Radiation dose–reduction techniques in North American dental schools

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Objective. The purpose of this investigation was to describe the extent to which dental schools use materials, equipment, and quality-assurance protocols that reduce radiation exposure to patients.
Study Design. Questionnaires soliciting information regarding intraoral and extraoral radiographic practices and quality-assurance procedures were sent to the directors of oral and maxillofacial radiology (OMR) at the 65 schools of dentistry in the United States and Canada.
Results. The response rate was 100%. E-speed film is used at 86% of institutions. Direct digital radiography is used at 58% of institutions for intraoral imaging and 11% for extraoral radiography. Other dose-reducing techniques include long source-film distances (88%), rectangular beam limitation (47%), leaded aprons (95% for extraoral films; 85% with thyroid collars for intraoral films), and rare earth intensifying screens (100%). The most commonly used tube potential is 70 kVp (88%). The director of OMR is solely responsible for radiographic policies at approximately 75% of institutions. Regular tests for film fog, speed, and contrast are done at roughly 75% of schools, while over 90% test darkroom lighting and x-ray equipment.
Conclusions. Some dose-reducing strategies are commonly used in dental schools, while others have not gained wide acceptance.
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The radiation exposure dose to dental patients from intraoral and extraoral radiographic procedures has been greatly reduced over the past several decades. The reduction in exposure time with the use of E-speed film[1-14] and direct digital radiography[15-19] compared with D-speed film is well known and is accomplished with no loss of diagnostic information. Significant decreases in radiation dose occur with the use of long, rectangular position indicating devices (PIDs) compared with round PIDs with a shorter source-film distance.[7,20-24] Leaded rubber aprons and thyroid collars have been shown to minimize x-ray exposure to various parts of the body.[25,26]

Extraoral radiography has also experienced improvements in radiation reduction through the use of rare earth intensifying screens and compatible films.[27-29] The implementation of quality-assurance protocols, including periodic checks of film, processing chemicals, darkroom lighting, and x-ray units, helps maintain a high level of radiographic quality and results in fewer reexposures.[27] The use of selection criteria in ordering radiographs has resulted in reduction in the radiation burden on patients.[30,31]

Research indicates that the use of the materials and techniques described earlier is not widespread among practicing dentists,[32-36] although dental and dental hygiene programs have used them in varying degrees over the past 15 years.[34,37-39] The use of selection criteria in dental educational facilities, representing a major dose-reduction policy, has been examined several times in the recent past.[40-42] The purpose of this investigation was to determine the use of radiation-reducing materials and techniques at schools of dentistry in the United States and Canada.

MATERIAL AND METHODS

A questionnaire consisting of 3 sections was created. A section concerning intraoral radiography asked for information regarding film speed, the use of direct digital radiography, the length and shape of position indicating devices, the use of leaded rubber aprons, and kVp settings. Questions pertaining to extraoral radiography, in the second section, solicited information about film-screen combinations, the use of direct digital radiography, and the policy for leaded rubber apron protection. The respondents were also asked to identify the person or persons responsible for selecting the materials and techniques used in intraoral and extraoral radiography. The third section of the survey consisted of questions about quality-assurance protocols, such as the frequency of tests for base-plus-fog density, speed and contrast indices, and darkroom

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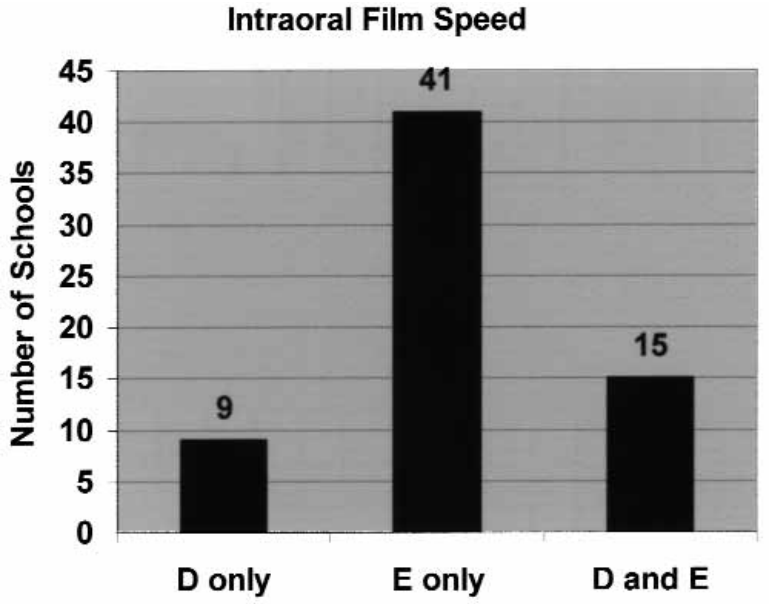

Fig 1. Speed groups of intraoral films used at the 65 schools of dentistry.

lighting, as well as tests of the x-ray units and the use of reference films.

Most questions involved selection of the appropriate answer from listed options, but space was provided for respondents to make comments or explain their answers. For example, any differences in standards between the radiology clinic and other departments could be explained.

Questionnaires were mailed in March 2000 to the directors of Oral and Maxillofacial Radiology at the 65 dental schools then in operation in the United States and Canada. The questionnaires were accompanied by an explanatory cover letter and a self-addressed return envelope. After 6 weeks, 41 surveys had been returned. A second mailing yielded 17 more returns. The radiology directors at the remaining 7 schools were contacted by telephone by 1 of the authors (JRG) and the survey was completed verbally. These techniques have been used before in surveys of radiographic practices.[32,33,37] As a result, information was obtained from all 65 schools, for a 100% response rate.

RESULTS

Intraoral Radiography

E-speed film is used exclusively at 41 of the 65 schools (63%). Both D- and E-speed films are used at 15 facilities (23%), and 9 schools (14%) use only D-speed film (Fig 1). Seven of the schools using both D- and E-speed film use the slower film in endodontic procedures and E-speed film elsewhere, while 6 schools use E-speed film for endodontics and D-speed film in other clinical settings.

Direct digital radiography (DDR) is employed for some patients in 38 schools (58%) and is not used in patient care at the remaining 27 (42%). Of the 38 dental schools that use DDR in patient care, 28 report that it is used for endodontics, with smaller numbers of schools indicating its use in implant procedures, emergency care, advanced education in general dentistry (AEGD) and faculty practice clinics, and for research purposes.

The round open-ended position-indicating device is used exclusively at 34 schools (52%). Both rectangular and round beam limiters are used at 21 facilities (32%), and 10 schools (15%) use rectangular beam limitation exclusively. None of the schools reported the use of pointed plastic cones. The most frequent position indicating device (PID) is the round PID with a 12-in source-film distance (SFD), used at 29 schools (45%). Round 16-in PIDs are found in 24 facilities (37%). When rectangular beam limitation is employed, 16 schools use 16-in SFD and 14 schools use 12-in SFD; 1 school uses both lengths (Fig 2). Overall, long cones (12-in or 16-in) are used at 57 schools (88%); 8 institutions (12%) use only 8-in PIDs.

In facilities where both round and rectangular beam limiters are used, 5 schools report that the rectangular devices are found only in the Radiology Clinic. Four of the 31 schools using rectangular beam limitation do not

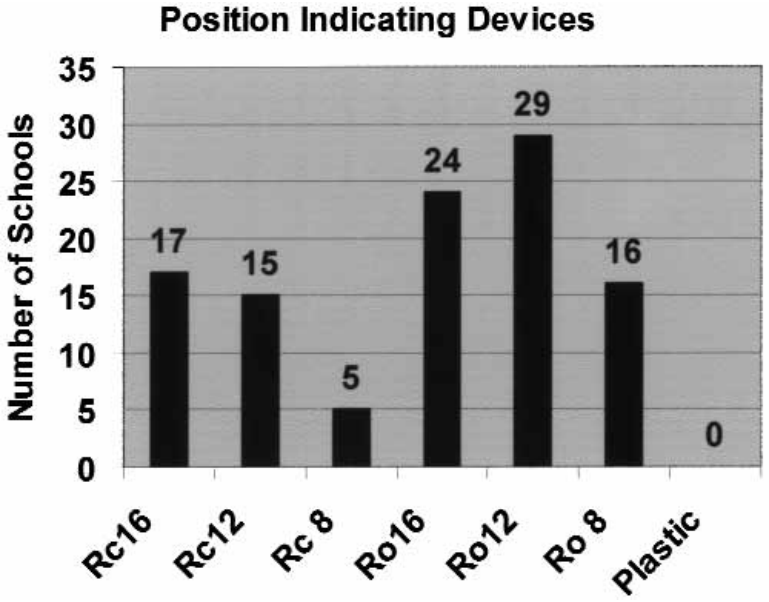

Fig 2. Lengths and shapes of position indicating devices for intraoral radiography. (Rc 16, 16-in rectangular; Rc 12, 12-in rectangular; Rc 8, 8-in rectangular; Ro 16, 16-in round; Ro 12, 12-in round; Ro 8, 8-in round.)

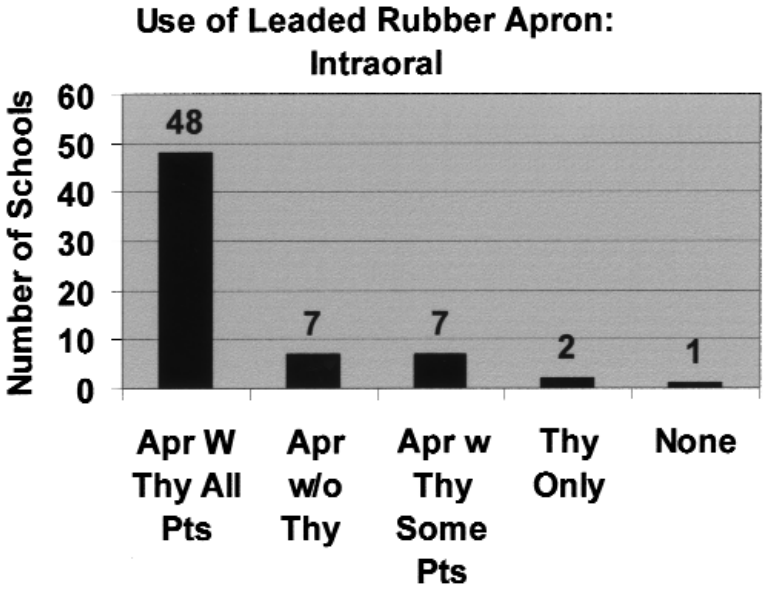

Fig 3. Use of leaded rubber aprons in intraoral radiographic procedures. (Apr w Thy All Pts, leaded rubber apron with thyroid collar for all patients; Apr w/out Thy, leaded rubber apron without thyroid collar for all patients; Apr w Thy Some Pts, leaded rubber apron with thyroid collar for some patients; Thy Only, thyroid collar only; None, no leaded rubber apron or thyroid collar.)

have rectangular PIDs. They use round cones fitted with rectangular metal inserts or a metal shield with a rectangular window attached to a film-holding device, such as the Precision instrument (Masel Enterprises, Bristol, Pa).

All patients are covered with leaded rubber aprons with a thyroid collar during intraoral radiography in 48 dental schools (74%), and aprons without thyroid collars are used for all patients at 7 schools (11%). In 7 other schools, aprons are used with collars for various situations, such as pediatric patients, patients under 30 years of age, or patients by request. Two dental facili-

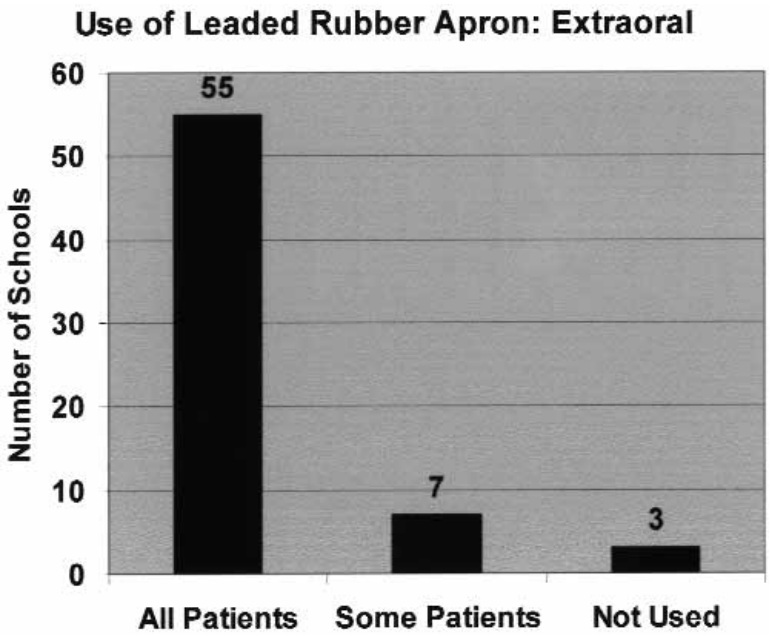

Fig 4. Use of leaded rubber aprons in extraoral radiographic procedures.

ties use only leaded rubber thyroid collars without aprons, and 1 school reported that leaded rubber protection is never used (Fig 3).

The most commonly used tube potential is 70 kVp; 57 schools (88%) operate intraoral units at this kilovolt (peak) setting. Sixteen facilities use 90 kVp x-ray machines, 14 schools use 75 kVp tubes, and other settings are found in smaller numbers. Two or more kilovolt (peak) settings are available at 30 facilities. Six of these respondents said that lower kilovolt (peak) settings are chosen for bitewing radiographs, while 3 schools alter kilovolt (peak) based on anatomical location of the radiograph (ie, anterior versus posterior).

Decisions regarding intraoral radiographic policies, materials, and procedures are made by a chairperson or director of Oral and Maxillofacial Radiology at 47 schools (72%). Directors or chairpersons of Oral Diagnosis make the decisions at 4 facilities, and the dean or director for clinical affairs is responsible at 3 schools. In 11 schools, the choices are made by the OMR chairperson or director in consultation with other chairpersons or deans.

Extraoral radiography

All schools of dentistry reported the use of rare earth intensifying screens for extraoral radiography. However, 3 schools also use calcium tungstate screens for some procedures.

Direct digital radiography is available for extraoral imaging at 7 dental schools (11%), but 57 respondents (88%) indicated that DDR is not used for patients. One questionnaire was returned with no answer. The most common clinical settings for extraoral DDR are orthodontics and faculty practice.

Leaded rubber aprons are used for all patients undergoing extraoral radiographic procedures at 55 schools (85%). Aprons are used for some patients at 7 schools; these situations include children and specific radiographic projections. Leaded rubber aprons are not used at all in 3 facilities (Fig 4).

The chairperson or director of OMR is solely responsible for extraoral radiographic policy at 50 dental schools (77%). The clinical dean or director makes the decisions at 3 facilities, and the Oral Diagnosis chair or director is in charge of this area at 3 schools. At 9 schools the responsibility rests with the OMR director in cooperation with other parties, such as the clinical dean or other department chairpersons.

Quality-assurance protocols

Regular measurement of the base-plus-fog density of film is performed at 48 schools (74%). These tests are performed 5 days per week at 22 facilities and once per week at 11 schools. Base-plus-fog density is not measured at 17 schools (26%) (Fig 5). Similar results were found for measurement of speed and contrast

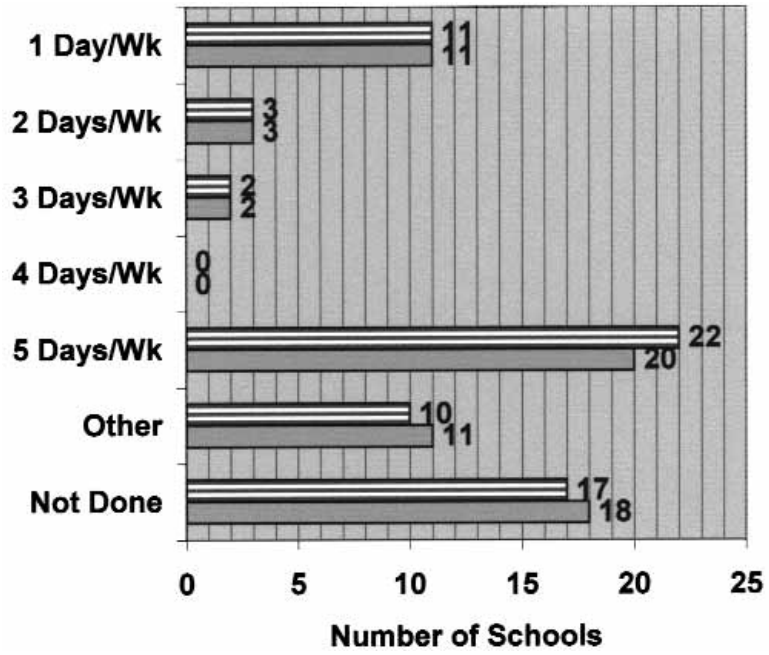

Fig 5. Quality-assurance protocols showing frequency of densitometric testing of films for base-plus-fog density *(horizontal line)* and densitometric testing for measurement of speed and contrast indices *(solid).*

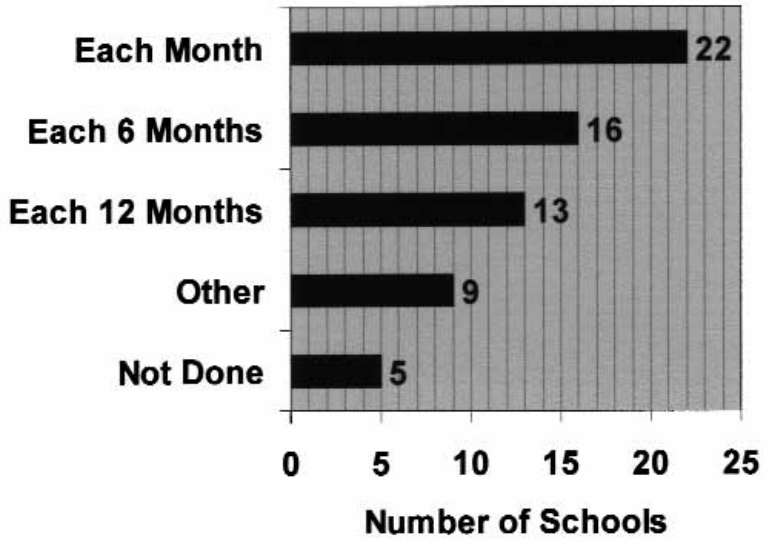

Fig 6. Frequency of testing for light leaks and safelight adequacy.

indices. This is performed regularly at 47 schools (72%), with 20 facilities measuring these indices 5 times each week and 11 conducting these tests 1 day per week. However, 18 schools (28%) do not regularly perform sensitometric testing (Fig 5). Sixty schools (92%) periodically evaluate the dark room for light leaks and adequacy of safe lighting. This is done monthly by 22 institutions, every 6 months at 16 schools, and annually by 13 (Fig 6).

All but 1 school (98%) report regular measurement of radiation output in their intraoral x-ray units. Of these, the most common period for evaluation is 12 months (45). Other exposure parameters are checked by more than 90%, including timer (63 schools),

milliamperes (62), kilovoltage (64), and half-value layer thickness (63) (Table). Effective focal spot size is periodically measured at 61 schools, and beam diameter is measured in 64 of the 65 institutions (Table). Reference films are a component of quality assurance at 48 dental schools (74%).

Table. Radiation parameters tested and frequency of tests as part of quality-assurance protocol

Radiation parameter and frequency	*No. of schools*
Radiation output	64
Annually	45
Semiannually	8
Other frequency	11
Timer	63
Annually	43
Semiannually	8
Other frequency	12
Milliamperage	62
Annually	42
Semiannually	8
Other frequency	12
Kilovoltage	64
Annually	45
Semiannually	8
Other frequency	11
Half-value layer thickness	63
Annually	43
Semiannually	7
Other frequency	13
Effective focal spot size	61
Annually	40
Semiannually	7
Other frequency	14
Beam diameter	64
Annually	44
Semiannually	7
Other frequency	13

DISCUSSION

Intraoral radiography

E-speed radiographic film is used exclusively at 63% of institutions, and in combination with D-speed film at 23%. This is an improvement over the data presented by Farman and Hines 16 years ago, when only 23% of dental schools used E-speed film exclusively and less than half used it at all.[37] Suleiman et al[34] reported that 71% of dental schools used E-speed film in 1995, but only 38 schools participated in that survey, which might have distorted the results. Our findings also confirm a trend noted in dental hygiene programs, where use of E-speed film increased from 25% of programs in 1985 to 70% in 1990.[38,39] While these results reveal a much higher use of E-speed film in schools of dentistry than among the practicing dental community,[32-36] it is somewhat surprising that 14% of schools still use only D-speed film. The reason for this may stem in part from the original Ektaspeed film that appeared on the market in 1981. Although it was found in objective research to be comparable with D-speed film in diagnosing caries and periodontal bone loss,[2,4-6,12-14] and permitted a reduction in exposure time of at least 40%,[1-14] Ektaspeed exhibited poor contrast in darker parts of the image.[1,3,8-11] Research demonstrates that dentists prefer greater contrast in radiographs,[43-45] which could explain the unfavorable opinion of Ektaspeed, leading to its removal from the market in favor of Ektaspeed Plus. It may be that some dental faculty members are not aware of the improvement of Ektaspeed Plus, thereby rejecting E-speed film on the basis of the performance of the original Ektaspeed.

However, in 8 of the 9 schools that use only D-speed film, the director of Oral and Maxillofacial Radiology alone makes the decisions on film use. In some cases, there may be pressure from other faculty to use D-speed film. One OMR director commented that it is difficult to convince other departments to accept E-speed film. Another director noted that department chairs are "very territorial" and desire to control everything in their own departments.

The most commonly mentioned discipline in which film speed differs from the other clinics is endodontics. Interestingly, the number of schools where endodontics faculty prefer D-speed film over the E-speed film used elsewhere is almost equal to the number of schools in which the endodontics faculty use E-speed film instead of the D-speed film used in the other clinics. One respondent noted that the endodontics instructors prefer D-speed film because they "can't see the apices of the teeth" on E-speed radiographs. These findings suggest that film selection may be driven by subjective opinion or improper exposure or processing techniques instead of scientific evidence in some cases.

After the conclusion of this survey, dental film in speed group F was introduced to the market. Early research indicates that this film has contrast equal to or greater than Ektaspeed Plus, with an exposure dose reduction of at least 20%.[46-48] It is being used at the home institution of 1 of the authors, and it will be interesting to see how rapidly F-speed film gains acceptance in other schools of dentistry.

Direct digital radiography is used in patient care at 38 of the 65 schools (58%), most frequently in endodontics, where the rapid production of an image is an appealing feature when instrumenting a canal. When used with a charge-coupled device or complementary metal-oxide semiconductor sensor, DDR allows a reduction of at least 50% in exposure time compared with E-speed film.[15,16,19] This is a signifi-

cant decrease in the radiation burden placed on patients during root canal procedures. DDR has been available since 1989, so the fact that it is not used at all in patient care at 27 dental schools (42%) was unexpected.

Long beam-limiting devices, producing a 12-in or 16-in source-film distance, are used at 57 schools (88%). This is encouraging, since the radiation dose reduction with longer PIDs is significant when compared with shorter cones. Cederberg et al[23] reported a difference of 30% in the effective dose when comparing full-mouth radiographic surveys performed with a 19.6 cm SFD round cone to the same procedure using a 29.8 cm SFD round PID. Gibbs et al[22] recorded reductions in effective dose ranging from 13% in the salivary glands to 38% in the thyroid gland when using a 16 in instead of an 8-in round cone. Kircos et al[20] described a reduction in irradiated tissue volume of approximately 30% when changing from an 8-in to a 16-in PID. Only 6 schools that use long PIDs also have short 8-in cones. However, it was found that 8 institutions (12.3%) use only 8-in beam limiters; 1 of these schools uses only D-speed film.

Even greater radiation dose reduction is accomplished with the use of PIDs with rectangular openings that are roughly the size of a #2 dental film. The tissue area exposed with rectangular beam limitation is approximately one third of the area exposed with the circular cone of 2.75 in diameter. Reductions in overall patient dose of 70% to 75% have been reported,[20-24] with decreases of more than 80% to certain organs.[22-24] Rectangular beam limitation is used in addition to round ended PIDs at 21 dental schools (32%), and is used exclusively at 10 (15%). This represents a much greater acceptance of rectangular beam limiters than is found in the practicing dental community in North America[32,33] and Sweden.[35,36] However, these figures are lower than those reported in 1986, when more than half of US and Canadian schools used rectangular beam limitation.[37]

It should be noted that 4 schools in our investigation reported the use of rectangular windows in film holders or metal inserts in round PIDs instead of rectangular cones. One respondent indicated a desire to use rectangular PIDs, but expressed unhappiness that they are hard to find and are rarely offered as an option by x-ray unit manufacturers. It is possible that rectangular PIDs or metal inserts are not as readily available now as they were 15 years ago, which would explain the difference between the 1986 research and our investigation.

It was also noted that most of the universities employing rectangular beam limiters use them only in the Radiology clinic; x-ray operatories in other clinics are rarely fitted with them. Reasons cited for this centered mainly on fears of non-OMR faculty that rectangular cones would cause an unacceptably high number of technical errors. The OMR director is responsible for the decision to use rectangular beam limitation at 22 of the 31 schools that have it.

The widespread use of leaded rubber aprons for intraoral radiography (62 schools, or 95% of schools) is a positive finding, similar to the results obtained in a survey of dental schools in 1986[37] and dental hygiene programs in 1990.[39] However, 14 of these institutions either do not use a thyroid collar with the apron (7) or add the collar only for some patients (7). This is also nearly identical to the results of the dental school study,[37] but lower than the thyroid collar use at 90% of the hygiene programs.[39] Use of thyroid shielding in educational institutions is more common than in private practices, where less than half of dentists used the collars in a 1992 survey.[32] Research indicates that thyroid shielding can reduce the dose to the thyroid gland by at least one third.[20,25-27] Two institutions use only a thyroid collar for intraoral exposures. Evidence suggests that leaded aprons should also cover the thorax, since radiation dose reductions of 20% to the breast have been recorded with their use.[20] However, some directors may dispense with the apron because of the extremely small radiation exposure to the gonads.[22]

By far, the most common tube potential setting is 70 kVp, followed by 90 and 75 kVp. This is similar to the results previously reported for dental schools[34,37] and practicing dentists.[32,34] The findings may be more reflective of the fact that many x-ray units on the market limit the selection of kVp, rather than any preference for specific levels of subject contrast. Only 6 respondents indicated that kVp is decreased to produce shorter gray scale images for bitewings.

Extraoral radiography

All dental schools in the United States and Canada employ rare earth intensifying screens for extraoral projections. Gratt et al[28] reported that several rare earth screen/film combinations provided the same diagnostic information as calcium tungstate screen/film systems with up to 50% less radiation. Skoczylas et al[29] obtained similar radiation reductions. Only 3 schools (5%) use calcium tungstate screens, but for limited purposes. One respondent wrote that the slower calcium tungstate screen/film combination is used only to see better definition of suspected lesions, and the other 2 institutions noted that this imaging system is restricted to older cephalometric units.

The use of direct digital extraoral radiography is somewhat limited, probably because these units have only recently become available. Several respondents indicated that they were planning on obtaining DDR extraoral units in the near future. There is a significant decrease in radiation exposure with the use of direct digital receptors compared with screen/film imaging systems.[27]

Leaded rubber aprons are used in extraoral radiography for all or selected patients at 62 schools (95%). One of the 3 facilities where aprons are not used is the 1 school where aprons are not used for intraoral procedures either.

Quality-assurance protocols

Quality assurance (QA) is broadly defined as a series of procedures to ensure production of high-quality radiographs with minimal radiation exposure to patients and operators. QA protocols should include periodic checks of films, processing solutions, darkroom adequacy, and x-ray generators.

Densitometric measurement of base-plus-fog (B+F) density is performed at least once per week by 74% of schools; of these, almost half test for B+F every day. Results of these tests can be very helpful in identifying batches of film that may have objectionably high levels of fog and removing them from use. Variability in fog levels between films has been reported, even when measured many months before the expiry date.[35]

Numerical measurement of speed and contrast is part of the QA protocol at 47 schools (72%), with 20 institutions making densitometric calculations daily and the rest at least once per week. It is known that many radiographs are unacceptable because of processing errors, and excessive exposure times are often used to compensate for the diminished radiographic density resulting from poor processing.[27] Sensitometric monitoring of developer and fixer can permit the solutions to be replaced if necessary before deleterious changes in the solutions become visible on the images.

A survey of dental hygiene programs in 1990 revealed that approximately 80% of respondents evaluated radiographic quality, but this was reported as subjective evaluation with no specification of sensitometric measurement.[39] Many of the respondents in the present investigation commented that all radiographs are evaluated for quality as they are produced. Many other facilities, however, reported neither subjective nor sensitometric evaluation. Reference films, which can improve the subjective inspection of radiographic quality, are used at only 74% of schools.

Whereas approximately 75% of dental schools measure film fog, speed, and contrast, over 90% report regular tests for light leaks, proper safelighting, and inspection of x-ray units. In many cases this is performed by external organizations, such as state departments of radiological health, and the majority of schools said that such tests are performed annually. The frequency ranges from every 4 months to every 3 years. Considering that modern x-ray equipment is very reliable and is rarely the cause of poor images, annual examination is probably sufficient for most units unless specific problems arise.[27]

One of the limitations of an investigation of this nature is the possibility of bias. It is possible that some answers may represent the ideal situations intended by the respondents, but adherence to these standards may be lax in other areas of the school not under the OMR directors' control. Thus, variation in standards may occur within educational facilities that are not reflected in our results. While some respondents commented on this in the questionnaire, it is possible that some variations are not accounted for in the results.

Several investigations over the past 13 years have documented increasing compliance on the part of dental educational facilities with the concept of selection criteria in prescribing radiographs.[40-42] The present investigation indicates that radiation burden to patients is also being reduced through the use of faster film and film/screen combinations, long PIDs, leaded rubber aprons, and regular checks of film fog, processing solutions, darkroom lighting, and x-ray equipment. Many of these are included in the quality assurance self-assessment published by the American Academy of Oral and Maxillofacial Radiology Committee on Radiology Practice.[49] However, other dose-reducing mechanisms such as direct digital imaging and rectangular beam limitation are not as widely used.

The significance of these findings lies in the fact that schools of dentistry serve as models for their graduates and should set the standard for keeping radiation exposure to patients as low as reasonably achievable. If educational facilities require their students to employ dose-reducing strategies, it is likely that the students will continue to use them as practicing dentists. Application of these tactics in schools could be a leading indicator of eventual use by dentists in practice, and therefore ultimately important for the radiation protection of the general public.

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