PEDIATRIC DENTISTRY/Copyright © 1981 by
The American Academy of Pedodontics/Vol. 3, No. 1

A quality assurance program in dental radiology

Richard W. Valachovic, DMD
Allan B. Reiskin, DDS, DPhil
Susan T. Kirchhof, RT

Abstract

A quality assurance program in radiology provides the basis for systematic measurement of various parameters which affect the quality and production of a radiographic image. We have outlined a program which can be implemented in dental offices by dentists or auxiliary personnel without sophisticated instruments. Tests designed to establish the adequacy of specific functions are described together with reasons for poor image quality. Implementation of a quality assurance program results in reduction in expenditures, increased radiation thrift and improved diagnosis.

Introduction

The production of radiographs involves several complex processes. Small variations in exposure geometry, beam quality or processing technique can have dramatic results on the final image. If one wishes to generate consistent and diagnostic radiographs, careful regulation of the imaging process must be rigorously maintained. Simple steps can be taken to assure that uniform image production is achieved through the utilization of a systematic quality assurance program.[1] In addition to its contribution to the production of high quality images, such a quality assurance program also plays a major role in keeping patient exposure to a practical minimum.[2]

This paper will describe a quality assurance program that can easily be implemented in the private dental office to efficiently monitor the various parameters that affect the characteristics of the radiographic image. Through the regular application of this program, problems in any aspect of image production can be readily identified and corrected.

Accepted: October 3, 1980

Parameters Which Affect Image Quality

There are four basic parameters which affect image quality that may be measured: (1) image processing; (2) the basic characteristics of the x-ray generator; (3) image receptors; and (4) darkroom integrity (Table 1). All of these parameters may be measured to a limited degree of sensitivity without sophisticated equipment.

The most frequently encountered reason for variability in producing an image is in the processing of the exposed film; this is the one parameter over which the dentist has the most control. X-ray generator performance is generally quite stable and maintenance is usually delegated to a qualified serviceperson. The quality of most commercial film products is not highly variable and is easily maintained through proper stor-

Table 1. Quality assurance tests and frequency of performance.

1. *Tests of Image Processing: Every Day*
   - A. Solution temperatures
   - B. An index of speed
   - C. An index of contrast
2. *Tests of X-Ray Generator Performance: Every 3 Months*
   - A. Reproducibility of x-ray output
   - B. Linearity of mAs stations
   - C. Field size and density
   - D. Mechanical stability of suspension
3. *Tests of Image Receptor Quality: Every Month*
   - A. Base plus fog
   - B. Film artifact identification
4. *Tests of Darkroom (or Daylight Loader) Integrity: Every Month (or with every change of safelighting)*
   - A. Light leaks
   - B. Safelight conditions

Table 2. Troubleshooting the poor quality image

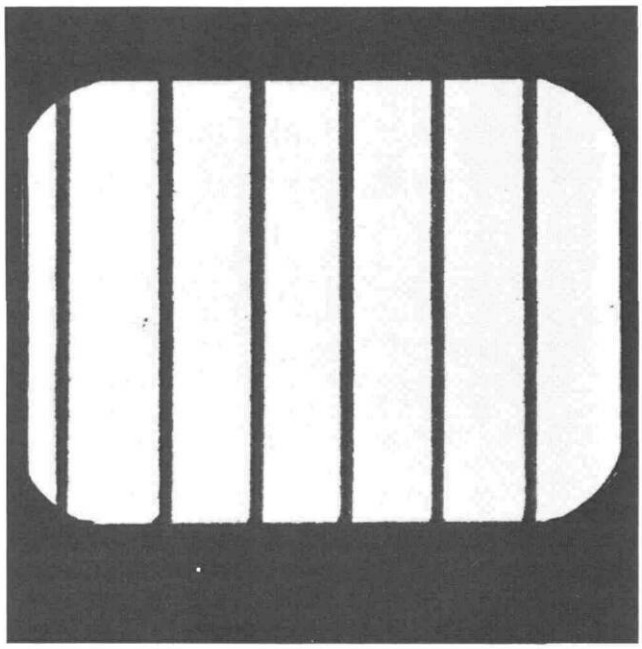
Observation	Possible Causes (Listed in descending order of probability)	Testing Procedures (if applicable: see text)	Corrective Action
Consistently light films	1. Sight development		Sight development should not be used
	2. Processing errors	Tests of image processing	
	A. Exhausted solutions		Replenish/replace at proper intervals
	B. Development time too short		Follow manufacturer's recommendations
	C. Developer temperature too low		Follow manufacturer's recommendations
	D. Improper mixing of chemicals		Follow manufacturer's recommendations
	3. Incorrect exposure factors	Check technique chart	Adjust exposure factors as necessary
	4. Expired film	Tests of image receptor quality	Discard expired film
	5. Variable generator performance	Tests of generator performance	Call serviceperson
Consistently dark films	1. Processing errors	Tests of image processing	
	A. Developer temperature too high		Follow manufacturer's recommendations
	B. Development time too long		Follow manufacturer's recommendations
	C. Developer too concentrated		Follow manufacturer's recommendations
	D. Solution contamination		Avoid cross contamination
	2. Incorrect exposure factors	Check technique chart	Adjust exposure factors as necessary
	3. Fogged films		
	A. Environmental exposure	Tests of image receptor quality	Store film properly (see text)
	B. Light leaks	Tests of darkroom integrity	Secure processing area from light leaks
	4. Variable generator performance	Tests of generator performance	Call serviceperson
Variable film density	1. Processing errors	Tests of image processing	Follow manufacturer's recommendations
	2. Variable generator performance	Tests of generator performance	Call serviceperson
	A. Timer malfunction	A. linearity and reproducibility	
	B. mA instability	B. linearity	
	C. Voltage instability	C. reproducibility	
	3. X-ray tube deterioration	Test of field size and density	Call serviceperson
Variable film contrast	1. Fogged films		
	A. Environmental exposure	Tests of image receptor quality	Store film properly (see text)
	B. Light leaks	Tests of darkroom integrity	Secure processing area from light leaks
	C. Improper handling	Test of film artifact	Handle film with care during processing
	2. Unstable developer temperature	Tests of image processing	Follow manufacturer's recommendations
	3. Variable generator performance	Tests of generator performance	Call serviceperson
Blurred image	1. Patient movement		Watch patient during exposure
	2. Instability of suspension	Test of mechanical stability	Adjust suspension as necessary
Partial image	1. Cone cutting		
	A. Technical malposition		Align field with image receptor
	B. P.I.D. malalignment	Test of field size and density	Adjust as necessary or call serviceperson
	2. Inadequate immersion of film into solutions	Tests of image processing	Replenish/replace at proper intervals
Film Artifact	1. Processing errors	Tests of image processing	
	A. Solution contamination		Avoid cross contamination
	B. Incomplete agitation		Follow manufacturer's recommendations
	C. Improper handling		Handle film with care during processing
	D. Soiled processor rollers		Clean processor at regular intervals
	2. Fogged films		
	A. Environmental exposure	Tests of image receptor quality	Store film properly (see text)
	B. Light leaks	Tests of darkroom integrity	Secure processing area from light leaks
	3. Defective film quality	Tests of image receptor quality	Discard defective film

age; however, all film packages should be routinely tested before use. Finally, the integrity of the darkroom (or daylight loader of an automatic processor) is easily evaluated and corrected as necessary (Table 2).

Quality Assurance Testing Procedures

A test object or step wedge which will be used throughout these quality assurance procedures, and which is sized for use with No. 2 dental x-ray film may be purchased commercially[a] or constructed using discarded sheets of lead foil saved from used No. 2 dental x-ray film packets. Figure 1 illustrates the method of

[a]Spectroline X-Ray Analyzer Model 8958, Spectronics Corp., 29 New York Ave., Westbury, Long Island, NY 11590.



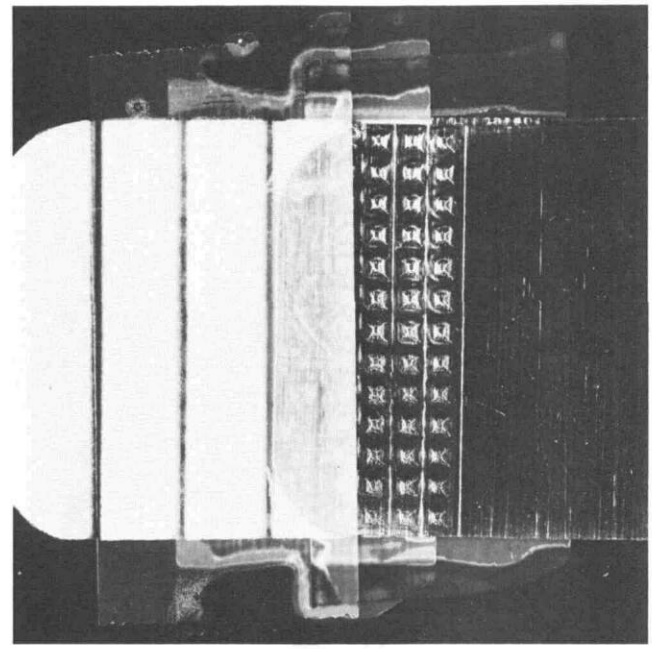
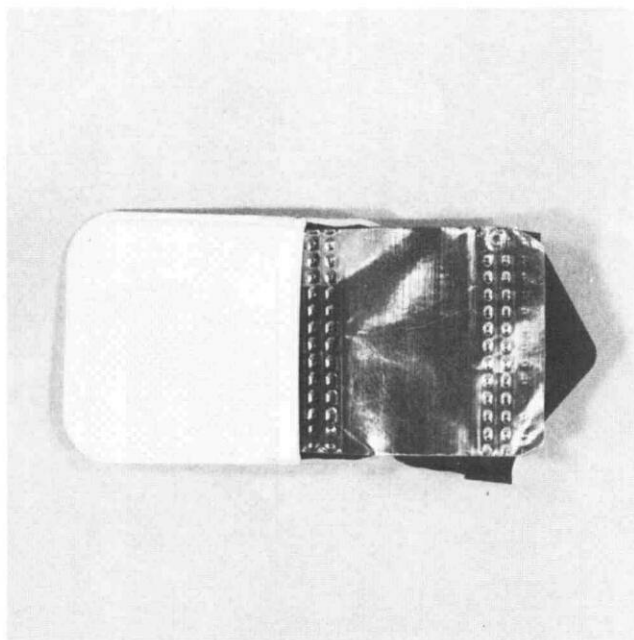
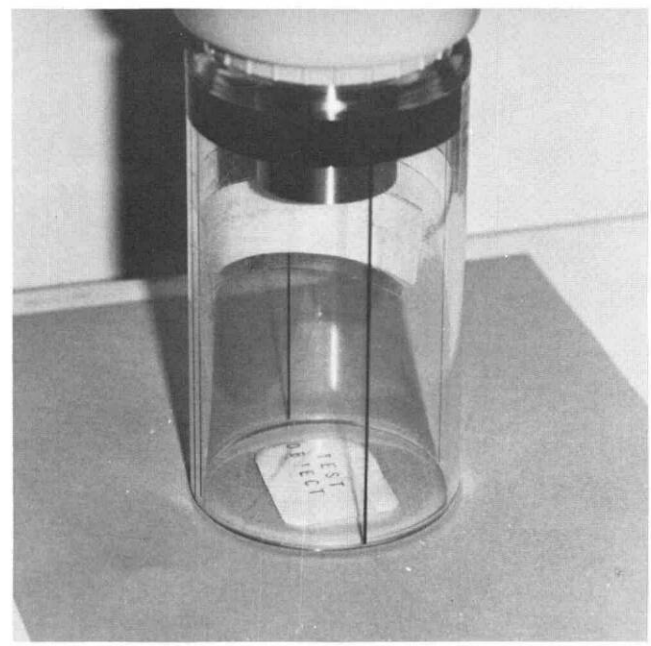


Figure 1: Construction and utilization of an office-constructed test object for use with No. 2 dental film.
1A: Cut a paper template to the size of a No. 2 dental film. Draw lines horizontally at ¼" intervals.

1B: Tape pieces of lead foil saved from used No. 2 dental film packets at each marked interval. Cut off excess lead foil to size of paper template.





1C: Insert template to which the pieces of lead foil have been taped into an empty No. 2 dental film packet.

1D: When using test object, place it on top of film to be exposed on a flat surface. Place tip of P.I.D. over test object and film in contact with flat surface.

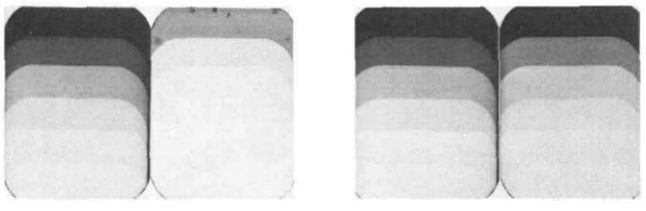
construction. A thermometer for measuring solution temperatures is the only other instrument that is needed.

1. Image Processing. Film processing is the single most variable step in the production of an x-ray image. Therefore, the following tests should be performed on a daily basis. Reproducible results can only be obtained if a time/temperature method of development is adhered to.[3] "Sight developing" should never be used during these quality assurance tests or routine processing.

A thermometer should be allowed to come to equilibrium in the developing solution before any testing of image processing begins. If at all possible, the optimal time and temperature recommended by the manufacturer should be used; with most products, this will be 68°F and five minutes.

A standard test film which will be the basis of future comparisons of image processing should be prepared using a machine which is known to be properly calibrated and its performance verified. Expose a No. 2 dental film through the test object using normal mandibular molar technique. This radiograph should be processed in freshly prepared solutions according to the manufacturer's recommendations. After the film has been properly washed and dried, it should be mounted and kept in a safe place for future daily comparisons. When similar exposures are made on a daily basis, changes in film speed can be determined by the recognition of overall decrease or increase in density (Figure 2A). A similar test for automatic processors can be performed by deriving a standard using the same procedures described above. Alterations in film contrast can be recognized by non-uniform changing of density on the steps exposed through the test object (Figure 2B). The step with the least amount of lead should be completely black, representing near maximum density. Each individual step should have a uniform density; variation within a step being an indication of artifact.

2. Tests of the Basic Characteristics of the X-ray Generator. The basic characteristics of the x-ray generator which may easily be measured by the dentist or auxiliary personnel without specialized equipment are: reproducibility of x-ray output, linearity of mAs stations, field size and density, and mechanical stability of the tube head and arm suspension.



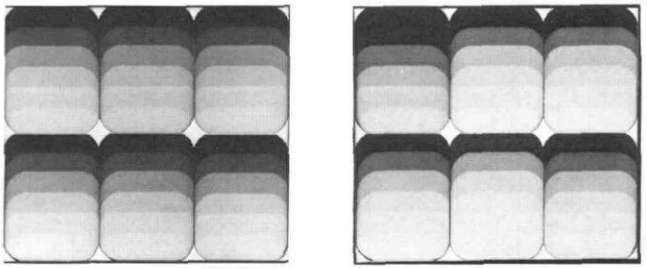
A B

Figure 2: A: Left side: standard test film (see text). Right side: test film showing change in film speed as evidenced by overall changes in density.
B: Left side: standard test film (see text). Right side: test film showing change in film contrast as evidenced by non-uniform changing of density on the steps.

Reproducibility refers to the consistency of the x-ray output over time of an individual machine using the same technique factors.[4] Linearity refers to the relationship between the change in x-ray output as a function of time from an individual machine assuming all other technique factors remain constant.[5] The size of the x-ray field as it exits the P.I.D. (position indicating device or "cone") must be no larger than a legal limit of the state in which the generator is located and its density should be uniform. The suspension of the tube head and arm must be stable in any given position to prevent motion distortion. It is our recommendation that the following tests be used to measure these elements of x-ray generator performance performed at a minimum of three month intervals.

(a) Reproducibility of x-ray output

Expose a group of films through the test object one at a time using normal mandibular molar technique at five minute intervals for a total of six exposures. When all of the films are processed together in freshly prepared chemicals, the densities at each step should match precisely (Figure 3A). If the density at each step of the test object does not match on a set of films which are processed together, one must presume that there is a fault in machine performance (Figure 3B).



A B

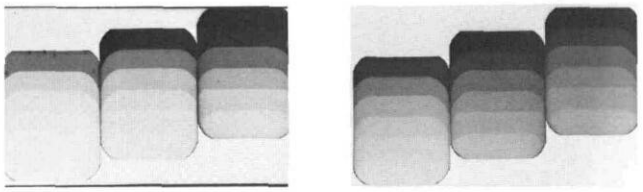
Figure 3: A: Six test films with equal densities at each step showing reproducibility of x-ray output.
B: Six test films with varying densities at each step showing lack of reproducibility of x-ray output.

Several factors may contribute to this variability. Unstable line voltage is a common reason for the production of films of different densities and contrast levels; however, in most parts of the country, electrical supplies are carefully regulated and information about the power supply can usually be obtained from the electric company or a building engineer. In addition to fluctuations in line current, deteriorating performance of the x-ray timer or mA stabilizer can also

produce differences in both density and contrast. The end result of each of these problems is a loss of reproducibility which means that images on radiographs exposed using the same technique factors will not be comparable.

(b) Linearity of the mAs stations

One film should be exposed through an office fabricated test object using normal mandibular molar technique. A second film should be exposed through the same test object using one-half of the mAs of the first exposure and a third film exposed using twice the mAs of the first exposure. When the three films are processed together, step two on the first film (normal molar technique) should be equivalent to step one on the second film (one-half of the mAs of the first film) and step three of the third film (twice the mAs of the first film). Figure 4A illustrates this relationship. Should a comparable visible shift fail to occur, one may presume that there is a lack of linearity in changing from one mAs to another (Figure 4B). The end result will be an inappropriate change in density as the mAs is changed.



A B

Figure 4: A: Three test films with appropriate relationship (see text) showing linearity of the mAs stations.
B: Three test films without appropriate relationship (see text) showing lack of linearity of the mAs stations.

(c) Field size and density

The field size at the end of the P.I.D. can be simply measured by exposing an occlusal film which is in contact with the open end of the cylinder. The darkened area of the film should measure no more than 2.75 inches or 7.0 centimeters.[6] In addition, the density across the exposed part of the film should be uniform (Figure 5A). If the field size exceeds the legal limit or if the density is not uniform, the possibility of a badly fitting or damaged P.I.D., or of a malpositioned x-ray tube in the tube housing should be investigated (Figure 5B). Machines which use a lead diaphragm for collimation should be examined for improper positioning or alignment of the diaphragm if problems are evident during testing.

Malalignment of the x-ray field may result in cone-cutting or image distortion. Density aberrations across the field may result in non-uniformity of the density of the image. In general, defects found as a result of these tests of machine performance cannot be remedied by the dentist but require the efforts of a properly trained serviceperson.

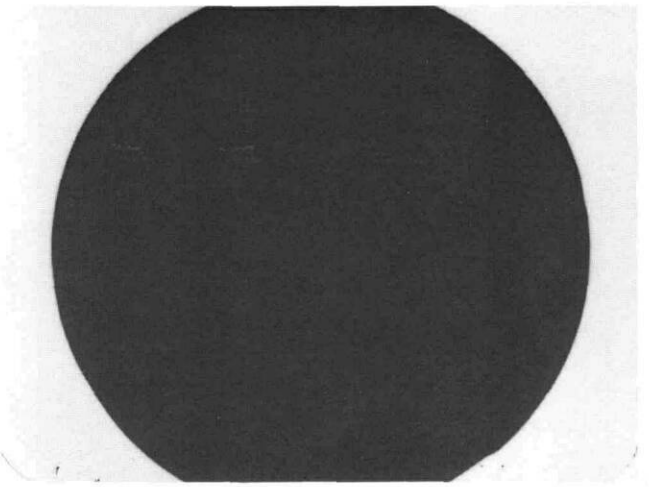
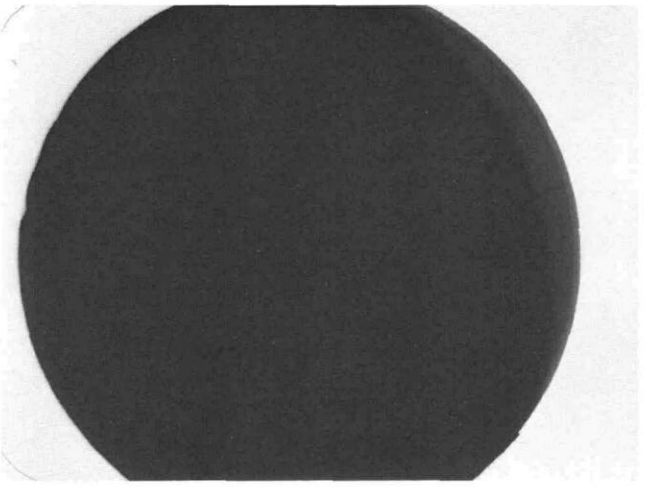


Figure 5: A: Occlusal test film showing acceptable field size and uniform density.



B: Occlusal size test film showing unacceptable field size and non-uniform density.

(d) Mechanical stability of the suspension

The tube head of an x-ray generator is suspended from its support by a retractable arm. If the suspension is not stable, the tube head may drift or vibrate while its arm is extended during use. The stability may easily be measured by placing the tube head and arm at the maximum extension from the support. Watch for drift or vibration as the tube head is released. If there is any movement of the tube head, the result may be motion distortion. Such instability may be corrected by adjusting the suspension as recommended by the manufacturer in the operator's manual.

3. X-Ray Receptors. The quality of most dental x-ray film is carefully controlled by the manufacturer in compliance with industry standards.[7] A common cause of spoiled film is fogging, often the result of improper storage. To measure the amount of base plus

fog[b] of dental x-ray film, process an unexposed film in freshly prepared solutions. Following adequate washing and drying, most dental x-ray film should appear transparent with a slight blue tinge. No artifacts should be noted on the film. If fogging is noted on the test film, one should examine the method of storage and rotation of the boxes of film. Dental film is best kept refrigerated and away from any source of radiation, chemical vapor, heat or high humidity. Film should be purchased at intervals which insures use prior to its expiration date. Film which has passed the expiration date should be discarded and never used for diagnostic purposes[c]. This test should be performed monthly.

4. Darkroom or Daylight Loader Integrity. It is important to insure that no light capable of sensitizing the film be allowed into the darkroom (or daylight loader of an automatic processor). A simple test for this problem is to remove a dental film from its packet in a safelighted darkroom and place it on a flat surface in the area where film is normally handled (or on a flat surface inside of the daylight loader). On top of the film, place a coin or other opaque object which incompletely covers the film. Allow it to remain in place for at least five minutes (this is presumed to represent the maximum time during which a film may be exposed to these conditions during normal processing). Following this interval, process the film using normal technique. If there are any light leaks from safelight defects or breaches in darkroom integrity, the area of film not under the coin will have been sensitized and appear to have an increased density after processing (Figure 6).

Discussion

There are a number of reasons for developing quality assurance programs in dental radiography. Prior to 1974, there were no requirements for machine performance[8] and the operating stability of many x-ray generators in use today is uncertain. Studies have shown that there are a variety of types of machine malfunction which may occur as a result of use and aging.[9,10] There is evidence to suggest that sight development is a common practice used to compensate for inadequate machine performance, inadequate operator training, or defective processing chemistry.[11] In a recent paper, we described how a quality assurance program may be helpful in minimizing patient exposure and radiation risk.[12] There is also an economic incentive for reducing the number of retakes through a quality assurance program which also minimizes the expenditure for labor and materials[13]. In addition, serious liability can result from mis-diagnosis caused by poor radiographs.

Governmental intervention in this area is becoming a more likely possibility. Several states, such as Illinois,[14] have established maximum allowable exposures for diagnostic x-ray procedures. The Commissioner of the Food and Drug Administration has recently proposed recommendations for the implementation of quality assurance programs in all diagnostic radiology facilities including private dental offices.[15] Several studies were cited by the F.D.A. as part of its proposed recommendation. The first citation referred to information obtained from an examination of radiographs submitted to the National Institute of Occupational Safety and Health under its pneumoconiosis compensation program.[16] Although facilities participating in this program were screened, Trout et al. found that 44% of the participating units had from 10 to 40% of their radiographs rejected as being of inadequate quality for the diagnosis of pneumoconiosis.

A second study by Beideman et al. examined preauthorization dental radiographs submitted to the Pennsylvania Blue Shield.[17] A preliminary assessment of these radiographs found that at least 50% of the films were not adequate as a basis for evaluating proposed treatment plans. The Food and Drug Administration pointed out two consequences of poor quality images. In the first case, a suboptimal image denies the practitioner the full extent of diagnostic information that should be available. In the second case, the patient may receive unproductive radiation exposures as a result of radiographs which must be repeated.

The F.D.A. concluded that a considerable number of inadequate films resulted from processing failures, and it estimated that a dose reduction to active bone marrow could range from 209,000 to 330,000 rems annually by reducing the number of repeated radio-

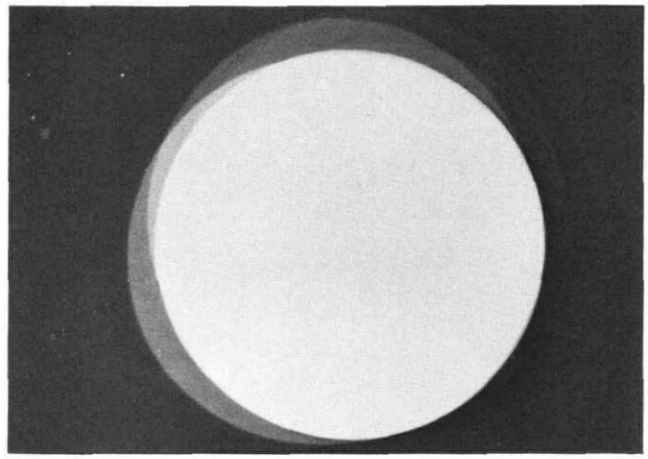


Figure 6: Test film showing result of exposure by darkroom light leak.

[b]Base plus fog: The amount of light attenuation which occurs when light passes through the celluloid backing plus any increased density due to sensitization of the emulsion of the x-ray film.

[c]Expired unexposed film or other discarded film can be sold for salvage because of their high silver content.

graphs in hospitals alone. The F.D.A. also estimated that elimination of retakes in non-hospital facilities would significantly add to this total, as would the elimination of unnecessary radiation exposure due to inappropriate films produced in both hospitals and private offices and clinics.

There are a number of programs which have attempted to improve radiologic practices in dentistry. The Dental Exposure Normalization Technique (DENT) program[d] is a federal project, managed by participating states, which is based on consultation with dentists to identify causes of excessive exposure and to suggest corrective actions which have been shown to effectively reduce the exposures.[18] The Nashville Dental Project proved the effectiveness of an educational approach for voluntary improvement of radiographic practice. Survey data were collected on 110 x-ray units (72 dental offices) in Nashville, Tennessee in 1972. Dental consultants visited the offices two months later to present the findings and to demonstrate techniques which would improve radiographic practice. In 1973, a follow-up survey was conducted to determine the effectiveness of the consultation visits. Average exposures were reduced from 472 mR/film in 1972 to 311 mR/film in 1973.[19]

In another Nashville study, Johnson and co-workers surveyed a number of dental offices to determine the reasons for high skin exposures. They found that although the dental x-ray generators surveyed were in general compliance with recommended standards, the overexposure was the result of dentists failing to use proper processing techniques[20].

Summary

We have described a quality assurance program for common intraoral dental x-ray generators and traditional modes of film processing. Practitioners who perform extraoral radiographic examinations will need to identify other test procedures to deal with the use of intensifying screens, cassettes, and adjustable collimators[21,22].

Dr. Valachovic was assistant professor, Dr. Reiskin is professor, and Ms. Kirchhof is staff radiologic technologist at the University of Connecticut School of Dental Medicine, Division of Oral Radiology, Farmington, Connecticut. Requests for reprints should be sent to Dr. Valachovic who is now Research Fellow in Dental Care Administration, Harvard School of Dental Medicine, 188 Longwood Avenue, Boston, Massachusetts 02115.

References

1. Nelson, R. E., Barnes, G. T., and Whitten, D. M.: "Economic analysis of a comprehensive quality assurance program," *Radiol Technol,* 49:129-134, 1977.
2. Goldman, L. and Vucich, J. J.: "Automatic processing Q.A.: impact on a radiology department," *Radiol,* 125:591-595, 1977.
3. Bureau of Radiological Health: "Fast film exposure and processing in dental radiography," DHEW Publ. No. (FDA) 78-8039, Supt of Documents, Govt Print Off, 1978.
4. Gray, J. E.: "Photographic quality assurance in diagnostic radiology, nuclear medicine and radiation therapy," DHEW Publ. No. (FDA) 76-8043, Supt of Documents, Govt Print Off, 1976.
5. Starchman, D. E., Johnson, R. G. and Howland, W. J.: "Linearity of exposure with indicated time and current for diagnostic radiography units," *Radiol,* 122:489-492, 1977.
6. National Council on Radiation Protection and Measurements: "Dental x-ray protection. NCRP Report No. 35," Washington, National Council on Radiation Protection and Measurements, 1970.
7. A.N.S.I.: "Reg. U.S. Pat. Off. PH6.2-1970 (Rev. of PH6.2-1961)," Approved March 3, 1970 by the American National Standards Institute, Inc.
8. Bureau of Radiological Health: "Regulations for the administration and enforcement of the radiation control for Health and Safety Act of 1968 — diagnostic x-ray systems and their major components," DHEW Publ. No. (FDA) 75-8003. Supt of Documents, Govt Print Off, 1974.
9. Rosenthal, R. B. and Malcolm, J. C.: "Results of a program directed toward reduction of dental x-ray exposure," *Radiol Health Data Rep,* 11:109-115, 1970.
10. Crabtree, C. L., Johnson, O. N., and Gibbs, S. J.: "Nashville dental project: an educational approach for voluntary improvement of radiographic practice," DHEW Publ. No. (FDA) 76-8011, Supt. of Documents, Govt Print Off, 1975.
11. Travis, K. L. and Hickey, J. E.: "A state program for reducing radiation exposure from dental x-ray machines," *Am J Publ Health,* 60:1522-1526, 1970.
12. Valachovic, R. W. and Lurie, A. G.: "Risk-benefit considerations in pedodontic radiology," *Pediatr Dent,* 2:128-146, 1980.
13. Patrylak, J.: "Counting x-ray retakes reduces cost," *Appl Radiol,* 7:35-36, 1978.
14. State of Illinois Dept. of Public Health: "Rules and regulations for protection against radiation," Adopted 1961 and Amended 1976.
15. U.S. Dept. of H.E.W.: "Quality assurance programs for diagnostic radiology facilities, final recommendations," *Fed Reg,* 44:71728-71740, 1979.
16. Trout, E. D., Jacobsen, G., Moore, R. T., and Shoup, E. P.: "Analysis of the rejection rate of chest radiographs obtained during the coal mine black lung program," *Radiol,* 109:25-27, 1973.
17. 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.
18. Gross, R. E., Crabtree, C. L., and Bunge, R. E.: "DENT, A quality assurance program in dental radiography," Health Physics Soc. - 9th Midyear Topical Symposium, 1976.
19. Gibbs, S. J., Crabtree, C. L., and Johnson, O. N.: "An educational approach to voluntary improvements of dental radiological practices," *J Am Dent Assoc,* 95:562-569, 1977.
20. Johnson, O. N., Crabtree, C. L., and Gibbs, S. J.: "Nashville dental x-ray study," *Proc Int Cong of Int Rad Prot Assoc,* 3: 1109-1112, 1974.
21. American Association of Physicists in Medicine: "Basic quality control in diagnostic radiology," AAPM Report No. 3, 1978.
22. Bureau of Radiological Health: "Health physics in the healing arts," DHEW Publ. No. (FDA) 73-8029, Supt of Documents, Govt Print Off, 1973.

[d]Dentists wishing to utilize the services of the DENT program should contact their own states' Departments of Radiation Control or other appropriate agencies.