AD-A268 589

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

tion is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, pleting and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this educing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson , and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
1993

3. REPORT TYPE AND DATES COVERED
THESIS/~~DISSERTATION~~XXXX

4. TITLE AND SUBTITLE
Interpretation of Endodontic File Length Adjustment Using RadioVisioGraphy

5. FUNDING NUMBERS

6. AUTHOR(S)
Beverly J. Leddy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
AFIT Student Attending: Indiana Univ School of Dentistry

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/CI/CIA- 93-069

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
DEPARTMENT OF THE AIR FORCE
AFIT/CI
2950 P STREET
WRIGHT-PATTERSON AFB OH 45433-7765

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release IAW 190-1
Distribution Unlimited
MICHAEL M. BRICKER, SMSgt, USAF
Chief Administration

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

DTIC
ELECTE
AUG 20 1993
S B D

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

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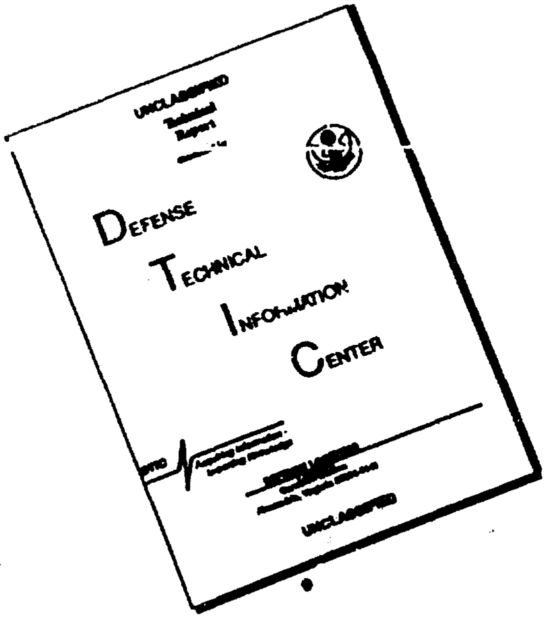

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INTERPRETATION OF ENDODONTIC FILE LENGTH ADJUSTMENTS USING RADIOVISIOGRAPHY

by

Beverly J. Leddy

Submitted to the Graduate Faculty of the School of Dentistry in partial fulfillment of the requirements for the degree of Master of Science in Dentistry, Indiana University School of Dentistry, 1993.

93 8 19 092

93-19387

Author: Beverly J. Leddy

Title: Interpretation of Endodontic File Length Adjustments Using RadioVisioGraphy

Rank: Major

Branch: U. S. Air Force

Date: 1993

Pages: 137

Degree: Master of Science in Dentistry

School: Indiana University School of Dentistry

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INTERPRETATION OF ENDODONTIC FILE LENGTH ADJUSTMENTS USING RADIOVISIOGRAPHY

by

Beverly J. Leddy

Indiana University School of Dentistry
Indianapolis, Indiana

The purpose of this in vitro investigation was to determine if accurate endodontic file length measurements can be made using RadioVisioGraphy (RVG) images. Comparisons were made between RVG images and conventional periapical radiographs.

Maxillary and mandibular human cadaver sections with a first or second molar and patent canals were used for experimental specimens. Size 10 K-type files were inserted into the canals at randomly selected lengths. Lengths varied from 4 mm short of the radiographic apex to 3 mm beyond. Radiographs were made using E-speed film, and images were made using the Trophy RVG. Radiographs and images were evaluated by three endodontists to determine the adjustment

needed to place the tip of the file 0.5 mm from the radiographic apex.

The results showed there is no significant difference in the ability of endodontists to make accurate file length adjustments using conventional radiography versus RVG. Under the conditions of this study, the following conclusions were drawn: (1) it is possible to make accurate file length adjustments from an image two times larger than the actual tooth, (2) RVG is not significantly better than conventional radiography for determining endodontic file length adjustments, (3) if both methods are available, RVG is preferred because of the significant reduction in patient radiation burden.

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Thesis accepted by the faculty of the Department of Endodontics, Indiana University School of Dentistry, in partial fulfillment of the requirements for the degree of Master of Science in Dentistry.

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ACKNOWLEDGMENTS

I wish to express my sincerest appreciation to those who assisted me in my endodontic education as well as with this research project and thesis.

I want to acknowledge the support of the United States Air Force in sponsoring my training and research.

My thanks to Dr. Carl Newton for helping me select the topic for my research. His influence on the endodontic department is the driving force behind its well-respected reputation.

My heartfelt gratitude goes to Dr. Cecil Brown. He didn't laugh to my face when he read the first draft of this thesis. The caring and interest he shows for his residents set this graduate program well apart from the others.

Thank you to the other members of my graduate committee, Dr. Joseph Legan, Dr. Dale Miles and Dr. Susan Zunt. Their contributions to my educational experience have been invaluable.

I want to thank my fellow resident, Dr. Eric Yokota for keeping the competitiveness low and the camaraderie high. The two years were more bearable shared with someone experiencing the same kind of family separation.

My appreciation to Karen Bissonette, not only for her hard work making my clinical experience easier, but also for her friendship.

And last, my love and thanks to my family. My parents Gene and Margie Kunzman provided unconditional support and encouragement for my training, even after I chose to attend a program 600 miles from them. They worry.

Words cannot express enough thanks to my husband, Carl Leddy. It is his belief in my ability to succeed at every endeavor these past 22 years that has made my career and my life a success.

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INTRODUCTION

Many studies have addressed the proper location within the root canal at which preparation and obturation should end. The location of the apical foramen is well documented.[1-9] Studies of periapical healing after endodontic treatment have shown the importance of accurately determining endodontic working lengths to confine preparation within the root canal.[10-17]

Traditionally, endodontic file length adjustments have been measured with the use of conventional radiographic techniques.[18-23] These are affected by a number of variables related to type of x-ray film,[24-30] processing,[31,32] and viewing conditions.[33-41]

Conventional radiography has the disadvantages of: (1) exposure of the patient to low level ionizing radiation,[42-44] (2) taking several minutes to process the film,[45] and (3) difficulty interpreting very small file sizes in the canal.[45,46]

The latest dental imaging system approved for use in the United States is RadioVisioGraphy (RVG).[47-49] RVG is purported to overcome some of the disadvantages associated with conventional radiography. The amount of radiation required for exposure is 80 to 95 percent less than for conventional x-ray film. It provides an image immediately for viewing in a monitor or on a videoprint; there is no idle processing time. The image can be enhanced either on the monitor or the printer for better viewing of very small files.

One clinical trial with RVG mentioned its use for endodontic treatment but made no assessment of its efficacy for making file length adjustments.[47] Subsequent studies have compared RVG images and conventional radiographs when viewed for root canal spaces and endodontic files.[50,51]

The printed image obtained with RVG has three sizes: approximately one half smaller, and two times or four times larger than the tooth (Figure 1). The image produced with conventional radiography is about 5 percent larger than the tooth.[52] No study has evaluated the ability of an operator to determine file length adjustments using the RVG image.

The purpose of this in vitro investigation is to determine if accurate endodontic file length adjustments can be made using RVG images approximately two times the size of the tooth, compared to conventional radiographs.

REVIEW OF LITERATURE

TERMINATION OF THE ROOT CANAL

Early 20th century dentists believed the pulp extended through the apical foramen.[10] Later, several authors offered macroscopic evidence that periapical tissue was different from pulpal tissue in human teeth, and that the periapical tissue ended at the dentinocemental junction.[10,18,53] The point of change could not be accurately determined. This led Coolidge[53] to state "it would matter little whether it [the pulp] were cut off at the foramen or 2 to 3 mm up in the canal." This began the present treatment philosophy of confining instrumentation, medications and obturation within the root canal space.

Anatomical Considerations

The concept that the change from pulpal tissue to periapical tissue occurs at the smallest diameter of the apical foramen is supported by anatomic studies. Kuttler[4] studied the apices of 236 extracted teeth microscopically, and concluded that the apical foramen has both a major and minor diameter. He determined that the minor diameter was away from the vertical apex in 68 to 80 percent of the teeth. The position of the minor diameter was an average of 0.5 mm from the vertical apex. Green[2,3] studied root apices of 1100 specimens. He showed a deviation of the foramen from the vertical apex in 50 percent of posterior teeth and in 44 percent (maxillary lateral incisors) to 78 percent (mandibular canines) of anterior teeth.

Microscopic studies of root apices were continued in the 1970s and 1980s. Burch and Hulen,[1] and Dummer et al.[5] found that the foramen deviated from the vertex an average of 0.59 mm and 0.89 mm in their respective studies. Using the radiographic apex as their reference point, Levy and Glatt[6] found that 66.4 percent of teeth studied had a foramen exiting short of the vertex. Furthermore, half of those deviations were to the buccal or lingual and could not be detected radiographically. Palmer et al.[7] found that 50 percent of their sample deviated from the radiographic apex from 1.0 to 2.5 mm. Singh Bal and Dua[8] concluded that the foramen deviated 80 percent of the time and ranged from 0.1 to 1.3 mm from the radiographic apex.

A recent study combining the stereomicroscope and radiographic interpretation of the foramen was conducted by Blaskovic-Subat et al.[9] They concluded that deviation of the major foramen occurs in 76 percent of teeth with an average distance of 0.99 mm. Radiographs alone were unreliable for identifying this deviation.

Treatment Philosophy

Authors differ on where to end instrumentation and obturation of the root canal space. When authors advocate working to the foramen and not beyond, it is assumed they mean instrumentation should only be done to the radiographic point of egress of the canal and not beyond.[18,53-55] Liebman [56] states that instrumentation should stop at the apical constriction.

The point at which instrumentation and obturation should end was identified more explicitly after anatomic studies. Weine[57] and Fink[58] advocate ending root canal preparations 0.5 to 1.0 mm from the radiographic apex. Their conclusion is based on the works of Kuttler et al.[4] Schilder[59] agrees and states that this will result in a root canal system "essentially filled to its entirety" if it has been filled in three dimensions. However, he adds that a root canal filling carried to the radiographic apex, or where the root canal joins the periodontal ligament space "may more closely approach the 100 percent total filling of the root canal system." Schilder advocates preparing canals to the radiographic apex.[60]

Buchanan [61,62] agrees, but he does not espouse the belief in a major versus minor diameter. He believes that the cementodentinal junction is a wider point in the canal anatomy than the apical constricture. He equates the apical constricture to the anatomic foramen and he advocates instrumentation and obturation to the apical constricture (foramen).

Periapical Healing

Studies assessing healing of the periapical tissues after root canal therapy reinforce the need to control instrumentation and obturation. Early belief in canal obturation to the radiographic apex was based on a study by Rickert and Dixon[63] in which implanted materials were used. They determined that root canals must be filled with substances that are tolerated by the tissues "to the very end of the tooth to prevent diffusion." But as early as 1921, Grove[10] showed radiographically more successful cases of healing when the canal was "fairly well-filled" as opposed to filled to the apex. In a retrospective study of 2,921 teeth, Seltzer et al.[11] reported 87.2 percent success when teeth were underfilled and 70.6 percent success with overfilling.

Torneck[12,13] repeated the studies of Rickert and Dixon using less irritating polyethylene tubing in rabbits. He observed that underfilling a completely cleaned canal would probably result in healing, as would leaving non-infected debris at the apex. Histologic studies in rats by Erausquin et al.[16] showed necrosis of the periodontal ligament when various filling materials partially or totally occupied the periodontal ligament space. Seltzer et al.[14,15] studied histologic specimens of periapical lesions in humans and monkeys. They demonstrated that instrumenting into the periapical tissues would cause apical granulomas, and sometimes epithelial proliferation leading to cyst formation. They believed that better results were obtained with vital pulps that were instrumented and filled short of the radiographic apex. In a retrospective study of 1,007 teeth, Swartz et al.[17] reported that teeth with overfilled canals were four times more likely to fail than teeth with underfilled canals. According to Storms[64] and Halse and Molven[65] there is no statistical difference between well-condensed underfilled and overfilled canals.

Questions of radiographic reproduction of periapical lesions have been raised. Duinkerke and van de Poel[66] could not visually determine differences in sizes of lesions even though rigid techniques were used in positioning. They concluded that inference must be limited when using results obtained from non-standardized radiographic views.

ENDODONTIC WORKING LENGTH

History of Dental Radiography

The x-ray was discovered in 1895 by Wilhelm Roentgen in Würzburg, Germany.[67,68] Walkoff in Brunswick, Germany, created the first intraoral radiograph the same year.[67]

Morton[69] was the first to mention to the dental profession that "the pulp chamber is beautifully outlined" on radiographs. The first use of radiographs in endodontics was reported in 1899 when C. Edmund Kells wrote of radiographing a lead wire in the central incisor of a young boy to see if it reached the end of the canal.[67,68] The use of radiographs as a standard in endodontic care took hold rapidly. In 1916 Merrit[70] advocated the use of pretreatment, instrumentation and postoperative films. In 1936 Liebman[56] also urged use of preoperative and postoperative films as well as recall radiographs because "pulpless teeth do not always remain the same." In his writing on the legal aspects of radiographs in 1938, Sweet[71] reported that, because of the universal availability of x-ray equipment, the courts make definite demand on dentists to use radiographs. By 1940 the consensus of the dental profession was for the use of frequent radiographs in the treatment of pulpless teeth.[72]

With the use of radiographs came the need for standardization of technique. An early example of a standardized reproducible technique was offered by McCormack[73] in 1920. He outlined his method of patient positioning, film positioning, exposure, and film processing. Because of the limits of technology at the time, his technique entailed the use of custom-cut film held in position with the patient's fingers.

A later technique that came into practice was the bisecting angle technique. It was developed independently early in this century by Price and Cieszynski.[74] This method relied on imagining a bisecting plane between the film and tooth and aiming the central ray perpendicular to that imaginary plane. This technique was fraught with image distortion and not very reproducible. It gradually fell from favor in the 1970s with the acceptance of the paralleling (right-angle) technique.

Fitzgerald[75] first wrote of the paralleling technique in 1947. He suggested the evaluation of the long axis of the tooth and placement of the film parallel to it. This method necessitates increasing the object-film distance. The development of higher energy x-ray generators and faster film made this feasible. Fitzgerald[76] recommended using a rubber cork and hemostat combination film holder to aid in achieving parallelism as well as reproducibility.

Increasing the object to film distance, however, caused loss of definition and resulted in blurring. Fitzgerald[77] addressed this problem by suggesting an increase in the film to anode distance. Prior to this time the conventional anode to film distance was 8 inches. Fitzgerald studied the effects of a variety of anode to film distances and found that a minimum of 14 inches was needed to maintain the highest possible degree of sharpness or definition of detail. He suggested that even greater cone distances would be advisable, up to the practical limit of 20 inches.

Updegrave[78-80] amplified the paralleling technique first by suggesting a set cone distance of 16 inches, purporting that any improvement past that length was negligible. In 1951 he showed how to construct a wire extension localizer to increase cone length on a standard 8 inch pointed tube head. This was the forerunner of today's open-ended long cone extension tube. In 1959 Updegrave introduced a set of plastic instruments to facilitate alignment of the film with the tooth and x-ray extension tube. These film holders eliminated mechanical angulation and specific head positioning and improved the ability to reproduce a radiograph. By 1968 Updegrave's instrument design had been developed into the Rinn XCP still used today (Rinn Corporation, Elgin, IL).

Radiographic Variables

Many variables affect interpretation of radiographs, including, among other things, the angulation of film placement before it is exposed and the viewing conditions used to evaluate the processed radiograph. In a series of articles, Thunthy[81-83] showed numerous examples of misinterpretation of radiographic images due to faulty angulation. Of importance to endodontics are examples of apparent carious pulpal exposure due to faulty vertical angulation and the inability to see two canals in a root due to improper horizontal angulation.

Although the paralleling technique improved some of the distortion inherent in the bisecting angle technique, some problems still exist. Barr and Grøn[84] studied palate contour to show the limitations of the technique when used in the maxilla. They found that films placed exactly parallel offered correct orientation of structures; however, the images were longitudinally magnified 5 to 10 percent and gave an adequate periapical view of only central and lateral incisors. In another series of projections, they positioned the film to diverge from the long axes of the teeth by not more than 20 degrees and directed the beam at right angle to the film. These radiographs showed more surrounding structure at the apex and freedom from longitudinal distortion, but there was less effective orientation of the structures. They suggested that true parallel film placement is probably not possible throughout the maxilla; however, good radiographs can be made with this technique if angles do not diverge more than 20 degrees.

Langland and Sippy[85] investigated the longitudinal distortion of maxillary and mandibular incisor teeth radiographed using the paralleling technique and the Rinn XCP film holder. They found 82 percent of the images were foreshortened and 18 percent slightly elongated. Of the 82 percent foreshortened, 78 percent were actually shortened to a value closer to the true tooth length. The elongated images were never elongated more than 0.6 mm. They concluded that the XCP anterior instrument should be used for working radiographs during endodontic treatment to minimize distortion and obtain consistently reproducible images.

The exposure parameters of kilovolt peak (kVp) and milliampere second (mAs) affect the diagnostic quality of radiographs. Knowledge of these concepts was of little consequence in the early days of radiography, because early x-ray equipment was manufactured to operate at a set kVp. With the addition of adjustable controls for kVp the need to understand exposure parameters became more important. Fitzgerald[86] and Updegrave[87] provided excellent understanding of the affects of kVp on density of the radiographic image. Density is defined as the degree of darkness on the film; contrast is the difference in degree of density between film areas. Kilovoltage is the indication of penetrative power of the x-rays. The higher the kilovoltage, the more penetrating the x-rays. This gives a wide gray range and low contrast. Low kilovoltage produces longer, less penetrating x-rays which produce high image contrast with fewer grays.

Webber et al.[88] compared radiographs using a phantom and exposures with 65 kVp and 90 kVp machines to assess presence of interproximal caries. Their results showed fewer diagnostic errors using 65 kVp. Oishi and Parfitt[89] studied the effects of varying kVp the on diagnostic quality of radiographs. They found that higher kVp settings reduced contrast between the tooth crown and interproximal space but that more evenly spaced shades of gray retained more of the available information. Also, the higher penetrance of the x-rays at 90 kVp allows for more variance in radiopacity of the tissues. The use of higher kVp techniques has the additional benefit of reduced radiation exposure to the patient because of shorter exposure time.

Thunthy and Manson-Hing[90] used a test pattern to assess the effect of kVp on resolution and image contrast. Resolution is the smallest distance between two objects that can be detected visually. In one experiment they kept density constant by adjusting mAs down as kVp increased. This resulted in lower resolution and lower contrast as kVp increased. However, increased mAs resulted in higher resolution and greater contrast. In another experiment the mAs and kVp were varied without correlation to each other, thus, density was not kept constant. The results were the same as with the initial study; however, there was no correlation between mAs and resolution or contrast. Okano et al.[91] altered the amount of radiation reaching the x-ray film by using screen-film systems and constant kVp to test diagnostic performance on an endodontic model using size 15 files. They found a wide range of diagnostically acceptable densities. This indicated the amount of exposure used was a less critical factor than observer variability for evaluating file position. They conclude that a "significant reduction in exposure would have a relatively small effect on the precision of endodontic distance measurements."

The type of film used can affect the quality of the image. Intraoral periapical x-ray film packets were first manufactured with hand-wrapped covers in 1913. In 1920 the machine-made periapical film packet was introduced. Periapical film suitable for rapid processing was introduced in 1938. This required 1 3/4 minutes processing time at 68°F.[92] The earliest dental x-ray films available required an 8 second exposure time. Today's technology makes it possible to use only 0.66 percent of the radiation formerly used.[25]

Absorbed x-ray doses have been reduced by the use of more sensitive films. Most recently E-speed film, which is twice as sensitive as D-speed film, has been introduced. Greater sensitivity is achieved by using larger grain sizes on film emulsion.[25] Kaffe et al.[30] studied the speed and quality of E-speed film and D-speed film. They found no deterioration in fog base, sharpness, resolution or contrast when using 50 percent less radiation and E-speed film. They highly recommended E-speed film for routine examinations.

In 1983 Girsch et al.[26] compared endodontic file length measurements using E-speed and D-speed films with cadaver specimens. Their study showed no significant difference in measurements using either film. In a clinical trial, Donnelly et al.[27] compared the suitability of E-speed film for routine endodontic purposes. They processed the films with rapid hand processing. Only nine of 168 Ektaspeed radiographs (5.4 percent) were deemed inadequate for the intended purpose. In addition, none of the evaluators were able to tell the difference between the two films while viewing them.

Kleier et al.[25] discovered that when radiographs made from Ektaspeed and Ultraspeed films were viewed side by side, evaluators consistently found Ultraspeed films superior in terms of contrast, image quality, and evaluator satisfaction. Endodontists generally prefer Ultraspeed to Ektaspeed film for diagnostic and working films.[29]

In 1990 Kaffe[24] reported no difference between brands of E-speed films. Kodak Ektaspeed was compared to Dentus M4 (Agfa Gevaert, Mortsel, Belgium) in an in vitro study. Both films were of almost equal image quality regardless of exposure or processing conditions.

Another variable in image quality relates to double film packaging. Jarvis, et al.[28] used a step-wedge, dried skull, and clinical study to test for differences in the double film packet. They found no difference in the step-wedge trial. They attributed that to the Mach band phenomenon and edge effect, which cause a compounded distortion in sharpness. However, they found significant differences between the two films in a dried skull versus clinical situation. Evaluators consistently chose the film closest to the x-ray source (front film) as having superior image quality. They concluded that, since the front film is sharper, it should be used for radiographic interpretation.

The processing of x-ray films in manual versus automatic processors was studied by Thunthy and Weinberg[31] and Kogon et al.[32] Thunthy and Weinberg found the highest image contrast for periapical films was obtained when manual processing was used; however, at low densities image contrast was nearly the same for manual and automatic processing. Resolution was the same for all processors.

Kogon et al.[32] compared Kodak Ektaspeed and Ultraspeed films in manual and automatic processors. With manual processing Ektaspeed films showed a sharp decrease in contrast when developed above 22°C. Ultraspeed film did not have this effect. With automatic processing neither film showed loss of contrast at temperatures higher than 28°C.

They concluded that "both films showed wide latitude through the full range of time variations in both processing methods."

Sewerin[33] reported on the influence of film mounting materials on the interpretation of intraoral radiographs. Eight film mounts made from different materials were compared. Six of these used a double layer of material to form a pocket, the other two were a single sheet of material to which the radiograph was taped or inserted into prepunched retentive slots. The result showed no association between opaqueness or thickness and ability to transmit light. The maximum density of the film mounts tested was 0.13, which is considered insignificant. He concluded that film mount material does not influence radiographic interpretation. Sewerin suggested the use of pocket film mounts to protect the radiograph and choosing a film mount based on qualities other than opacity and blurring effect of the material.

Manson-Hing[34] examined the relationship between vision and interpretation. Based on the physiology of the eye, he stated that radiographs should not be viewed through windows or in transparent mounts to reduce glare. Small or single films should be masked and surrounding light should be dimmed. The diagnostician should develop a standard pattern for scanning the radiograph a number of times, each time looking for a different entity or pathosis. He emphasized avoiding interruptions during scanning for maximum attention.

Brynolf[35] introduced a viewer that was held up to the eyes to simultaneously mask out room light and provide magnification of the radiograph. She advocated use of this viewer with a masked viewbox of variable light intensity. A simpler magnifier-viewer was suggested by Weisman.[36] It was a magnifier originally developed to view photographic slides. When used inversely it concentrated light and magnified the radiograph for more definitive viewing. Several studies were later conducted comparing Brynolf's viewer with other techniques for interpreting radiographs.

Antrim[37] compared the magnifier viewer to holding the radiograph up to the viewbox or projecting the image on a screen. He concluded that holding the radiograph up to the viewbox was more accurate than the other methods to detect a periapical radiolucency. He stated that the magnification of the other two methods allowed more to be seen and confused interpretation; diagnosis was more difficult.

In 1983 Welander et al.[38] radiographed test objects to compare (1) an unmasked viewbox under normal room light, (2) holding the radiograph up to a ceiling light with normal room light, (3) a masked viewbox under dimmed room light, and (4) normal room light using the magnifier viewer. They found no difference between an unmasked viewbox and holding the film up to the ceiling light. There was also no difference between the masked viewbox and the magnifier viewer. There was a significant difference between the unmasked methods and the masked methods. It was concluded that optimal viewing conditions include: (1) light-masking film mounts, (2) a masked viewbox, and (3) dimmed room light.

Mileman et al.[39] looked at the variable of viewbox illumination for interpreting proximal carious lesions. Examiners did not know the effect of viewbox illumination was the variable being studied. They found that illumination level was significantly associated with diagnostic accuracy of caries detection but at a degree one-tenth of that caused by examiner variability. Therefore, they concluded that illumination level is of minor clinical importance.

Arnold[40] investigated the influence of viewing conditions on the detection of interproximal carious lesions. He used the conditions suggested by Welander et al.[38] He compared those conditions to modification in illumination, use of accessories, projecting the images as slides, and projecting the images via televisions systems. Modification of illumination had only a slight negative influence on diagnostic quality; using a magnifying glass or magnifier viewer had a positive influence. The projection systems were generally disappointing. He did show that overexposed radiographs should be viewed under standard conditions and that underexposed radiographs were more accurately interpreted against the light of a window. For purposes of statistical analysis, the observer proved to be the most important element.

In a similar project, Espelid[41] compared viewing with ceiling light to using the magnifier viewer in a darkened room. He also used interproximal carious lesions. He discovered that diagnostic quality showed small variations with differing viewing conditions but that most differences were not statistically significant. He showed agreement with Arnold in that room illumination provided the best viewing conditions for underexposed radiographs and overexposed radiographs were best viewed in conditions of dimmed room light.

Examiner Reliability and Variability

Many studies have examined reproducibility of interpretations of an examiner or examiners (intraexaminer and interexaminer agreement.) Garland[93] first studied examiner agreement in 1950 using radiographic surveys for tuberculosis. He cited a 1944 study in which intraexaminer agreement using chest films was 76 to 95 percent. Interexaminer agreement ranged from 69 to 97 percent. He suggested that the reliability of the results using radiographic surveys depends on the competence of the examiners, the use of dual readings, and the quality of the radiograph.

Brynolf[94] studied the reproducibility of radiographic interpretation of the periapical area of 290 anterior teeth using one examiner at two settings. She found agreement with herself 70 percent of the time when only one radiograph was viewed. Using three views from different angles, she agreed with herself on 87 percent of the cases. Substantial disagreement occurred in 3 to 5 percent.

Goldstein and Mobley[95] tested the ability of senior dental students to correctly identify interproximal caries on bite-wing films projected as slides. The students were retested within two hours. Overall, 72.5 percent of the slides were correctly classified. Intraexaminer agreement was 90 percent for the two readings. Interexaminer agreement was 70 percent. The authors concluded that radiographic interpretation is not a consistent process and, given the low interexaminer agreement, dual reading of questionable radiographs is not a panacea for observer error. In a follow-up study,[96] when examiners were given an incentive to correctly identify pathosis and not penalized for identifying pathosis where none existed, there was a higher number of false positives. On the other hand, when penalized for false positives, responses were more conservative. The examiners made the lowest number of correct identifications as well as the lowest number of false positives.

Many studies followed Brynolf's initial intraexaminer investigation. Goldman et al.[97] had six examiners assess 253 endodontic cases for healing, based on criteria of apical appearance. The six examiners agreed 47 percent of the time. The agreement was less than 50 percent whether examiners were determining the presence of radiolucencies on one film or two films. Cases were re-examined six to eight months later by three of the original examiners. Interexaminer agreement was

55 percent in the second reading. The intraexaminer agreement ranged from 72 to 88 percent. Intraexaminer agreement was only slightly better when determining the presence or absence of a radiolucency on one film compared to two films. The authors concluded that there is little confidence in radiographic interpretation.

Nielson[98] reported an interexaminer agreement of 65-75 percent and intraexaminer agreement of 75-90 percent in assessing quality of root canal filling and extent of periapical changes in 191 endodontically treated teeth. Assessing the same parameters of treatment in 119 roots, Reit and Hollander[99] found interexaminer agreement among three endodontists and three radiologists to be 27 to 37 percent for detection of apical pathosis, and only 12 to 25 percent on quality of root filling. Lambrianidis[100] had nine dentists evaluate 90 teeth for periapical healing and quality of root canal filling. He reported interexaminer agreement only slightly higher at 38 to 41 percent. His intraexaminer agreement was 57 to 65 percent when nine weeks elapsed between viewings.

A different approach was taken by Gelfand, et al.[101] Ten endodontically treated cases were evaluated by 79 dentists to assess success or failure of treatment. Inter-examiner agreement was less that 50 percent. They found that 21.8 percent of the examiners disagreed with themselves after viewing an identical case 2 1/2 minutes after seeing it the first time.

When comparing viewing techniques, Antrim[37] also found that six examiners agreed with each other 48.2 percent of the time. In a post-evaluation questionnaire the examiners had predicted there would be agreement in 50-90 percent of the cases.

Four endodontists examined 330 cases in a study by Zakariasen et al.[102] in 1984. One third of the cases were viewed a second time. There was better interexaminer and intraexaminer agreement when the number of diagnostic categories decreased from four to two categories. They also found that variables related to the quality of radiographs, anatomic location imaged, and time between postoperative and recall radiographs did not affect interpretation results. Wahab et al.[103] attempted to determine pulp vitality from non-vitality using radiographs of anterior teeth. Their examiners agreed among themselves on only 1 of 50 radiographs on the first viewing and none on the second session when assessing periapical status. Intraexaminer agreement was 47 percent. They concluded the probability of determining pulpal vitality from a radiograph is 0.5 percent.

Long-term investigations having a large number of experimental participants frequently need to employ multiple examiners. High levels of inter- and intraexaminer reliability are needed to avoid distorted findings. In an effort to improve agreement levels, several studies were undertaken to test the effect of calibration of examiners prior to interpreting radiographs. Using two observers, Eckerbom et al.[104] designed a project to evaluate 20 sets of radiographs for various endodontic entities. Calibration was done by having both examiners review 20 sets of radiographs not included in the study, then compare and discuss their positive findings. Strict criteria for positive findings were agreed upon. Their examiners were in agreement 97 percent of the time regarding presence of apical radiolucency and 71 percent of the time concerning quality of root canal filling. These figures appear to show the value of calibration.

Studies by Halse and Molven[105] and Molven et al.[106] tested the efficacy of using an observer strategy to improve examiner agreement. This included training of examiners with test material prior to the actual experiment. Halse and Molven reported 82 percent agreement when each examiner evaluated the radiographs separately, using the agreed upon criteria; however, when joint evaluation of disagreement was done there was 98 percent agreement. The strategy used by Molven, et al. was similar using criteria agreed upon and calibration prior to evaluating the experimental radiographs. These cases were examined separately by an oral surgeon and an endodontist for a 79 percent agreement rate. After discussion they agreed on a further 15 percent for a total agreement of 94 percent. The remaining cases were then independently reviewed by an oral radiologist who disagreed with both main examiners 7 percent of the time. The authors concluded that use of specialists and identifying a strategy and classification will increase the reliability of a radiographic investigation.

The entire realm of radiographic interpretation of endodontic entities was summed up by Tidmarsh:[107]

> "The radiographic interpretation of pathological lesions which are endodontic in origin is relatively imprecise as so many variables are involved. Even the presence or absence of a lesion cannot be determined with accuracy and there is little agreement on the criteria which should be applied. Strict attention to the technique of exposing, processing and viewing radiographs is necessary if the information to be gained is to be optimal. The major problem of visual interpretation and the psychological factors involved have been subjected to a certain amount of study and recent work on the mental processes of clinical decision making provide further insight. There is considerable promise being shown by methods of computer analysis and image enhancement and it may be that further development in these fields will provide the degree of objectivity that is essential if improved accuracy in diagnosis is to be achieved."

Radiographic Methods of Determining Working Length

In 1918 Custer[108] wrote, "pulp canals have been half filled and overfilled for want of accurate knowledge of root length." The traditional method for determining endodontic working length from his time to the present is the use of conventional radiographs with instruments placed in the root canals. Custer created a set of steel broaches with millimeter notches in the handles for placement in canals. The tooth was then "skiagraphed" with the broach in place and the root length determined by the notches on the handle.

Blayney[18] advocated the use of radiography with assorted sizes of measuring wires in the root canal. He reported that radiographs will not always give the true length of the root but offered a formula relating the length of the measuring wire to the shadow cast by the wire to arrive at an accurate estimate. Cave[19] used a grid made of cellophane with enameled wire embedded in it, divided into squares of 5 mm. The only necessity was that the grid be placed parallel to the tooth somewhere between the tooth and the x-ray tube head. He suggested strapping the grid to the outside of the face with adhesive plaster.

Adams[21] used multiple angled radiographs to determine root length. A wire was used to compare its image on a radiograph. He believed that if one image of the wire was the same length as the wire, the image of the tooth was true. In 1950 Bregman[23] reported a simple mathematical formula that took advantage of the elongation that so often occurred in endodontic radiographs. He place a file a known distance into the canal, radiographed the tooth, and measured both the length of the wire in the film and the length of the tooth. His formula stated the real length of the wire divided by its apparent length times the apparent length of the tooth equals the real length of the tooth. He offered one example showing a perfect result. The advantage to his method was that he always worked within the tooth to avoid trauma to the periapical tissue.

Ingle's[20] method appears to be the simplest for file length determination. He estimated the root length from a diagnostic radiograph and inserted a file to that length and made a second radiograph. Adjustment was made by adding or subtracting an amount as needed, depending on the location of the file relative to the apex. Cox et al.[46] subsequently found that this type of determination was most accurate when the adjustment was no greater than 0.5 mm. They suggested a second radiograph when the needed adjustment was 2.0 mm or greater.

Best et al.[109] proposed a method for root length determination that did not require inserting a file in the tooth. Before making a preoperative radiograph, a 10 mm stainless steel pin was placed parallel with the tooth and held in position with soft wax. The resultant radiograph was held next to a measurement scale in a position relative to the radiographic length of the pin and in a position relative to the radiographic length of the tooth. The actual length could then be read off the scale. The authors believed the advantage of this technique was eliminating the need for radiographs after rubber dam placement. They found their method to be 95 percent accurate against actual measurement of extracted teeth and 99 percent accurate when evaluated against post-obturation films.

With the same goal in mind, i.e., eliminating the need for additional radiographs during endodontic treatment, Benkel et al.[110] proposed a method for making the diagnostic radiograph with a paralleling technique and an x-ray film with a grid attached. Their clinical study compared measurements obtained with the grid film to a conventional file length film taken during endodontic treatment. They found that the gridded films provided measurement within $\pm$ 0.5 mm of those made with conventionally placed intratreament films in 24.4 percent of the cases and within $\pm$ 1.0 mm in an additional 34.4 percent. In 37.7 percent of the cases there was no difference between the measurements from the gridded films and conventional films. The authors concluded that a parallel gridded pretreatment radiograph was accurate enough to replace conventional intratreatment file length radiographs.

A technique using a set of beam guiding instruments was introduced by Jensen and Turek[111] in 1978. These instruments differed from the Rinn XCP in having variable position bite blocks to accommodate endodontic files. They were also shielded to decrease radiation dose to the skin. Larheim and Eggen[112] studied the use of a similar film holding device coupled with x-ray film prestenciled with a 2 mm square measuring grid. Radiographing 50 teeth scheduled for extraction, they found the technique accurate to $\pm$ 1 mm of actual tooth length after extraction for 95 percent of the teeth. In 1989 Voss and Hickel[113] sought to further improve length determination techniques with the development of a measuring instrument made from hard gold alloy. This material combined the flexibility of steel instruments with the radiopacity of silver.

All of these techniques were developed over a 70-year span of time. Some used the bisecting angle technique, others the paralleling. In a treatise on radiographic techniques, Walton[22] identified the need for both methods depending on the area being treated. He recommended the paralleling technique for mandibular posterior teeth and the bisecting angle technique for mandibular anterior teeth and all maxillary teeth. He gives a definitive description for taking radiographs of a tooth in any segment undergoing endodontic treatment.

Heling and Karmon[114] examined the accuracy of the bisecting angle technique. They used 50 extracted human teeth mounted in a plastic arch form. Teeth were radiographed with a rubber dam clamp and an endodontic file in place. They calculated tooth length using three different formulae and compared that to actual tooth measurement. Their results showed comparable distortion to the paralleling techniques. They concluded that the bisecting angle technique is adequate for determining tooth length. However, comparison study of the two techniques by Forsberg[115] indicated a different result. He found that when a 10° vertical angulation was used with the bisecting angle technique, it produced a true position of an apical marker as accurately as the paralleling technique. Unfortunately, average jaw anatomy will not allow use of such a moderate vertical angulation. Generally, a much larger vertical angulation is needed. He also found that overangulation produced a much higher degree of error, and even correctly angled films showed many errors in reproduction of apical anatomy. His conclusion was that the paralleling technique provides a better reproduction of the distance between the apex and a root canal instrument than the bisecting angle technique.

One tooth that is especially difficult to accurately radiograph is the maxillary first molar. It has been suggested that two radiographs be made of this tooth for accurate length adjustment.[116,117] In 1921 LeMaster[118] reported a method to prevent the overlap of the zygomatic process and maxillary sinus from the apices of the molar roots. He suggested changing the angle of the film in relation to the tooth to one approaching parallelism. This was accomplished by placing the inferior edge of the film away from the crown of the tooth using a cotton roll interposed between the two. The film was held in position at its superior border by the patient's finger. This pressure brought the upper part closer to the apices.

As was customary for his day, LeMaster's report is anecdotal. Sixty years later LeMaster's observation of the undesirability of the bisecting angle type of film placement was borne out by scientific research. Tamse et al.[119] reviewed 524 radiographs showing both the maxillary first and second molars taken with the bisecting angle technique. Three examiners evaluated the films for interference from the zygomatic arch. They found interference with the first molar an average of 20 percent and with the second molar an average of 24 percent. They concluded that the bisecting angle technique is unreliable for making radiographs of diagnostic value in endodontics.

Much research has been done assessing the reliability of radiographs made with various techniques for determining file length adjustment. In 1966 Langland and Sippy[85] reported on longitudinal distortion of anterior teeth using the paralleling technique. They made intraoral radiographs with the Rinn XCP instrument of 76 maxillary and 78 mandibular anterior teeth that were planned for extraction. Their result showed the mean difference of radiographic image length and actual tooth length was positive for each tooth with the exception of the maxillary lateral. That tooth had a mean value of zero. This meant the mean radiographic length was longer than the mean actual measured length. In raw numbers 85 percent of all the radiographic lengths were longer than actual lengths and 14 percent were shorter. Eighty percent of the radiographic image lengths of maxillary teeth fell within +1.7 mm and -0.3 mm; for mandibular teeth the range was +1.6 mm to -0.1 mm. The authors concluded that this was a minimum amount of distortion and advised use of the paralleling technique and the Rinn XCP instrument to minimize distortion consistently.

Vande Voorde and Bjorndahl[52] completed a study similar to that of Langland and Sippy and agreed with their finding. They radiographed a total of 101 anterior teeth with the paralleling technique that were later extracted and measured directly. They added measurements of the location of the apical foramen and apical constriction to the original measurement of the apical vertex. They found: (1) the length of the extracted teeth from incisal edge to apex was an average of 1.2 mm less than the radiographic image with a magnification factor of 5.4 percent, (2) the length of the extracted teeth from incisal edge to apical foramen averaged 1.6 mm less than the radiographic image, and (3) the length of the extracted teeth from incisal edge to the apical constriction was an average of 2.3 mm less than the radiographic image. They concluded that right-angled paralleling radiographs are consistent enough to be a reliable guide for determining endodontic working length.

Bramante and Berbert[120] compared three radiographic methods of determining tooth length. They studied the techniques of Best, Bregman, and Ingle. A variety of teeth were chosen in patients who were scheduled to undergo extractions for orthodontic or prosthodontic reasons. Teeth were measured in vivo, then extracted for determination of the actual length. The authors considered measurement to be accurate when the radiographically determined length was equal to the actual tooth length or up to 0.5 mm shorter. The method of Ingle was shown to be most accurate with a low variability. Best's method was least successful giving lengths generally longer that the actual tooth. The Bregman technique also showed low success and had high variability.

A comprehensive study of six radiographic techniques and four types of film holders was made by Bhakdinaronk and

Manson-Hing.[121] In vivo radiographs were made by a random selection process of teeth requiring extraction. The teeth were then extracted and measured directly. The authors found the most successful techniques to be (1) the paralleling technique using either the Rinn XCP film holder or the hemostat with bite block, and (2) the bisecting angle technique using the Rinn XCP. These were statistically equivalent. A beam guiding film holder was found to be more accurate than one without a guide. All methods were equally accurate for use on mandibular molar teeth.

To test the ability of the radiograph to depict the foramen, Marsh and von der Lehr[122,123] looked at the radiographic appearance of the root canal filling in relation to the location of the apical foramen. They filled maxillary central incisors with silver points to a level continuous with the external root surface. The bisecting angle technique was used for their radiographs. Citing other studies of apical anatomy,[2-4] the author expected to find fillings to appear short on the radiographs. Instead, they found an average of 8 percent that appeared radiographically short of the apex, even though visual inspection revealed 60 percent did actually deviate coronally from the apex. Their explanation was that those foramina that exited to the mesial or distal were clearly seen on the radiographs since they were at a right angle to the x-ray beam, and gave the appearance of a flush filling. Those foramina exiting to the facial or lingual fell parallel to the beam and, therefore, were not visible on the radiograph, giving the appearance of a short root canal filling. The conclusion drawn was that radiographs are accurate 94 percent of the time in relaying the actual situation at the foramen area.

A study of similar design was reported in 1991 using a variety of extracted teeth rather than just maxillary incisors.[124] This study corroborated the results of Marsh and von der Lehr. The authors could see an endodontic file tip flush with root surface in 251 of 305 canals (82.3 percent). The file tip appeared to be at the radiographic apex in 212 of those canals. The remaining 17.7 percent were canals in which the foramen exited to the facial or lingual. Further investigation showed canals exited facially or lingually most often in maxillary canines (50 percent) followed by maxillary molars (25 percent) then maxillary centrals (23 percent). They did not specify any particular root for the maxillary molar; however, Burch and Hulen[1] showed the palatal root deviated to the facial or lingual more often than the other roots by an average of 50 percent.

Electronic Apex Locators

As early as 1907 the hazardous effects of radiation exposure were enumerated by Kells.[67] The search soon began for a way to judge tooth length without radiographs. In 1918 Custer[108] reported an electrical method, based on "the difference in electrical conduction of a dry pulp canal or one filled with a non-conducting liquid, and the conductivity of the tissues just beyond the apical foramen." Custer's technique required two or three dry cell batteries, an ammeter, a negative electrode to be placed on the alveolus and a broach attached to the positive wire. When the apical tissues were penetrated the needle on the ammeter would move several points to the right indicating the conductance of the tissue and fluid. This procedure was painless except for a slight electrical shock if three dry cells were used. Suzuki[125] did the first scientific studies corroborating the concept used by Custer. His in vivo research on dogs showed the resistance between oral mucosa and the periodontal membrane to be a relatively constant value of 6.5 kilo Ohms (kΩ).

Sunada[126] developed a resistance type electronic apex locator. In a two-part project, he first established the resistance between the oral mucous membrane and the periodontal membrane on human subjects, determined to be an average of 6.5 kΩ paralleling Suzuki's finding. He then looked at the relation between the tip of the measurement instrument and the apex when the apparatus showed 6.5 kΩ. He demonstrated the tip of the reamer to be at the apex in nine of 11 canals. In the other canals the tip was 2 mm short in one and 0.5 mm short in the other. Sunada concluded that his instrument could accurately determine the length of the root canal.

Inoue[127] added sound to the resistance type apex locator. His instrument, the Sono-explorer, emits a varying tone as the measuring instrument proceeded into the canal. The pitch is low at the coronal aspect and becomes high and identical to the predetermined pitch of the mucous membrane when the apical periodontal tissue is reached.

Another type of electronic apex locator is the impedance type.[128] It works on the principle that there is greater impedance across the walls of the root canal coronally than apically. This is based on the presence of transparent dentin that begins forming about 17 years of age and continues throughout life. Impedance type instruments use a hand-held return electrode instead of a contact on the oral mucosa. An example of this type of unit is the Endocater.

The frequency-dependent apex locator is yet another type.[128] It operates on the principle of maximum difference between electrodes, depending on the frequency used. It uses a lip clip as the mucosal contact. The Endex is one brand of this type of electronic apex locator.

There are advantages and disadvantages of each type of electronic apex locator. These are listed in Table I.

One early investigation of the accuracy of electronic apex locators used an operator-fabricated device. Felger[129] constructed his resistance type device using an electronic alternating-current impedance bridge, a size 15 endodontic file as the positive electrode, and an aluminum foil disc as the negative electrode. He used the device to measure canal length in human teeth scheduled for extraction. The resultant measurements were then compared to the actual length of the extracted tooth. He demonstrated identical measurements in 6 of the 7 teeth tested.

In their extensive evaluation of methods for determining tooth length, Bramante and Berbert[120] included a device built according to Sunada's design, called an electroconductometer. It appears very similar to the instrument used by Felger. It also uses an endodontic file, but the negative electrode is a cheek clip. Using human teeth selected for extraction, they evaluated 224 teeth by various methods and compared those measurements to the length of the extracted teeth. Besides the electronic apex locator, they used radiographs and formulae. They found the electronic device performed better than the methods with formulae but not as accurately as the radiographic technique offered by Ingle.[20] However, the device obtained better results for palatal roots of maxillary premolars and molars than the radiographic techniques. They attributed this to radiographic distortion not to the efficacy of the device.

The Sono-Explorer, introduced by Inoue in 1972, was found to be quite accurate compared to direct measurement of extracted teeth. Research by O'Neill,[130] using 53 canals, showed 83 percent identical measurements and 17 percent having variation of 0.5 mm. The electronic measurement was always the shorter of the two. Very similar results were obtained by Plant and Newman.[131] Their findings showed 30 of 32 canals having identical lengths when the two measurements were compared. Again, the electronic measurement was the shorter one by 0.3 mm and 0.5 mm in the remaining two canals.

Seidberg et al.[132] compared the Sono-Explorer to digital-tactile sense. They verified their results with wire-grid radiographs. The results showed digital-tactile sense to be accurate in establishing endodontic working length 64 percent of the time, whereas, the Sono-Explorer had a 48 percent accuracy. They concluded the concept was good but, at its present level of sophistication, should not replace digital-tactile sense followed by a confirmatory radiograph. A direct comparison of the Sono-Explorer to radiographs was done by Busch et al.[133] in 1976. They found an accuracy of 93.9 percent for the electronic device within $\pm$ 0.5 mm of the radiographic apex. They found it to be more accurate in teeth with vital pulps than necrotic pulps. Based on their results, they recommended it for cases where radiographs are difficult to interpret.

The Sono-Explorer was evaluated against another electronic apex locator, the Endometer.[134] The Endometer uses a needle dial to determine correct apical file placement as opposed to the change in tone heard with the Sono-Explorer. These methods were found to be comparable for locating the foramen. Unlike previous reports, the Sono-Explorer tended to give long measurements when it was inaccurate. The authors felt that the Endometer was slightly easier to use clinically than the Sono-Explorer, requiring fewer factors to be controlled by the operator.

Two studies comparing electronic apex locators and radiographic techniques showed unfavorable results for the electronic devices. Becker et al.[135] compared the Forameter to radiographs, and Tidmarsh et al.[136] compared the Dentometer and Endo Radar to radiographs. The former used an experimental model with pig mandibles, the latter was a human clinical study. In both projects the electronic devices were less accurate than the radiographic techniques.

The Neosono-D was evaluated in an in vivo trial of 47 human teeth planned for extraction to assess the effect of the diameter of the major and minor foramina.[137,138] Accuracy was judged against the actual length of the extracted tooth. The authors found that as the width of the major foramen increased, the measurement made with the electronic instrument was increasingly short. They also reported the Neosono-D measured a mean value of 0.24 mm coronal to the cementodentinal junction. They felt the probability of being within 0.76 mm of the cementodentinal junction was 68 percent when this electronic apex locator was used.

The Endocater is an example of the impedance type of electronic apex locator. McDonald and Hovland[139] evaluated its ability to locate the apical constriction. Their study involved human teeth scheduled for extraction. Probe placement was visually inspected after extraction. They found 17.1 percent of the probes bound in the coronal portion of the canal and did not reach the apex. However, in those teeth in which the probes did reach the apex, the Endocater was accurate within 0.5 mm of the apical constriction in 93.4 percent of the canals. They felt the presence of a hand-held rod for the positive electrode was preferable over the mucosal lip clip.

A similar in vivo study by Keller et al.[140] assessed the ability of the Endocater to locate the apical constriction. The probes bound coronal to the apex in 28 percent of the canals. For those teeth in which the probes approximated the apex, radiographs were made with the probe in place. The teeth were then extracted for direct visualization of probe location relative to the minor foramen. An independent evaluator then viewed the radiographs and made file length adjustments to place the instrument within 0.5 to 1.0 mm of the radiographic apex. The evaluator was 95.8 percent accurate and the Endocater was 67.7 percent accurate in positioning the probe at a clinically acceptable level. With the Endocater 59.9 percent of the working lengths were beyond the cementodentinal junction. For the evaluator 32.3 percent were outside the minor diameter. On the basis of this study, it appears many canals would be overinstrumented if the Endocater is used alone.

RADIOVISIOGRAPHY

RadioVisioGraphy (RVG) is currently the latest alternative to film for determining endodontic working length. The RVG system was invented in France by Dr. Francis

Mouyen, and was first demonstrated in the United States at the Chicago Midwinter Meeting in 1988.[49] The system is presently marketed in the United States by Trophy U.S.A., Inc., Marietta, GA. A similar system is being developed by Electro-Optics Corporation and the University of Arizona with funding by the U. S. Army.[141] Their prototype has not yet undergone clinical trials.

The RVG equipment has three major components (Figure 2).[47,48] The "Radio" component is a conventional x-ray generator having a precise microprocessor to produce very short, highly accurate exposure times. The RVG is compatible with other brands of x-ray generators for use with conventional x-ray film. The x-ray generator exposes a sensor, or scintillation screen, adjacent to a fiberoptic bundle, and a miniature charged-coupled device (CCD). This sensor is housed in a plastic casing 40.6 mm long x 22.8 mm wide x 14 mm thick. The actual x-ray sensitive area is 17 mm x 26 mm.

The "Visio" part is a display processing unit (DPU) and monitor that stores the incoming signals during exposure and converts them point by point into 256 levels of gray. After exposure is made the image appears almost instantly on the monitor. This initial image represents a four-fold magnification of the primary image on the intensifying screen. The DPU contains controls that allow image manipulation. The image contrast can be reversed so that black becomes white and vice versa. The image can be enhanced by changing the scale of contrast. There is also the capability to zoom in on a particular segment of the image and display the area on the monitor.

The "Graphy" component is a digital mass storage unit that is connected to a thermal printout device. The hard copy images have the appearance of black and white photographs and are somewhat smaller than the monitor image.

The heart of RVG imaging is the CCD. Solid-state silicon devices such as the CCD were introduced in the 1960s.[142] Over the next 20 years the technology was refined, making them more practical and affordable. CCDs are widely used in video cameras, microscopes, intraoral video cameras, and astronomical telescopes.

A typical CCD is processed from a silicon wafer of about 500 μm in thickness. The crystalline lattice structure of silicon has each atom covalently bonded to its neighbor. These bonds can be broken by x-rays as well high energy particles and cosmic rays. The energy generated when the bonds break is collected in a potential well that has been created in the device by growing a thin layer of silicon dioxide on the section of silicon and topping it with a conductive gate structure (Figure 3). The CCD may contain thousands of these potential wells through which collected charge from broken bonds is transferred. The principle of charge transfer is the essential concept of the CCD.

An image is created on the device if it is exposed to x-rays. A pattern of charge is produced on the array of potential wells in proportion to the flux incident on each pixel in the array. The array of potential wells is called the parallel register. The collected charges are then transferred from row to row, upward in the parallel register to a one-dimensional CCD called the serial register (Figure 4). From the serial register the charge is released at the output node as a signal which is amplified and displayed on the video monitor.

Four generations of RVG systems have been produced since 1984. The first generation was presented in the literature by Mouyen et al.[48] in 1989. In this initial trial the authors compared RVG to conventional radiography using Kodak D-speed film. They tested various image qualities and absorbed radiation dose on a phantom head. Their results showed the RVG resulted in considerably lower radiation dose than film. Depending on the working mode and enhancement used, RVG has lower resolution than the radiographs. The authors felt this was overcome by the inherent magnification of the RVG image, and image manipulation capability.

In 1990 the second generation RVG system was evaluated by Horner et al.[47] In a preliminary evaluation they measured air kerma for RVG, E-speed film, and D-speed film timer settings that gave images of good clinical quality. They concluded that the radiation dose with the RVG timer setting was 41 percent of that for E-speed film and 23 percent of the dose generated with the D-speed film timer setting. Next, they conducted a clinical trial of patients requiring periapical exposures of different oral areas for a variety of purposes. They included the evaluation of endodontically treated teeth in this trial. The resolution of the RVG was found to be less than that of E-Speed film. However, their subjective opinion was that resolution was adequate for the clinical applications of the study. Some disadvantages of the unit noted included: (1) the bulkiness of the sensor, especially in posterior areas, and (2) the small size of the receptor area of the sensor which typically accommodates only one molar or two incisors.

Horner et al. were chided by Dr. Mouyen[143] for using a less-than-scientific approach for determining resolution in judging "by eye." Mouyen tested resolution using an oscilloscope. He also pointed out that the disadvantages noted with the sensor were nearly eliminated by using the positioners developed for it for correct placement.

Benz and Mouyen[144] reported on the third generation version of the RVG system in 1991. In this generation the electronic design had been upgraded significantly. The purposes of the improvements were to enhance the resolving power, reduce the intensity quantization from 256 levels of gray to 64 levels, increase the sensitivity and exposure latitude of the sensor, and provide more image enhancement capability. The authors compared the latest RVG system to its immediate predecessor and to two brands of high speed radiographic film. They demonstrated that RVG can display adequate details at significantly lower radiation dose than film. This third generation RVG system provides a wider exposure latitude compared to the previous system but still not as much as film. In the standard mode, RVG gives resolution of 7 lines/mm; the zoom mode resolution is 11 lines/mm. It should also be noted that the zoom mode requires four times the exposure time of the standard mode. The resolving power of the radiographic films was 14 lines/mm. The authors believe the resolution available in the standard mode meets all clinical requirements.

A fourth generation version of the RVG system is now commercially available, but no studies using it have been published to date.[145]

Relatively few research projects have been published concerning the usefulness of RVG in clinical dental application. Wenzel et al.[146] studied the detection of occlusal caries in noncavitated teeth comparing conventional radiographs, digitized film radiographs and RVG. They concluded RVG was as accurate as digital radiography for detection of occlusal caries. Both systems were better than conventional radiography but not at a statistically significant level.

Two reports by Shearer et al.[50,51] looked specifically at the endodontic application of RVG. Their first study evaluated the percentage of length of root canal visible on conventional radiographs and on RVG images. They used 60 extracted teeth mounted in polymethylmethacrylate for a tissue equivalent. The comparison film was Kodak E-speed film. The radiographs were viewed under standardized conditions while the RVG images were evaluated directly from the screen of the display processing unit. The length of visible root canal from its most apical extent to a line drawn at the level of the cementoenamel junction was recorded. This was expressed as the percentage of the distance between the radiographic apex and the cementoenamel junction. The results showed no significant difference in the percentage of root canal visible between conventional radiographs and standard RVG images or between conventional radiographs and enhanced RVG images. Enhanced RVG images did show a significantly greater percentage of root canal than standard RVG images for all teeth. The conclusion was that RVG and conventional radiography were of equal value for imaging root canals. The advantage of RVG is its immediate image display and lower radiation absorbed dose.

Shearer et al.[51] evaluated the percentage of endodontic file length visible in a root canal using 60 extracted teeth mounted in polymethylmethacrylate for tissue equivalency. Access cavities were prepared, and size 15 Hedstrom files were inserted in each canal as far as they would go without jamming. Radiographs were made using E-speed film and RVG images. The radiographs and RVG images were viewed as previously reported. The percentage of visible file length was recorded. The length of each file visible was significantly greater on conventional radiographs than on standard RVG. There was no significant difference between conventional film and enhanced RVG. Enhanced RVG showed a significantly greater length of file than standard RVG. The authors note that the difference between conventional film and RVG, although statistically significant, represented only about 2 percent of the file length. For an average root length of 20 mm that would represent 0.4 mm and may be of little clinical significance. Again, RVG was found to be about equal to conventional radiography for assessment of images.

Periodic reports have shown that the effects of low levels of ionizing radiation have higher risks than previously believed. These risks are continually monitored by the Committee on the Biological Effects of Ionizing Radiations (BEIR V) and the United Nations Scientific Committee on Exposure to Atomic Radiations (UNSCEAR). One half of the diagnostic x-ray generators in the United States are owned by dentists.[147] Diagnostic radiation accounts for only approximately 11 percent of all annual radiation exposure to a person in the United States. Dental radiography results in approximately 0.3 percent of the total exposure.[42]

Torabinejad and associates[43] investigated the risks associated with endodontic radiography. They first reported absorbed radiation doses by various tissues during simulated endodontic radiography. They used a phantom constructed of a human skull, cervical vertebrae, and complete dentition, embedded in a tissue-equivalent material. Using a long-cone paralleling technique, exposures were made at 70 and 90 kVp without any lead shielding on the phantom. The absorbed dose readings were obtained from dosimeters embedded in the phantom. They concluded that endodontic doses are relatively low compared with the biological effects of medical therapeutic and other diagnostic x-ray procedures. They also found that using 90 kVp did not spare the patient additional tissue dose over 70 kVp, except at the skin surface. The 90 kVp energy x-rays traveled farther through the tissue to deposit doses to organs remote from the primary x-ray site.

Using these data, Danforth and Torabinejad[44] then assessed estimated radiation risks associated with endodontic treatment. They determined the chance of getting leukemia from x-rays when 90 kVp is used is 1 in 7.69 million. The risk of thyroid cancer is 1 in 667,000, the same as smoking 11.6 cigarettes. The risk of salivary gland neoplasia is 1 in 1.35 million. They also estimated it would take 10,900 endodontic radiographs to produce the threshold dose to the eyes to produce cataract changes.

Even with the low risk associated with conventional endodontic radiography, the use of protective measures is mandatory. This includes lead aprons, thyroid collars and E-speed film. White[42] urged further investigation into the use of RVG as a radiation sparing technique for diagnostic imaging.

RVG is purported to decrease the exposure to ionizing radiation by 90 percent of that used with D-speed film.[45] It is estimated that five RVG images can be exposed with the radiation equal to that needed for one standard D-speed film.[148] The true dose savings may be negligible when exposing a full-mouth series because only one molar can be visualized in the RVG image, whereas two or three may be seen on the standard radiographic film.

In an in vitro trial, Farman et al.[149] evaluated the absorbed dose used with RVG during endodontic treatment. A phantom was used in the study. Comparisons were made to both E-speed and D-speed film. They found a dose saving of approximately 80 percent over D-speed film in normal RVG mode. When using image enhancement, savings of over 94 percent and nearly 90 percent were realized when compared to D-speed and E-speed film, respectively. Since only a single tooth needs to be imaged for endodontic treatment, RVG represents a technique with significant reduction in dose to the patient.

Trophy claims their equipment also reduces scatter radiation to only 5 mrems per exposure compared to the current standard of 100 mrems per exposure.[45]

There are other advantages of the RVG besides low radiation and quick processing. It is mobile. It does not require darkroom processing. The manufacturer estimates it takes six minutes from the time a conventional radiograph is exposed until the image is available for review.[45] The RVG image is available on its video screen almost instantly. A hard copy takes an additional 15-30 seconds.

RVG has the additional advantages of storing images on computer tape or disk and allowing electronic transfer of images.[49,150] This capability allows recall of the image for future comparison to assess healing. The image can also be transferred rapidly via telephone lines for long-distance consultations, insurance approvals and forensic applications. Farman et al.[149] studied the transfer of images over various high-speed telephone links from Louisville, Kentucky, to Paris, France. They found there was no significant loss of diagnostic information in the transfer process.

METHODS AND MATERIALS

Preserved human jaw sections of two maxillae and two mandibles, each containing intact first or second molars were obtained from the Anatomy Department, Indiana University School of Medicine. All soft tissue were removed using a scalpel and hemostat. The sections were scrubbed with Hibiclens antimicrobial soap (Stuart Pharmaceuticals, Wilmington, DE) and dried. They were stored dry in room atmosphere and temperature. The sections were radiographed to evaluate canal patency. One set of jaw sections served as the primary experimental set; the second set was used as a back-up.

The occlusal surfaces of the molar teeth were flattened using a high speed handpiece. Canal length was estimated from the diagnostic radiograph and confirmed by placing a #10 file to that length. A radiograph was made to see that the file was flush with the radiographic apex. If adjustments were needed, the length was changed and a new radiograph was taken to ensure the file was at the radiographic apex. The diagnostic and initial length films were taken without tissue equivalent.

Custom mounts were fabricated for the specimens to ensure consistency of angulation and source-object distance for the radiographs and the RVG images. These were made using 6 x 6 in squares of 6 mm Plexiglas acrylic (Rohm and Haas, Philadelphia, PA) for the base on which the specimens were mounted with self-curing orthodontic resin (L.D. Caulk Co., Milford, DE). The holder for the RVG sensor and radiograph was made with three 4 mm acrylic rectangles 24 mm x 40 mm x 15 mm that were glued with cyanoacrylate (Figure 5). The position of the holder on the base was determined by making RVG and radiographic exposures after the sections were fixed in place on the base. A Rinn paralleling device (Rinn Corp., Elgin, IL) was attached to the base to ensure repeatable tube head placement. A removable tissue equivalent material was inserted between the specimen and the paralleling device.[151] The tissue equivalent material was made of 3 mm squares of acrylic stacked to a thickness of 24 mm (Figure 6).

Size 10, K-type files (Union Broach, Emigsville, PA) were placed randomly at 0.5 mm intervals in the canals to be evaluated. Three canals were evaluated in the maxillary molar: mesiofacial, distofacial, and palatal. In the mandibular molar the mesiofacial and distal canals were used. The mesiolingual canal was not used to eliminate any confusion in distinguishing it from the mesiofacial canal. A range of 4 mm short of the radiographic apex to 3 mm beyond the radiographic apex was selected. The length of each file was checked twice before insertion in the canal and again upon removal to ensure the rubber stop had not changed position.

All experimental steps were carried out in one session. First, an RVG image was made in the positive mode, then in the reverse mode. A pilot study showed a diagnostically acceptable RVG setting to be film type f1 and 0.08 second. Image contrast enhancement was accomplished, when needed, to give the best view of both the file and the apex. Next, a radiograph was exposed without disturbing the files with the use of a Ritter Explorer x-ray unit (Ritter Co., Rochester, NY) set at 90 kVp, 15 mA, and 6 impulses. These settings had been calibrated within two weeks of the exposures. Kodak Ektaspeed film (Eastman Kodak Co., Rochester, NY) was used. Immediately after exposure the film was developed in an A/T 2000 automatic processor (Air Techniques, Inc., Hicksville, NY), which had been cleaned and filled with fresh solutions according to the manufacturers instructions.

A total of 30 radiographs were exposed with 45 canals evaluated in the maxillary specimen and 30 canals evaluated in the mandibular specimen. There were 60 RVG images made, 30 in the positive mode showing a black file in a white canal and 30 in reverse mode with a white file in a black canal (Figures 7 and 8). The radiographs were mounted in Adamount single-film black opaque holders (Block Drug Corp., Jersey City, NJ), coded, and randomly ordered. The RVG images were trimmed to show only the image being evaluated and then mounted in a photograph album with clear plastic pouches measuring 4 x 6 in. These were also coded and randomly ordered. The films and RVG images were evaluated by three endodontists, each having more than 15 years of radiographic experience. All were inexperienced with interpretation of

RVG images. The radiographs and images were evaluated in the same sitting. The films were viewed on a masked viewbox (Star Dental, Valley Forge, PA) having fixed light intensity. The RVG images required only reflected room light. Examiners could take as long as they wished to evaluate the radiographs and RVG images (Figure 9). Before viewing, each examiner was given an answer sheet and the following written instructions:

> On each of the following radiographs and images please note what adjustment, if any, you would make in file length to have the position of the file be 0.5 mm. short of the radiographic apex or 0.5 mm. short of where you perceive the apical foramen to be. Make note of the amount of your adjustment on every root where a file is present to the nearest 0.5 mm. If the length needs to be increased place a (+) in front of the number; if the length needs to be shortened place a (-) in front of the number; if you feel no adjustment is needed place (0) in the space. (Please note: the RVG images are approximately two times larger than the actual tooth.)

All of the examiners viewed the radiographs and RVG images a second time after at least five days.

Statistical analysis consisted of repeated measures analysis of variance for categorical data using least squares approach, and repeated measures analysis of variance using G-G and H-F correction factors. Interobserver and intraobserver agreement was done using intraclass correlations. Computer software by SAS Institute, Inc. was used for all analyses (SAS Institute, Inc., Cary, NC).

RESULTS

The data collected were the measurements the observers determined were needed to place the file tip 0.5 mm from the radiographic apex. Results were derived for absolute agreement and for agreement within 0.5 mm. For all charts the term RVG.1 refers to a positive RVG image showing a white file in a black canal space similar to a radiograph. RVG.2 refers to the reverse image of a black file in a white canal.

Tables II-IV show the number and percent correct by observer with absolute agreement. The number correct is out of 15 possible for each image type and each root. In two instances in each session, Observer #1 was not able to discern a file in the maxillary mesiofacial canal.

Improvement was expected between the first and second readings. Observer #1 had a low of one correct to a high of eight correct adjustments on the first reading. His second reading ranged from a low of four to a high of 10. Observer #2 ranged from one to four and from one to six. The number correct for Observer #3 ranged from one to nine on the first reading and from zero to six correct the second time. Improvement was found for Observer #1 but not for Observers #2 and #3.

Tables V-IX show the number of correct readings by individual root for each image type. There was little difference for each root among the three image types. The numbers correct were generally higher on the second reading.

Repeated measures analysis of variance for categorical data, using a least squares approach, revealed no statistically significant difference among the three types of images as shown in Tables X and XI. There was no significant difference between maxillary and mandibular molars, or among the observers. For the mesiofacial root there was a significant difference among the image types by observer; a given observer was better with one image type than another but this was not consistent. The data collected for the maxillary palatal root and mandibular distal root would not support analysis by this method.

Repeated measures analysis of variance using G-G and H-F correction factors in Tables XII-XIV also revealed no significant difference among the three image types, between maxillary and mandibular roots or comparing the image type and tooth.

Table XV shows interobserver agreement for exact measurements. The x-ray image of the maxillary mesiofacial and mandibular mesial roots showed higher interobserver agreement than the other two. The reverse RVG image showed the greatest agreement for the maxillary palatal and distofacial roots. Agreement was equal between the x-ray image and positive RVG image for the mandibular distal root; both of them were higher than the reverse RVG image. Overall, interobserver agreement was essentially equal for the x-ray image and reverse RVG image at 0.630 and 0.627, and only slightly less for the positive RVG image at 0.540.

Intraobserver agreement for all roots for exact agreement is shown in Tables XVI-XVIII. Highest agreement was for Observer #1, with an average agreement of 0.95 out of 1.0 for all image types. Observer #3 had an average agreement of 0.91 for all three image types. The average for Observer #2 was 0.76 out of 1.0.

Tables XIX-XXI show the results obtained at an acceptable level of ± 0.5 mm of the actual adjustment. At this level there is approximately a 50 percent improvement in accuracy for all observers. There was not a noticeable change from the first reading to the second.

Results for each individual root at the 0.5 mm level is shown in Tables XXII-XXVI. The repeated measures analysis of variance for categorical data is given in Tables XXVII-XXIX. There was a significant difference between Observers #1 and #3 and Observer #2 for the maxillary distofacial root in that #1 and #3 were more often accurate. Comparing the maxillary palatal root and mandibular distal root the observers were statistically more accurate for the distal root than the palatal. For the mandibular distal root, Observer #2 was less accurate than the other two at a statistically significant level.

Tables XXX and XXXI show the mean absolute distance incorrect for each root by image type. For the mandibular tooth the lowest mean distance incorrect was for the x-ray images for each root. The maxillary tooth showed lowest mean distances for the RVG image on the mesiofacial root and all image types were equally low for the distofacial root.

FIGURES AND TABLES

FIGURE 1. Photograph of RVG images representing the three available sizes.

FIGURE 2. The RVG system.

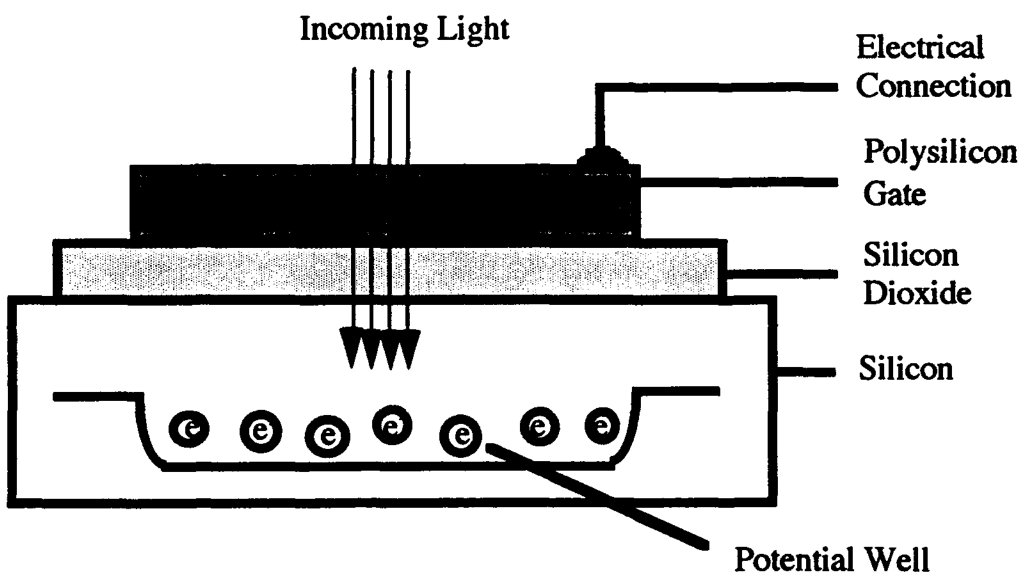

FIGURE 3. Diagram of a potential well.

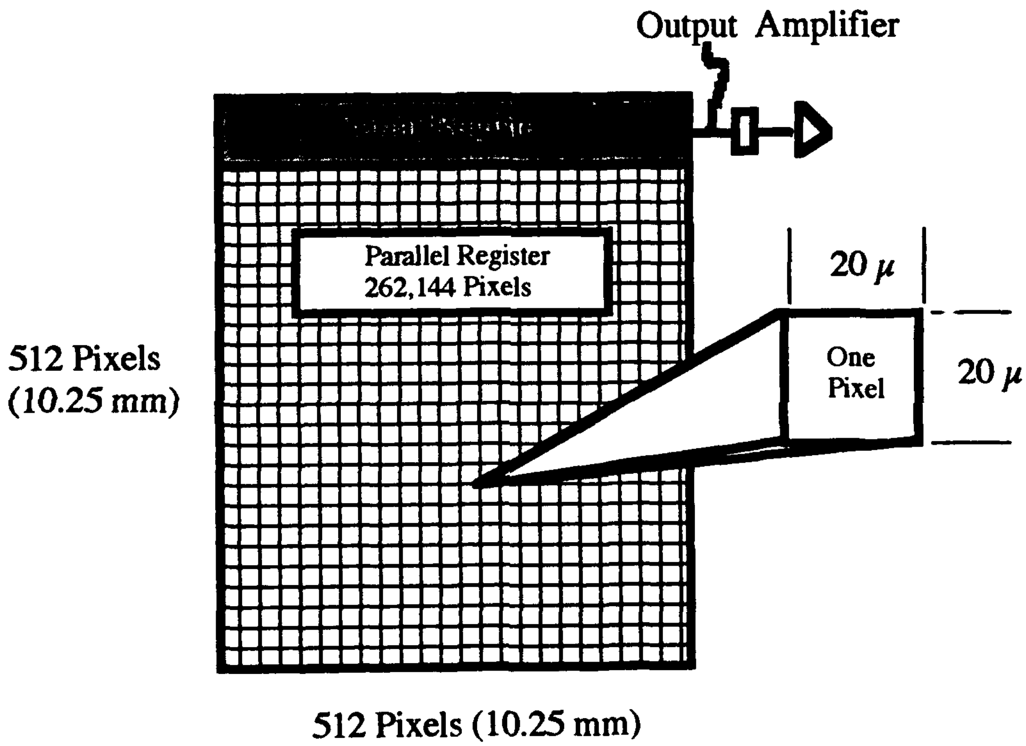

FIGURE 4. Diagram of parallel and serial registers in a typical CCD imager.

FIGURE 5. Specimen in acrylic mounting

FIGURE 6. Specimen in acrylic mounting with tissue equivalent and RVG sensor.

FIGURE 7. Photograph of representative file settings for maxillary tooth. Top: radiograph, left: positive RVG image, right: reverse RVG image.

Figure 8. Photograph of representative file settings for mandibular tooth. Top: radiograph, left: positive RVG image, right: reverse RVG image.

FIGURE 9. Viewbox, radiographs, RVG images, data sheet, and instructions.

TABLE I

Advantages and disadvantages of electronic apex locators

Apex Locator	Advantages	Disadvantages
Resistance type	* Easy to operate * Digital read-out * Audible indicator * Uses K-type files * Operates with RC Prep	* Requires a dry environment * Unreliable beyond 2 mm * Patient sensitivity * Requires calibration * Requires lip clip
Impedance Type	* Operates in fluid * Analog meter * No patient sensitivity * No lip clip * Operates with RC Prep	* Difficult to operate * No digital read-out * Requires coated probes
Frequency Type	* Easy to operate * Operates in fluid * Uses K-type files * Analog read-out * Audible indicator * Rechargeable * Operates with RC Prep	* May be short circuited * Requires lip clip

Modified from McDonald[128]

TABLE II

Observer #1, absolute agreement
number and percent correct

	First Reading			Second Reading		
Root	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
MF	1 6.67	4 28.57	4 28.57	4 26.67	5 35.71	4 28.57
P	3 20.00	3 20.00	1 6.67	3 20.00	6 40.00	5 35.71
DF	4 26.67	3 20.00	8 53.33	8 53.33	7 46.67	7 46.67
M	4 26.67	6 40.00	8 53.33	10 66.67	6 40.00	9 60.00
D	3 20.00	4 26.67	8 53.33	8 53.33	7 46.67	6 40.00

TABLE III

Observer #2, absolute agreement
number and percent correct

	First Reading			Second Reading		
Root	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
MF	2 13.33	3 20.00	2 13.33	5 33.33	6 40.00	3 20.00
P	4 26.67	2 13.33	2 13.33	2 13.33	3 20.00	2 13.33
DF	2 13.33	2 13.33	4 26.67	2 13.33	3 20.00	1 6.67
M	4 26.67	2 13.33	1 6.67	5 33.33	4 26.67	2 13.33
D	2 13.33	2 13.33	2 13.33	1 6.67	3 20.00	2 13.33

TABLE IV

Observer #3, absolute agreement
number and percent correct

	First Reading			Second Reading		
Root	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
MF	3 20.00	4 26.67	2 13.33	2 13.33	3 20.00	4 26.67
P	2 13.33	3 20.00	4 26.67	4 26.67	2 13.33	3 20.00
DF	4 26.67	4 26.67	3 20.00	4 26.67	5 33.33	3 20.00
M	4 26.67	4 26.67	2 13.33	0 00.00	2 13.33	3 20.00
D	9 60.00	4 26.67	1 6.67	6 40.00	2 13.33	2 13.33

TABLE V

Mesiofacial root, absolute agreement number and percent correct

MF root	First Reading			Second Reading		
Observer	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
#1	1 6.67	4 28.57	4 28.57	4 26.67	5 35.71	4 28.57
#2	2 13.33	3 20.00	2 13.33	5 33.33	6 40.00	3 20.00
#3	3 20.00	4 26.67	2 13.33	2 13.33	3 20.00	4 26.67

TABLE VI

Palatal root, absolute agreement
number and percent correct

P root	First Reading			Second Reading		
Observer	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
#1	3 20.00	3 20.00	1 6.67	3 20.00	6 40.00	5 35.71
#2	4 26.67	2 13.33	2 13.33	2 13.33	3 20.00	2 13.33
#3	2 13.33	3 20.00	4 26.67	4 26.67	2 13.33	3 20.00

TABLE VII

Distofacial root, absolute agreement
number and percent correct

DF root	First Reading			Second Reading		
Observer	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
#1	4 26.67	3 20.00	8 53.33	8 53.33	7 46.67	7 46.67
#2	2 13.33	2 13.33	4 26.67	2 13.33	3 20.00	1 6.67
#3	4 26.67	4 26.67	3 20.00	4 26.67	5 33.33	3 20.00

TABLE VIII

Mesial root, absolute agreement
number and percent correct

M root	First Reading			Second Reading		
Observer	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
#1	4 26.67	6 40.00	8 53.33	10 66.67	6 40.00	9 60.00
#2	4 26.67	2 13.33	1 6.67	5 33.33	4 26.67	2 13.33
#3	4 26.67	4 26.67	2 13.33	0 00.00	2 13.33	2 13.33

TABLE IX

Distal root, absolute agreement
number and percent correct

D root	First Reading			Second Reading		
Observer	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
#1	3 20.00	4 26.67	8 53.33	8 53.33	7 46.67	6 40.00
#2	2 13.33	2 13.33	2 13.33	5 33.33	4 26.67	2 13.33
#3	9 60.00	4 26.67	1 6.67	6 40.00	2 13.33	2 13.33

TABLE X

Repeated measures analysis of variance for maxillary mesiofacial root and mandibular mesial root. Exact agreement

Source	Probability
Tooth	0.3958
Image type	0.5451
Observer	0.0517
Image type & observer	0.0201*

Significant: P=0.05

TABLE XI

Repeated measures analysis of variance for maxillary distofacial root. Exact agreement

Source	Probability
Image type	0.3106
Observer	0.3281
Image type & observer	0.1715

Significant: P=0.05

TABLE XII

Repeated measures analysis of variance with correction factors for maxillary mesiofacial root and mandibular mesial root. Exact agreement

Source	F Value	P=H-F
Tooth	0.14	0.7140
Image type	2.07	0.1539
Image & tooth	1.61	0.2153

Significant: P=0.05

TABLE XIII

Repeated measures analysis of variance with corrections for maxillary distofacial root. Exact agreement

Source	F Value	P=H-F
Image type	0.00	0.9993

Significant: P=0.05

TABLE XIV

Repeated measures analysis of variance for maxillary palatal root and mandibular distal root. Exact agreement

Source	F Value	P=H-F
Tooth	2.62	0.1169
Image type	0.09	0.8949
Image & tooth	0.41	0.6391

Significant: P=0.05

TABLE XV

Interobserver agreement

Root	X-ray	RVG 1	RVG 2
MF	.911	.583	.606
P	.590	.373	.774
DF	.503	.635	.747
M	.603	.562	.522
D	.546	.546	.484
Average	.631	.540	.627

1=Exact Agreement

TABLE XVI

Intraobserver agreement
Observer #1

Root	X-ray	RVG 1	RVG 2
MF	.976	.985	.987
P	.963	.978	.960
DF	.992	.716	.981
M	.981	.977	.840
D	.991	.986	.949
Average	.981	.928	.943

1=Exact agreement

TABLE XVII

Intraobserver agreement
Observer #2

Root	X-ray	RVG 1	RVG 2
MF	.866	.679	.897
P	.619	.293	.907
DF	.749	.711	.856
M	.708	.764	.881
D	.750	.807	.918
Average	.738	.651	.892

1=Exact agreement

TABLE XVIII

Intraobserver agreement
Observer #3

Root	X-ray	RVG 1	RVG 2
MF	.979	.876	.774
P	.973	.963	.978
DF	.873	.972	.974
M	.886	.879	.873
D	.909	.892	.838
Average	.924	.916	.887

1=Exact agreement

TABLE XIX

Observer #1, + or - 0.5 mm
number and percent correct

	First Reading			Second Reading		
Root	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
MF	8 53.33	7 50.00	9 64.29	8 53.33	9 64.29	9 64.29
P	6 40.00	9 60.00	7 46.67	8 53.33	9 60.00	10 66.67
DF	12 80.00	11 73.33	12 80.00	13 86.67	13 86.67	12 80.00
M	13 86.67	12 80.00	11 73.33	14 93.33	13 86.67	13 86.67
D	13 86.67	12 80.00	13 86.67	14 93.33	14 93.33	13 86.67

TABLE XX

Observer #2, + or - 0.5 mm
number and percent correct

	First Reading			Second Reading		
Root	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
MF	5 33.33	8 53.33	9 60.00	11 73.33	12 80.00	8 53.33
P	7 46.67	5 33.33	6 40.00	6 40.00	9 60.00	8 53.33
DF	9 60.00	10 66.67	8 53.33	10 66.67	10 66.67	7 46.67
M	12 80.00	8 53.33	9 60.00	12 80.00	10 66.67	7 46.67
D	7 46.67	7 46.67	7 46.67	6 40.00	8 53.33	5 33.33

TABLE XXI

Observer #3, + or - 0.5 mm
number and percent correct

	First Reading			Second Reading		
Root	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
MF	10 66.67	9 60.00	5 33.33	9 60.00	10 66.67	5 33.33
P	6 40.00	9 60.00	9 60.00	7 46.67	8 53.33	10 66.67
DF	12 80.00	13 86.67	11 73.33	12 80.00	11 73.33	11 73.33
M	11 73.33	7 46.67	9 60.00	6 40.00	5 33.33	5 33.33
D	12 80.00	11 73.33	12 80.00	14 93.33	8 53.33	10 66.67

TABLE XXII

Mesiofacial root, within 0.5 mm
number and percent correct

MF root	First Reading			Second Reading		
Observer	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
#1	8 53.33	7 46.67	9 64.29	8 53.33	9 64.29	9 64.29
#2	5 33.33	8 53.33	9 60.00	11 73.33	12 80.00	8 53.33
#3	10 66.67	9 60.00	5 33.33	9 60.00	10 66.67	5 33.33

TABLE XXIII

Palatal root, within 0.5 mm
number and percent correct

P root	First Reading			Second Reading		
Observer	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
#1	6 40.00	9 60.00	7 46.67	8 53.33	9 60.00	10 66.67
#2	7 46.67	5 33.33	6 40.00	6 40.00	9 60.00	8 53.33
#3	6 40.00	9 60.00	9 60.00	7 46.67	8 53.33	10 66.67

TABLE XXIV

Distofacial root, within 0.5 mm
number and percent correct

DF root	First Reading			Second Reading		
Observer	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
#1	12 80.00	11 73.33	12 80.00	13 86.67	13 86.67	12 80.00
#2	9 60.00	10 66.67	8 53.33	10 66.67	10 66.67	7 46.67
#3	12 80.00	13 86.67	11 73.33	12 80.00	11 73.33	11 73.33

TABLE XXV

Mesial root, within 0.5 mm
number and percent correct

M root	First Reading			Second Reading		
Observer	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
#1	13 86.67	12 80.00	11 73.33	14 93.33	13 86.67	13 86.67
#2	12 80.00	8 53.33	9 60.00	12 80.00	10 66.67	7 46.67
#3	11 73.33	7 46.67	9 60.00	6 40.00	5 53.33	5 53.33

TABLE XXVI

Distal root, within 0.5 mm
number and percent correct

D root	First Reading			Second Reading		
Observer	X-ray	RVG.1	RVG.2	X-ray	RVG.1	RVG.2
#1	13 86.67	12 80.00	13 86.67	14 93.33	14 93.33	13 86.67
#2	7 46.67	7 46.67	7 46.67	6 40.00	8 53.33	5 33.33
#3	12 80.00	11 73.33	12 80.00	14 93.33	8 53.33	10 66.67

TABLE XXVII

Repeated measures analysis of variance for maxillary mesiofacial root and mandibular mesial root Within 0.5 mm

Source	Probability
Tooth	0.1374
Image type	0.3789
Observer	0.3019
Image type & observer	0.0639

Significant: P=0.05

TABLE XXVIII

Repeated measures analysis of variance
for maxillary distofacial root
Within 0.05 mm.

Source	Probability
Image type	0.7523
Observer	0.0165*
Image type & observer	0.4857

Significant: P=0.05

TABLE XXIX

Repeated measures analysis of variance for maxillary palatal root and mandibular distal root Within 0.5 mm

Source	Probability
Tooth	0.0156*
Image type	0.8171
Observer	0.0051*
Image type & observer	0.7914

Significant: P=0.05

TABLE XXX

Mean absolute distance incorrect in mm

MAXILLARY

Root-image	Minimum	Maximum	Mean	Std Dev
MF X-ray	0.1667	1.8333	0.8111	0.5083
MF RVG	0	1.0000	0.4611	0.3448
MF RVG Rev	0.0833	6.1667	1.0944	1.4689
DF X-ray	0	1.2500	0.4944	0.4208
DF RVG	0	1.3333	0.4944	0.4100
DF RVG Rev	0	2.2500	0.4889	0.5841
P X-ray	0	1.7500	0.8611	0.5856
P RVG	0.0833	1.4167	0.7944	0.4617
P RVG Rev	0	5.4167	0.9556	1.2959

TABLE XXXI

Mean absolute distance incorrect in mm

MANDIBULAR

root-image	minimum	maximum	Mean	Std Dev
M X-ray	0.0833	2.9167	0.5944	0.71013
M RVG	0	2.8333	0.7389	0.7970
M RVG Rev	0.0833	2.5000	0.7944	0.6275
D X-ray	0	1.0833	0.4944	0.2895
D RVG	0	3.5000	0.6500	0.8581
D RVG Rev	0	1.5000	0.5333	0.4212

DISCUSSION

Magnification of the image has been viewed as a disadvantage of radiographs when used for assessing file length during root canal treatment. Vande Voorde and Bjorndahl[52] found that actual tooth length is magnified 5.4 percent in a radiographic image made with the right angle paralleling technique. Magnification ranged from 4.1 percent for mandibular posterior teeth to 5.5 percent for maxillary and mandibular anterior teeth in radiographs made with the bisecting angle technique.[114] If file length adjustment is made by directly measuring the radiographic image, this magnification would play an obvious role.

Antrim[37] studied the ability of examiners to judge the presence or absence of periapical lesions looking at regular size radiographs, radiographs enlarged four times, and radiographs projected on a screen. He found the highest agreement among examiners occurred looking at regular size radiographs, the least when viewing the projected radiographs.

From these studies it would seem that determining endodontic file length adjustments might be less accurate using images larger than conventional radiographs.

In their studies comparing conventional radiographs and RVG relative to visible canal length and instrument length, Shearer and associates[50,51] did not attempt direct measurement of the canal or instrument length "because of the magnification inherent in RVG images." They also did not attempt to compare actual file length in their specimen teeth leaving the question of the clinical usefulness of RVG images for endodontic file length adjustments unknown.

The results of this study showed no significant difference between conventional size radiographs and RVG images that were approximately two times larger than the actual tooth. The adjustment needed was determined without use of measuring devices; therefore, the true test was the examiners' ability to mentally transform the enlarged image distance to an actual distance. They were able to do this equally well whether the magnification was minimal or great.

Statistically, there was no difference between the positive RVG image showing a white file in a black canal and the reverse image. This is in agreement with Horner et al.[47] who found that reversing the gray scale of the image on the monitor did not seem to have any clinical advantage.

One problem noted with four of the RVG images was the inability to see a file in the canal when the image was enhanced to make the apex clearly visible. This was also found by Shearer et al.[50,51] They stated that too much enhancement resulted in a loss of fine detail such as the tip of the file disappearing from the image. In this study the problem was not too much enhancement, but rather the choice between enough enhancement to see either the tip of the file or the root apex.

Interobserver agreement among the three image types was about 63 percent for both the x-ray and reverse RVG images. Agreement for the positive RVG images was slightly less at 54 percent. These values are somewhat lower than interobserver agreement found in studies that evaluated radiographic parameters for judging success and failure of endodontic treatment.[98,104]

Intraobserver agreement ranged from an average of 76 percent to 95 percent for all three image types. This range is very similar to previous studies which show a range of intraobserver agreement from 72 percent to 90 percent.[98,101,152]

When the data were recalculated to include adjustments accurate within 0.5 mm of the actual measurement, there was approximately a 50 percent improvement in accuracy. This increase may be due to differences among observers in their interpretation of where the radiographic apex was located or where they perceived the foramen to be.

Future in vitro investigations using RVG could be done using a larger sample of a variety of teeth. Another variable to examine is evaluation of the RVG image on the monitor, the method which would probably be used in a clinical setting. The image on the monitor is considerably larger than a conventional radiograph and has less resolution than the video print.

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to determine if accurate endodontic file length adjustments could be made using RVG images approximately two times the size of the tooth and to compare the accuracy of those adjustments with conventional radiography that produces an image only 5 percent larger than the tooth. Images evaluated included a conventional radiograph, a positive RVG image, and a reverse RVG image for a variety of molar teeth. Variables assessed were type of image, individual root, and maxillary versus mandibular tooth. Intraobserver and interobserver agreement was also determined.

Two dry jaw sections (a mandible and a maxilla) from human cadavers, in conjunction with a tissue equivalent of 25 mm of acrylic, were used for this study. Size 10 files were placed in each root of first or second molars at distances of 4.0 mm short of the radiographic apex to 3.0 mm beyond the radiographic apex in 0.5 mm increments. For this study, ideal working length was considered to be 0.5 mm short of the radiographic apex. Radiographs and RVG images were made in a standard manner. Radiographs were evaluated on a masked viewbox under ideal viewing conditions; RVG images were evaluated using reflected room light at the same session. Observers were asked to evaluate each radiograph with regard to what adjustment they would make in each case to have the file tip be 0.5 mm short of the radiographic apex the tooth. Use of a measuring aid was not allowed. A total of 225 measurements were evaluated (135 on the maxilla and 90 on the mandible) from 30 radiographs and 60 RVG images.

Results of the study showed little difference in the number of absolute correct readings for each root among the three image types. There was no statistically significant difference among the three types of images. There was no difference between the maxillary and mandibular tooth, or for the evaluations among the observers.

For exact agreement for the adjustment needed, interobserver agreement was essentially equal for the radiographs and reverse RVG images, and only slightly lower for the standard RVG image.

Results at the level of $\pm$ 0.5 mm. of the actual adjustment showed about 50 percent improvement in accuracy. At this level observers were statistically more accurate for the mandibular distal root.

Within the parameters of this study it can be concluded that: (1) it is possible to make accurate file length adjustments from an image two times larger than the actual tooth, (2) RVG is not significantly better than conventional radiography for determining endodontic file length adjustments, (3) if both methods are available, RVG is preferable because of the significant reduction in patient radiation burden.

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ABSTRACT

INTERPRETATION OF ENDODONTIC FILE LENGTH ADJUSTMENTS USING RADIOVISIOGRAPHY

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The purpose of this in vitro investigation was to determine if accurate endodontic file length measurements can be made using RadioVisioGraphy (RVG) images. Comparisons were made between RVG images and conventional periapical radiographs.

Maxillary and mandibular human cadaver sections with a first or second molar and patent canals were used for experimental specimens. Size 10 K-type files were inserted into the canals at randomly selected lengths. Lengths varied from 4 mm short of the radiographic apex to 3 mm beyond. Radiographs were made using E-speed film, and images were made using the Trophy RVG. Radiographs and images were evaluated by three endodontists to determine the adjustment needed to place the tip of the file 0.5 mm from the radiographic apex.

The results showed there is no significant difference in the ability of endodontists to make accurate file length adjustments using conventional radiography versus RVG. Under the conditions of this study, the following conclusions were drawn: (1) it is possible to make accurate file length adjustments from an image two times larger than the actual tooth, (2) RVG is not significantly better than conventional radiography for determining endodontic file length adjustments, (3) if both methods are available, RVG is preferred because of the significant reduction in patient radiation burden.

CURRICULUM VITAE

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Professional Organizations

American Dental Association
American Association of Endodontists
American Association of Women Dentists
Academy of General Dentistry