indicator of total absorbed dose [24]. Wall et al [25] found lower values for integrated dose in the head and neck at 45 kV than at 65 kV, reflecting the increased deep penetration associated with higher energy beams. Furthermore, increasing the kilovoltage far beyond 70 kV would result in a beam spectrum ill-matched to the optimal sensitivity [26, 27] of dental non-screen film. While dose is important, so is the diagnostic quality of the image. High contrast images associated with lower kilovoltages are most appropriate for dental caries diagnosis [28–31], while the lower contrast found with 80 kV X-ray sets is said to offer superior visualization of the thin bone of the alveolar crest in imaging for periodontal disease [32, 33]. Overall, the 70 kV sets currently advocated in British guidelines [23] to dentists probably represent the most reasonable compromise choice in terms of limiting dose and all-round diagnostic efficacy.

Until relatively recently, all dental X-ray sets were fixed kilovoltage, half-wave self-rectified units with sinusoidal potentials giving pulses of X-ray production synchronous with AC mains supply. However, in addition, because the effective kilovoltage in the X-ray tube is usually lower than the stated kilovoltage, the X-ray beam contains a proportionately high level of low energy, "soft" X-rays. Recently, constant potential or "DC" X-ray sets, such as the Intrex (Keystone X-ray Inc., Neptune, NJ, USA), the Minray (Soredex Orion Corporation, Helsinki, Finland), the Heliodent MD (Siemens, Sunbury-on Thames, UK) and the Phot-X (Takara Belmont Co. Ltd., Osaka, Japan) have been developed for dental work. Several panoramic X-ray units are also manufactured with this mode of X-ray generation. The constant potential across the X-ray tube results in a proportionately smaller level of low energy X-rays. In addition, McDavid et al [34] showed that the average X-ray energies from the Intrex are in the range 37.5–40 keV, corresponding fairly well to the optimum spectral sensitivity of dental non-screen film determined by Richards et al [26] and by MacDonald et al [27]. Consequently, dose reductions for dental and panoramic radiology are to be anticipated with the use of DC generators. This has been confirmed for intraoral

radiography by McDavid et al [34], who found that skin doses could be reduced by about 25% using the Intrex. Good image contrast is essential for radiographic caries diagnosis, but unfortunately the use of constant potential X-ray sets results in a loss of contrast. However, the latter was shown not to be of practical significance [35]. For panoramic radiography, Stenstrom and colleagues [36] demonstrated that the Orthopantomograph Model OP10 (Siemens, Sunbury-on-Thames, UK), which incorporates a constant potential generator, was associated with a reduction in energy imparted of one-half compared with the same manufacturer's Model OP5 using a conventional generator.

#### Filtration

Ideally the diagnostic X-ray beam should be matched in energy range with the optimal spectral sensitivity of the image receptor used. The optimal sensitivity of dental film is in the 35–55 keV range [26], with a peak sensitivity of 40–45 keV for E-speed film [27]. An ideal X-ray filter would tailor the X-ray beam to remove not only the “soft” X-rays but also those photons whose energy is outside the optimal sensitivity range of the film. Rare-earth materials can act in this fashion by virtue of their K-shell absorption edge on their photoelectric absorption curve. The role of rare-earth filters in general radiology has been questioned by Koedooder and Venema [37] and Nagel [38], who found that conventional filters can achieve similar levels of dose limitation at a lower cost. However, Nagel [38] did express the view that K-edge filters did offer advantages “when imaging thin objects, *i.e.* in dental radiology”. There is a large dental literature on rare-earth filtration, the interpretation of which is limited by the problems of correlating studies having different methodologies: a variety of rare-earth materials and different thicknesses of filter have been used; sometimes the filter material was added to the conventional aluminium filter and sometimes it was an alternative to it; different kilovoltage X-ray generators are used, etc. Nevertheless, most show that significant dose reductions can be achieved with rare-earth filtration, mostly without a deleterious effect on image contrast. This has led to some vigorous marketing of filters, such as the Niobi-X niobium filter (Rad/Red Laboratories Inc., Toronto, Canada). The cost of these rare-earth materials is a real barrier to their widespread use. White and Gratt [39], while demonstrating the efficacy of this material as a means of dose reduction, questioned its cost/benefit. However, Kodak now produce a cheap means of rare-earth filtration for dentists in the form of a piece of intensifying screen, which can be cut-to-size to fit most dental sets. This is primarily manufactured to make it possible for dentists using X-ray sets with timers that are inaccurate at very short exposure times to use fast film. Nevertheless, it also appears to be an effective means of dose reduction: Kapa et al [40] showed that a piece of Lanex screen used as additional filtration can reduce skin exposure by 50% while still permitting diagnostically acceptable images. Similar levels of dose reduction have been reported for

panoramic radiography [41] and for cephalometric radiography [42].

#### Collimation

Traditionally, round collimation is used for intraoral radiography. Current statutory guidelines set a maximum diameter beam of 6 cm. However, a circular beam of this size is 135% larger in area than a conventional dental film packet (3 cm × 4 cm), indicating an obvious way of reducing patient dose. Rectangular collimation can be achieved using either a suitably shaped collimator cone on the X-ray set or a film holder incorporating a steel plate with an appropriately sized window (Figure 2). Various workers have estimated that rectangular collimation can achieve dose reductions exceeding 60% in dental radiography [43–48], the variation in dose reduction reflecting whether the comparison is made with a 7.5 cm or a 6 cm round beam. Despite the fact that this method of dose reduction is simple, very few dentists use it. This is for two reasons. Few manufacturers offer rectangular collimation; those that do simply offer it as an alternative to the conventional round beam. Secondly, its use necessitates the use of film holders to avoid “coning off” the film. Few dentists routinely use film holders, either because of ignorance of their existence or a reluctance to pay for them. The widespread use of rectangular collimation is unlikely to be achieved except by a marked improvement in postgraduate and undergraduate “hands-on” radiological teaching.

Panoramic radiography was originally designed as a means of examining the whole of the mandible, maxilla and their respective dentitions. However, the area radiographed is frequently far in excess of that of diagnostic interest. Dentists had no facility for reducing the field irradiated. However, several machines now offer

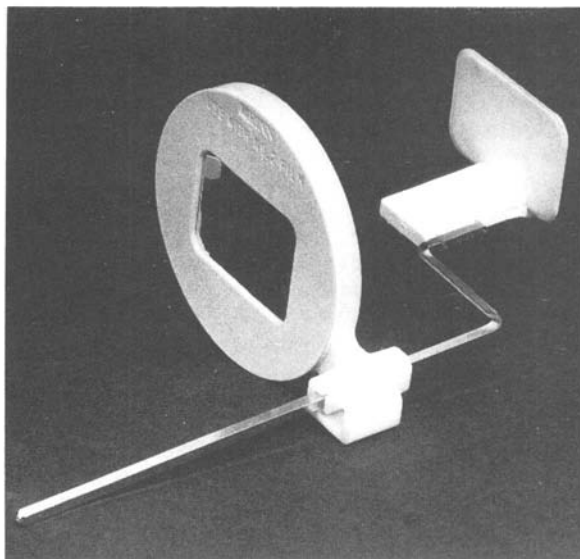


Figure 2. Film holder (Rinn Corporation, Elgin, Illinois) incorporating a rectangular collimator.

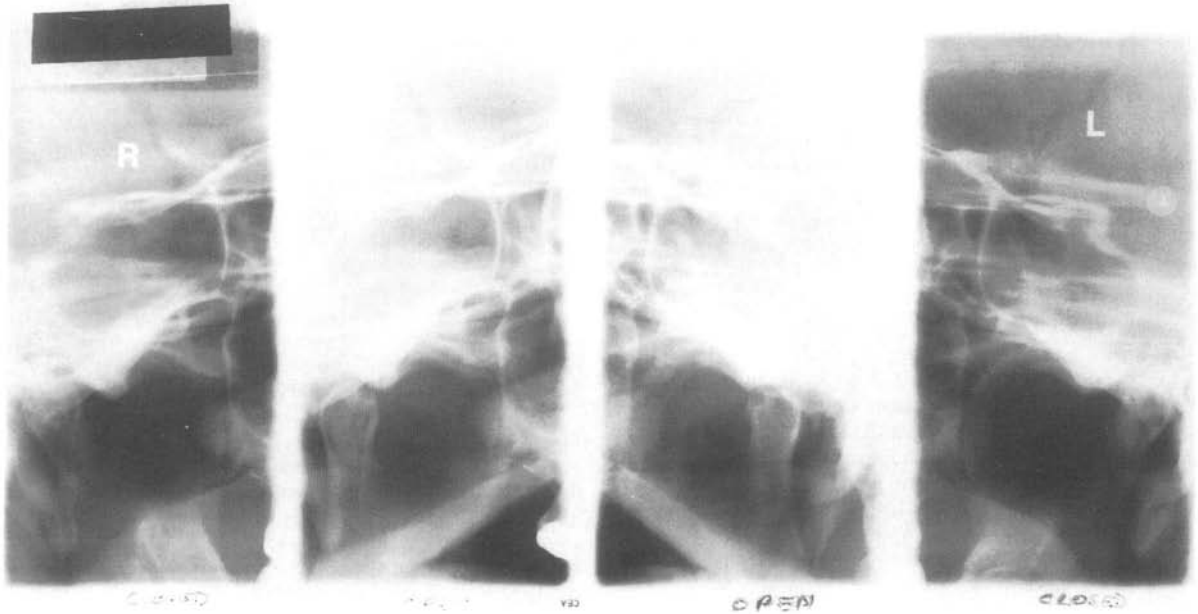


Figure 3. Temporomandibular joint images produced on the Cranex DC3 panoramic using programmed field-size trimming.



Figure 4. Lateral cephalometric radiograph of the head carried out using a wedge-shaped collimator. This limits the area irradiated to that required for cephalometric tracing and analysis.

programmed field-size trimming as a means of reducing patient dose. Both the Cranex DC3 (Soredex Orion Corporation, Helsinki, Finland) and the Planmeca 2002CC (Planmeca, Helsinki, Finland) have a child imaging mode, which reduces the exposed area in the vertical plane by 27%. The latter machine also has a mechanically driven horizontal collimator so that the total reduction in field size is 45%. The Orthoralix (Philips, London, UK) has a "dentition-only" mode offering similar reductions in the exposed area. Some units offer more sophisticated programmes to permit imaging of individual jaw segments and temporomandibular joints (Figure 3). In a recent study, Lecomber and Faulkner [49] reported that by using a field size programme on the Orthophos X-ray unit (Siemens, Bensheim, Germany) limited to the tooth-bearing regions of the jaws, effective dose could be reduced by more than 50%. Such facilities offer a simple way of reducing dose and the purchase of machines with these facilities should be encouraged.

Cephalometry traditionally produces images of the entire head and much of the cervical spine. However, the area of interest to orthodontists usually stops at the level of the base of the skull. This anomalous situation was addressed by the Joint Working Party of the British Society for the Study of Orthodontics and the British Society of Dental and Maxillofacial Radiology [50]. They recommended a simple wedge collimation to exclude the unwanted regions from irradiation (Figure 4). This system has been adopted in many hospitals, but its widespread introduction has been hindered by the failure of manufacturers of cephalometric equipment to include this form of collimation as standard. Soft-tissue profile enhancement using wedge filters is usual on lateral

cephalometric radiographs. Some dose reduction can be included by placing the filter between the patient and the X-ray source rather than on the cassette.

#### *The image receptor*

For intraoral radiography, the standard method of recording the image has, since 1919, been machine-wrapped non-screen film. There have been steady improvements in film speed over the years and E-speed represents the current fastest film available. An even faster, F-speed film, Dentus M4 (Agfa-Gevaert, Antwerp, Belgium), was recently introduced but subsequently withdrawn, possibly because of its reduced diagnostic accuracy for approximal caries diagnosis [51].

E-speed film requires about 50% less exposure than its predecessor to achieve the same optical density, a difference that Kaffe et al [52] showed to be consistent over the range of kilovoltages commonly used on dental X-ray sets. Despite this film being introduced in 1981, it is still used by a minority of dentists [53,54]. This may be for several reasons. First, both D and E speed continue to be marketed and "brand loyalty" may play a part in a resistance to change. Secondly, many older dental sets are not fitted with timers capable of the short exposure times required with E-speed film, although Ponce et al [55] pointed out that extra filtration could be used to avoid this problem. Finally, E-speed film has a lower contrast and higher fog level than D-speed film [56–58]. In addition, some workers report an increased "graininess" of images with E-speed film [57,59]. Poor quality clinical images with E-speed film probably result from less than ideal storage and processing conditions. This, in turn, may contribute to the disappointingly slow conversion to E-speed film among clinicians. However, a large literature comparing film speeds for a range of applications has demonstrated no significant loss in diagnostic quality [31,59–67]. The use of E-speed film costs no more than D-speed film and thus offers the most cost-effective means of dose reduction in dental radiography. Consequently, the statement of Gibbs et al [68] that "the use of D-speed film can no longer be justified" is undeniable. However, successful change to the faster film depends on careful attention to storage, film handling and processing.

Until recently the availability of alternative image receptors for intraoral radiography was extremely limited. Despite favourable early experience with dental xeroradiography, which offered wide exposure latitude and edge enhancement, the system is no longer marketed commercially. The use of screen-film combinations for intraoral work has never gone beyond the research stages. However, the past 5 years have seen a very real challenge to non-screen film. Direct digital intraoral radiographic systems, using charge-coupled devices, are now marketed by four companies. Such systems have still to be evaluated fully and compared. However, they offer the potential of substantial dose reduction. Radio-VisioGraphy (Trophy Radiologie, Vincennes), the first commercially available system (Figure 5), was shown to require only 41% of the exposure required for conven-



**Figure 5.** The RadioVisioGraphy system for direct digital dental imaging. The system consists of an intraoral charge-coupled device sensor and a processing unit with monitor.

tional radiography using E-speed film [69,70]. A more recently developed system, the Sens-a-ray (Regam Medical Systems, Sundsvall, Sweden), gave speed values of over three times that of E-speed emulsion [71]. Currently the limitation of the systems available is sensor size, which is smaller than that of a dental film packet. Thus more than one exposure may be required to cover the anatomical area imaged using a single conventional film and, unless strict collimation is used, the dose advantage of digital systems may be lost. Furthermore, problems with positioning sensors have been reported as leading to a high reject rate [69]. Nevertheless, it seems likely that in due course digital systems will displace film as the standard image receptor for intraoral imaging.

The introduction of rare-earth film-screen combinations has been shown to give dose reductions of around 50% for panoramic and cephalometric radiology [72,73] with Lanex regular screen in combination with T-Mat-L being the receptor of choice for the latter [42,73].

#### *Lead shielding*

The use of lead aprons in dental radiography is commonplace. Despite the extremely small gonadal dose associated with dental radiography, the use of lead aprons has been recommended on the grounds of patient reassurance. However, it has been shown that gonadal doses are not significantly different in dental radiography with and without a lead apron [74]. In contrast, the thyroid gland, one of the more radiosensitive organs in the head and neck region, is frequently exposed to scattered radiation and occasionally to primary beam during dental radiography. Thyroid shielding reduces dose to this organ by about half [48]. However, it is probable that rectangular collimation for intraoral radiography offers similar levels of thyroid protection to lead shielding, in addition to its other dose reducing effects. Clearly, lead protection is of relatively low importance in radiation protection for dental radiology. Thyroid shielding is inappropriate for panoramic radiography

because of the well-collimated beam and its direction; for cephalometric radiography additional shields may be of use where the beam collimation does not exclude the thyroid.

### Quality assurance

Studies in both the USA and Europe consistently report that many dental radiological examinations result in poor quality or non-diagnostic images, because of both poor radiographic technique and inadequate processing [6,7,75–79]. Efforts at reducing dose by such methods as increased film speed and collimation are ineffective if examinations are subsequently performed to an unacceptable standard. Thus quality assurance programmes form an essential component of radiation protection in dental radiology.

### Summary

Wall and Kendall [3] estimated the effective dose equivalent for an intraoral radiograph to be 10  $\mu$ Sv. The use of fast film and rectangular collimation can reduce this to around 2  $\mu$ Sv. Constant potential generators, rare-earth filters and digital systems will offer further reductions. In panoramic radiology, Wall and Kendall [3] estimated the effective dose equivalent to be 80  $\mu$ Sv. By using constant potential generators, rare-earth screen–film combinations and rare-earth filtration, this can be reduced by up to one-eighth, with field size trimming offering further reductions. Similar levels of dose reduction are achievable with cephalometric radiology by introducing rare-earth screen–film combinations and strict collimation. However, it is evident that the introduction of radiographic selection criteria and quality assurance programmes will themselves make an essential contribution to achieving optimal radiation protection in dental radiology.

### References

1. DENTAL PRACTICE BOARD, Dental Data Services: Personal communications (Dental Practice Board, Eastbourne) (1993).
2. HUGHES, A P, SHAW, K B, and O'RIORDAN, M C, *Radiation Exposure of the UK Population—1988 Review* (National Radiological Protection Board, HMSO, London), (1989).
3. WALL, B F, and KENDALL, G M, Collective doses and risks from dental radiology in Great Britain, *Br. J. Radiol.*, *56*, 511–516 (1983).
4. SMITH, N J D, Selection criteria for dental radiography, *Br. Dent. J.*, *173*, 120–121 (1992).
5. HEWITT, J M, SHUTTLEWORTH, P G, NELTHORPE, P A and HUDSON, A P, Improving standards in dental radiography. In *Radiation Protection—Theory and Practice. Proceedings of the 4th International Symposium of the Society for Radiological Protection*, ed. by E P Goldfinch (Institute of Physics, Bristol), p. 83 (1989).
6. RUSHTON, V E, *A Comparative Study of Five Periapical Radiographic Techniques in General Dental Practice* (MDS thesis, University of Manchester) (1992).
7. SMITH, N J D, TODD, J, BARSAM, S and McCARTHY, R, Assessment of the quality of panoramic radiographs taken in general dental practice, *J. Dent. Res.*, *72*, 712 (1993).
8. WHITE, S C, 1992 assessment of radiation risk from dental radiography, *Dentomaxillofac. Radiol.*, *21*, 118–126 (1992).
9. PRESTON-MARTIN, S, THOMAS, C C, WHITE, S C and COHEN, D, Prior exposure to medical and dental X-rays related to tumours of the parotid gland, *J. Natl. Cancer Inst.*, *80*, 943–949 (1988).
10. PRESTON-MARTIN, S and WHITE, S C, Brain and salivary gland tumours related to prior dental radiography: implications for current practice, *J. Am. Dent. Assoc.*, *120*, 151–158 (1990).
11. DENTAL RADIOGRAPHIC PATIENT SELECTION CRITERIA PANEL and JOSEPH, L P, *The Selection of Patients for X-ray Examinations*, HHS publication FDA 88-8273 (US Department of Health and Human Services, Public Health Service, Food and Drug Administration, Center for Devices and Radiological Health, Rockville, Maryland), p. 9 (1987).
12. BRITISH ASSOCIATION OF ORAL AND MAXILLOFACIAL SURGEONS WORKING PARTY, *Selection Criteria for Radiography in Oral and Maxillofacial Surgery*, Document distributed to Society members (1992).
13. BRITISH ENDODONTIC SOCIETY, Guidelines for root canal treatment, *Int. Endod. J.*, *16*, 192–195 (1983).
14. PITTS, N B and KIDD, E A M, The prescription and timing of bitewing radiography in the diagnosis and management of dental caries: contemporary recommendations, *Br. Dent. J.*, *172*, 225–227 (1992).
15. DENTAL PRACTICE BOARD, *Guidelines for Panoramic Radiography* (Dental Practice Board, Eastbourne) (1983).
16. VALACHOVIC, R W, DOUGLASS, C W, REISKIN, A B ET AL, The use of panoramic radiography in the evaluation of asymptomatic dental patients, *Oral Surg., Oral Med., Oral Pathol.*, *61*, 289–296 (1986).
17. MUHAMMED, A H and MANSON-HING, L R, A comparison of panoramic and intraoral radiographic surveys in evaluation of a dental clinic population, *Oral Surg., Oral Med., Oral Pathol.*, *54*, 108–117 (1982).
18. OSMAN, F, SCULLY, C, DOWELL, T B and DAVIES, R M, The use of panoramic radiography in general dental practice, *Community Dent., Oral Epidemiol.*, *14*, 8–9 (1986).
19. ZEICHNER, S J, RUTTAMAN, U E and WEBBER, R L, Dental radiography: efficacy in the assessment of intraosseous lesions of the face and jaws in asymptomatic patients, *Radiology*, *62*, 691–695 (1987).
20. HINTZE, H, WENZEL, A and WILLIAMS, S, Diagnostic value of clinical examination for the identification of children in need of orthodontic treatment compared to clinical examination and screening pantomography, *Eur. J. Orthod.*, *12*, 285–288 (1990).
21. KOGON, S L and STEPHENS, R G, Selective radiography instead of screening pantomography—a risk benefit evaluation, *J. Can. Dent. Assoc.*, *48*, 271–275 (1982).
22. WHITE, S C, FORSYTHE, A B and JOSEPH, L P, Patient selection criteria for panoramic radiography, *Oral Surg., Oral Med., Oral Pathol.*, *57*, 681–690 (1984).
23. STANDING DENTAL ADVISORY COMMITTEE, *Radiation Protection in Dental Practice* (Department of Health and Welsh Office, London and Cardiff), p. 10 (1988).
24. PRICE, C, The effects of beam quality and optical density on image quality in dental radiography, *Oral Surg., Oral Med., Oral Pathol.*, *62*, 580–588 (1986).
25. WALL, B F, FISHER, E S, PAYNTER, R, ET AL, Doses to patients from pantomographic and conventional dental radiography, *Br. J. Radiol.* *52*, 727–734 (1979).

26. RICHARDS, A G, BARBOR, G L, BADER, J D and HALE, J D, Samarium filtration in dental radiography, *Oral Surg., Oral Med., Oral Pathol.*, 29, 704–715 (1970).
27. MacDONALD, J C F, REID, J and LUKE, M, The spectral sensitivity of dental X-ray films, *Dentomaxillofac. Radiol.*, 16, 29–32 (1987).
28. WEBBER, R L, BENTON, P A and RYGE, G, Diagnostic variations in radiographs, *Oral Surg., Oral Med., Oral Pathol.*, 26, 800–809 (1968).
29. ARNOLD, L V, *The Radiographic Detection of Initial Carious Lesions on the Proximal Surfaces of Teeth* (Stafleu & Tholen, Brussels), pp. 93–147 (1983).
30. OKANO, T, HUANG, H J and NAKAMURA, T, Diagnostic accuracy on detection of proximal enamel lesions in non-screen radiographic performance, *Oral Surg., Oral Med., Oral Pathol.*, 59, 543–547 (1985).
31. SVENSON, B, GRONDAHL, H G, PETERSSON, A and OLVING, A, Accuracy of radiographic caries diagnosis at different kilovoltages and two film speeds, *Swed. Dent. J.*, 9, 37–43 (1985).
32. LANG, N P and HILL, R W, Radiographs in periodontics, *J. Clin. Periodontol.*, 4, 16–28 (1977).
33. THUNTHY, K H and MANSON-HING, L R, Effect of mAs and kVp on resolution and on image contrast, *Oral Surg., Oral Med., Oral Pathol.*, 46, 454–461 (1978).
34. McDAVID, W D, WELANDER, U, PILLAI, B K and MORRIS, C R, The Intrex—a constant potential X-ray unit for periapical dental radiography, *Oral Surg., Oral Med., Oral Pathol.*, 53, 433–436 (1982).
35. SVENSON, B and PETERSSON, A, Accuracy of radiographic caries diagnosis using different X-ray generators, *Dentomaxillofac. Radiol.*, 18, 68–71 (1989).
36. STENSTROM, B, JULIN, P and KARLSSON, L, Comparison between panoramic radiographic techniques. Part IV: Absorbed doses and energy imparted from the Orthopantomograph® model OP10, *Dentomaxillofac. Radiol.*, 16, 11–15 (1987).
37. KOEDOODER, K and VENEMA, H W, Filter materials for dose reduction in screen-film radiography, *Phys. Med. Biol.*, 31, 585–600 (1986).
38. NAGEL, H D, Comparison of performance characteristics of conventional and K-edge filters in general diagnostic radiology, *Phys. Med. Biol.*, 34, 1269–1287 (1989).
39. WHITE, S C and GRATT, B M, Evaluation of Niobi-X filtration in intraoral radiology, *Oral Surg., Oral Med., Oral Pathol.*, 72, 746–755 (1991).
40. KAPA, S F, TYNDALL, D A and OUELLETTE, T E, The application of added beam filtration to intraoral radiography, *Dentomaxillofac. Radiol.*, 19, 67–74 (1990).
41. KAPA, S F and TYNDALL, D A, A clinical comparison of image quality and patient exposure reduction in panoramic radiography with heavy metal filtration, *Oral Surg., Oral Med., Oral Pathol.*, 67, 750–759 (1989).
42. TYNDALL, D A, MATTESON, S R, SOLTMANN, R E ET AL, Exposure reduction in cephalometric radiology: a comprehensive approach, *Am. J. Orthod. Dentofac. Orthop.*, 93, 400–412 (1988).
43. WINKLER, K G, Influence of rectangular collimation and intra-oral shielding on radiation dose in dental radiography, *J. Am. Dent. Assoc.*, 77, 95–101 (1968).
44. WHITE, S C and ROSE, T C, Absorbed bone marrow dose in certain dental radiographic techniques, *J. Am. Dent. Assoc.*, 98, 553–558 (1979).
45. GIBBS, S J, PUJOL, A, CHEN, T-S, MALCOLM, A W and JAMES, A E, Patient risk from interproximal radiography, *Oral Surg., Oral Med., Oral Pathol.*, 58, 347–354 (1984).
46. KIRCOS, L T, ANGIN, L L and LORTON, L, Order of magnitude dose reduction in intra-oral radiography, *J. Am. Dent. Assoc.*, 114, 344–348 (1987).
47. LUNDEEN, R C, Rectangular vs. round collimation in intra-oral radiography: a volumetric perspective. *Dentomaxillofac. Radiol.*, 18, 93 (1989).
48. STENSTROM, B, HENRIKSON, C O, HOLM, B and RICHTER, S, Absorbed doses from intraoral radiography with special emphasis on collimator dimensions, *Swed. Dent. J.*, 10, 59–71 (1986).
49. LECOMBER, A R and FAULKNER, K, Dose reduction in panoramic radiography, *Dentomaxillofac. Radiol.*, 22, 69–73 (1993).
50. JOINT WORKING PARTY OF THE BRITISH SOCIETY FOR THE STUDY OF ORTHODONTICS AND THE BRITISH SOCIETY OF DENTAL AND MAXILLOFACIAL RADIOLOGY, Reduction of the dose to patients during lateral cephalometric radiography, *Br. Dent. J.*, 158, 415 (1985).
51. SVENSON, B, LINDVALL, A-M and GRONDAHL, H-G, A comparison of a new dental X-ray film, Agfa Gevaert Dentus M4, with Kodak Ektaspeed and Ultraspeed dental X-ray films, *Dentomaxillofac. Radiol.*, 22, 7–12 (1993).
52. KAFFE, I, LITTNER, M M and KUSPET, M E, Densitometric evaluation of intra-oral X-ray films: Ektaspeed versus Ultraspeed, *Oral Surg., Oral Med., Oral Pathol.*, 57, 338–342 (1984).
53. GOREN, A D, SCIUBBA, J J, FRIEDMAN, R and MALAMUD, H, Survey of radiologic practices among dental practitioners, *Oral Surg., Oral Med., Oral Pathol.*, 67, 464–468 (1989).
54. HORNER, K, SHEARER, A C, RUSHTON, V E and CZAJKA, J, The use of rapid processing techniques by a sample of British dentists, *Dentomaxillofac. Radiol.*, 22, 145–148 (1993).
55. PONCE, A Z, McDAVID, W D, UNDERHILL, T E and MORRIS, C R, Use of E-speed film with added filtration, *Oral Surg., Oral Med., Oral Pathol.*, 61, 297–299 (1986).
56. DIEHL, R, GRATT, B M and GOULD, R G, Radiographic quality control measurements comparing D-speed film, E-speed film and xeroradiography, *Oral Surg., Oral Med., Oral Pathol.*, 61, 635–640 (1986).
57. CATANDELLA-FLETCHER, J, A comparison of Ektaspeed and Ultraspeed films using manual and automatic processing solutions, *Oral Surg., Oral Med., Oral Pathol.*, 63, 94–102 (1987).
58. KAFFE, I and GRATT, B M, E-speed dental films processed with rapid chemistry. A comparison with D-speed film, *Oral Surg., Oral Med., Oral Pathol.*, 64, 367–372 (1987).
59. GIRSCH, W J, MATTESON, S R and McKEE, M N, An evaluation of Kodak Ektaspeed periapical film for use in endodontics, *J. Endodont.*, 9, 282–288 (1983).
60. GRONDAHL, K, GRONDAHL, H G and OLVING, A A, Comparison of Kodak Ektaspeed and Ultraspeed films for the detection of periodontal bone lesions, *Dentomaxillofac. Radiol.*, 12, 43–46 (1983).
61. WHITE, S C, GRATT, B M and HOLLENDER, L, Comparison of xeroradiographs and film for detection of calculus, *Dentomaxillofac. Radiol.*, 13, 39–43 (1984).



62. WHITE, S C, HOLLENDER, L and GRATT, B M, Comparison of xeroradiographs and film for detection of proximal surface caries, *J. Am. Dent. Assoc.*, 108, 755-759 (1984).
63. WHITE, S C, HOLLENDER, L and GRATT, B M, Comparison of xeroradiographs and film for detection of periapical lesions, *J. Dent. Res.*, 63, 910-913 (1984).
64. DONNELLY, J C, HARTWELL, G R and JOHNSON, W B, Clinical evaluation of Ektaspeed X-ray film for use in endodontics. *J. Endodont.*, 11, 90-94 (1985).
65. KLEIER, D J, HICKS, M J and FLAITZ, C M, A comparison of Ultraspeed and Ektaspeed dental X-ray film: an *in vitro* study of the radiographic and histologic appearance of interproximal lesions, *Quint. Int.*, 18, 632-631 (1987).
66. WAGGONER, W F and ASHTON, J J, A comparison of Kodak D-speed and E-speed X-ray film in detection of proximal caries, *J. Dent. Child.*, 55, 459-462 (1988).
67. WAGGONER, W F and ASHTON, J J, Predictability of cavitation based upon radiographic observation: comparison of two film types, *Quint. Int.*, 20, 55-60 (1989).
68. GIBBS, S J, PUJOL, A, CHEN, T-S and JAMES, A E, Patient risk from intraoral radiography, *Dentomaxillofac. Radiol.*, 17, 15-23 (1988).
69. HORNER, K, SHEARER, A C, WALKER, A and WILSON, N H F, Radiovisiography: an initial evaluation, *Br. Dent. J.*, 168, 244-248 (1990).
70. WALKER, A, HORNER, K, CZAJKA, J and SHEARER, A C, Quantitative assessment of a new dental imaging system, *Br. J. Radiol.*, 64, 529-536 (1991).
71. McDONNELL, D and PRICE, C, An evaluation of the Sens-A-Ray digital dental imaging system, *Dentomaxillofac. Radiol.*, 22, 121-126 (1993).
72. GRATT, B M, WHITE, S C, PACKARD, F L and PETERSSON, A R, An evaluation of rare-earth imaging systems in panoramic radiography, *Oral Surg., Oral Med., Oral Pathol.*, 58, 475-482 (1984).
73. HUTTON, J B, BRENNAN, A G and BIRD, P D, Dose reduction in lateral cephalometry using rare-earth screens, *Br. Dent. J.*, 163, 378-382 (1987).
74. WOOD, R E, HARRIS, A M P, VAN DER MERWE, E J and NORTJE, C J, The leaded apron revisited: does it reduce gonadal radiation dose in dental radiology?, *Oral Surg., Oral Med., Oral Pathol.*, 71, 642-646 (1991).
75. BEIDEMAN, R W, JOHNSON, O N and ALCOX, R W, A study to develop a rating system and evaluate dental radiographs submitted to a third party carrier, *J. Am. Dent. Assoc.*, 93, 1010-1013 (1976).
76. COLLETT, W K, Intraoral radiographic errors in films submitted for orthodontic consultation, *Oral Surg., Oral Med., Oral Pathol.*, 49, 370-372 (1980).
77. BEIDEMAN, R W, PETTIGREW, J C and GREEN, P H, A follow-up study of a third-party radiographic evaluation system, *Oral Surg., Oral Med., Oral Pathol.*, 56, 103-108 (1983).
78. JENSEN, O E, HANDELMAN, S L and IKER, H P, Use and quality of bitewing films in private dental offices, *Oral Surg., Oral Med., Oral Pathol.*, 63, 249-253 (1987).
79. ELIASSON, S, LAVSTEDT, S, WOUTERS, F and OSTLIN, L, Quality of intraoral radiographs sent by private dental practitioners for therapy evaluation by the Social Insurance Office, *Swed. Dent. J.*, 14, 81-89 (1990).