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A Comparison of Rectangular vs. Circular Radiographic Collimation During Simulated Endodontic Therapy

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

by

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Abstract

A COMPARISON OF RECTANGULAR VS. CIRCULAR RADIOGRAPHIC COLLIMATION DURING SIMULATED ENDODONTIC THERAPY

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Rectangular collimation is used in dentistry to reduce radiation by restricting the x-ray beam to approximately the size of a number 2 intraoral film (3.2X4.1 cm). However, this restricted beam size can lead to exposure errors. The aim of this study was to retrospectively evaluate the number of radiographs exposed and the presence of technical errors by the use of traditional circular or rectangular collimators during endodontic therapy on simulated teeth in manikins. A total of 1475 digital radiographs of 84 teeth exposed by 60 dental students were evaluated. Evaluation was done by a board certified endodontist, an endodontic resident, and a dental student. Analysis of the different raters showed no significant differences among the three. Radiographs were randomized and blindly renamed. Repeated-measures mixed-model ANOVA was used to compare the number of radiographs exposed using the different collimators. Although not statistically significant ($P<.05$), there were 15% more radiographs taken with the rectangular collimator when compared to the circular collimator. Using a repeated-measures logistic regression, there was a significant difference of the proportion of radiographs with cone

cuts (P = .0003) taken with a rectangular collimator (59%) compared to radiographs taken with a circular collimator (19%). There was no significant evidence for a collimator difference when considering missed apex (P = .0986) or missed apex due to a cone cut (P = .0631). In order to expose high quality radiographs avoiding cone cuts, a traditional circular collimator may be indicated for use during endodontic therapy.

Introduction

Radiography is one of the critical tools that dentist use to diagnose dental pathosis and abnormalities in the oral cavity. Although radiation doses in dental radiography are low, dentists should minimize patient's exposure to radiation (1). The low dose received by the patient from dental radiography produces very little damage, but damage does occur. Every photon does some biologic damage every single time (2).

As of most of planned treatment, there are risks and benefits. Dentist should weigh the benefit of dental radiography against the risk of radiation exposure. The "as low as reasonably achievable" (ALARA) principle should be followed to minimize exposure to radiation (1).

Production of X-rays

X-rays are produced when a fast electron beam strikes a target. This results in loss of electron energy when the fast electrons collide with the atomic electrons in the target. This causes ionization and excitation of atoms. Electrons can also be sharply deflected by the electric field of the atomic nuclei. This will cause them to lose energy by emitting X-ray photons.

Diagnostic radiology uses an X-ray tube made of an oil-filled housing containing an X-ray tube. The X-ray tube is an evacuated envelope of glass of a metal ceramic construction which houses a cathode with a filament and an anode. Exposures are made when the filament is heated by passage of electric current. This produces a narrow beam of electrons. The electrons then interact with the material of the anode, slow down and stop. A small amount of the absorbed energy emerges as X-rays and the rest of the energy absorbed appear in the form of heat. Some of the produced X-rays pass through the exit windows of the insert and the tube housing. This forms the primary radiation beam. Any X-rays emitted in other directions are absorbed by the housing. The X-ray tube has a multi-leaf collimator which can vary the primary radiation field as necessary. (3)

The dentist should minimize the patient exposure by first determining the need for radiographs. If the radiographs were necessary for diagnosis, then the clinician should take many precautions to minimize patient exposure. These include the use of a lead apron, (4,5), employing X-ray generators with open ended long cones (6,7), using rectangular collimation, using fast X-ray film, and ensuring that the processing procedure are minimum (8).

In 1980, per capita exposure of the US population to natural background radiation was six times that of medical imaging. In 2009 each were equal (9). This is a result of the increase in people being exposed to medical imaging and the increase in radiation per exposure. The collective effective dose to the US population rose from 835,000 person-Sv to 1,870,000 person-Sv. The annual effective dose rose from 3.6 to 6.2 mSv. The sources of non–background exposure in the US are as follow:

-Computed tomography 24%

-Nuclear medicine 12%

-Interventional fluoroscopy 7%

-Conventional radiography/fluoroscopy 5%.

Conventional dental imaging is only 2.5% of the 5% conventional radiography/fluoroscopy (10,11).

Radiation Injury

There are two main types of radiation injury, deterministic and stochastic.

Deterministic effects are cause by a high radiation dose that directly kills cells. These are similar to the oral mucositis associated with radiation therapy to the oral cavity. Stochastic effects are a result of damaging of the DNA rather than killing the cells. The effects are a result of low exposures. Dental exposures are capable of causing stochastic effects over a lifetime of an exposed individual. Cancer and leukemia are examples of stochastic effects. (12)

Estimating Risk

Analysis of the literature citing an extensive link of radiation to cancer, led to the development of the linear non-threshold (LNT) hypothesis. The hypothesis is that there is a linear relationship between dose and the risk of inducing a new cancer. It is utilized widely to set policies in radiation safety and protection even though it is not based on scientific fact (9). A dosage of 100 mGy has a solid body of work that demonstrates the increased risk of tumors (13). Despite the high required dose, complex damage to DNA may occur with even one X-ray photon (14). DNA however, has repair mechanisms that fix most of the damage but, some damage is beyond enzymatic repair (15).

Medical Exposure

It is estimated that in 2007 Computed Tomography exposures in the US caused 29,000 additional solid cancers over the lifetime of individuals exposed. These are mainly scans of the abdomen, pelvis, chest and head (16). An estimated one in 270 women who underwent CT coronary angiography at age 40 years will develop cancer from that CT scan (one in 600 men), compared with an estimated one in 8,100 women who had a routine head CT scan at the same age (one in 11,080 men) (17). There is also data linking diagnostic medical exposures to leukemia (18,19).

Dental Exposure

The risk of radiation in dental radiography is related to the radiosensitive structures in the head and neck area. Sensitive structures include brain, bone marrow, thyroid glands and salivary glands (18,20). There are studies showing a strong link between dental radiographs and meningiomas, salivary gland tumors and thyroid tumors (21,22). The probability of one excess cancer fatality may be expected from 47,620 full mouth examinations made with D-speed film and circular collimation or from every 17,000 CBCT examinations (11,23,24). Even though the benefits of diagnostic imaging outweigh the risk, a dentist must always act as if this imaging carries a risk (25,26)

There are many techniques available for dental intraoral radiography. These techniques include the use of additional beam filtration, extended focal to detector distance, using fast film or digital image receptors, and use of leaded aprons and/or thyroid collars on patients (27). Collimation in radiography is an effective way to reduce radiation exposure to the patient (28,29). For the radiation protection methods used by dentists refer to Figure 1.

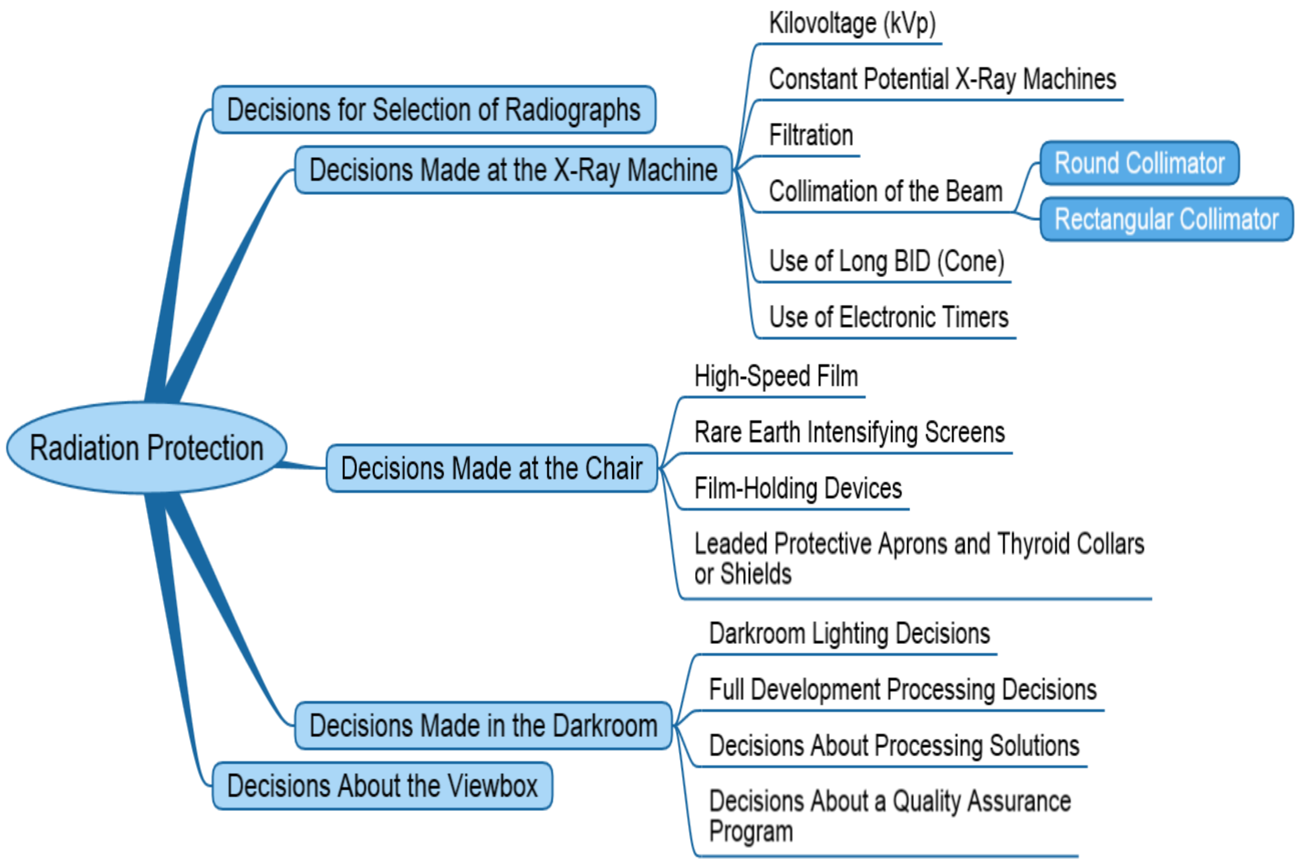

Figure 1: Radiation Protection Methods

Collimation means restriction of the cross sectional area of the beam. This is usually done with a lead diaphragm (Collimator) within the tube head or at the end of a lead lined cylinder (incorrectly referred to as a cone). Circular collimation, which is the minimum required by law (7 cm diameter), is almost 3 times the area necessary to expose a number 2 film (3.2X4.1 cm). Rectangular collimation restricts the beam to approximately the size of the number 2 intraoral film (3.2X4.1 cm). The exposed area of rectangular collimation is 48% when compared to circular collimation (30). The margin for error is very small using the rectangular collimation when aligning the film holder with the position-indicating device of the X-ray unit. Therefore, there are higher possibilities for cone cut and misalignment errors resulting in retakes (31,32).

In a study done by Parrot and NG, the use of film holders with circular collimation significantly reduced the incidence of cone cut errors from 21.7% to 3.3%. There was an increase in the incidence of cone cut errors from 3.3% to 20.9% when rectangular collimation was used (33).

During endodontic therapy, dentists usually take shifted radiographs to separate buccal and lingual canals. These shifted radiographs add difficulties in aligning the positioning indicating device to the film which can create many technical errors resulting in retakes and lower radiographic quality. Dentists also take intraoperative radiographs with the rubber dam and the metal clamps attached to the patient. The rubber dam adds difficulties in aligning the positioning indicating device as it restricts the direct vision of the dentist to the film and adds physical strain to the film holder. The aim of this study was to retrospectively evaluate the number of radiographs exposed and the presence of technical errors by the use of traditional circular or rectangular collimators during endodontic therapy on simulated teeth in manikins.

Materials and Methods

Endodontic therapy is completed as a part of the dental students' clinical requirements for graduation in the predoctoral program at VCU School of Dentistry. These clinical requirements include simulated non-surgical root canal treatment, anterior and posterior, performed in the ModuPro (Acadental, Overland Park, KS) utilizing extracted human teeth. The procedures are performed in one of two clinics in the School of Dentistry. During simulated treatment the students are required to take radiographs in order to monitor their progress and make adjustments accordingly. The radiographs taken are digital radiographs stored in a central server. Upon completion of the simulated endodontic procedure, the students are graded by the attending faculty. The students attempting simulation were randomly selected by student number to complete entire simulation procedures in one of two clinics. The first clinic, the Lyons clinic, was equipped only with circular collimators, (Figure 2). The second clinic, the Douglas clinic, was equipped only with rectangular collimators, (Figure 3). Every case was assigned with a clinic operatories number with half of the spaces having X-ray units equipped with circular collimators (the Lyons clinic) and the other half equipped with rectangular collimators (the Douglas clinic).

Figure 2: Circular Collimator

Figure 3: Rectangular Collimator

The images were acquired by an Optime (PaloDEx Group Oy, Milwaukee, WI, USA) phosphor plate radiographs reader. Images were identified as those of either an anterior or a posterior tooth. Normally each student completed one of each in the same clinic using the same collimation for the entire treatment procedures. On two occasions, the student did one tooth in each of the two clinics, therefore used each of the two collimators.

The exposed radiographs were evaluated retrospectively. Each radiograph was evaluated by dental student, faculty, resident using Dell computers and monitors, Mipacs in the same light in the same room. Each evaluator tabulated the total number of radiographs taken and determined if a technical error had occurred. Cone cuts, missed apices, missed apices due to cone cut were identified and tabulated. Technical errors were recorded as occurring in a case using circular or rectangular collimation.

Cone cut is defined as a technical error in which the position-indicating device (PID) is improperly aligned. This will make an area of the film appear white because it was not completely exposed by the radiation beam.

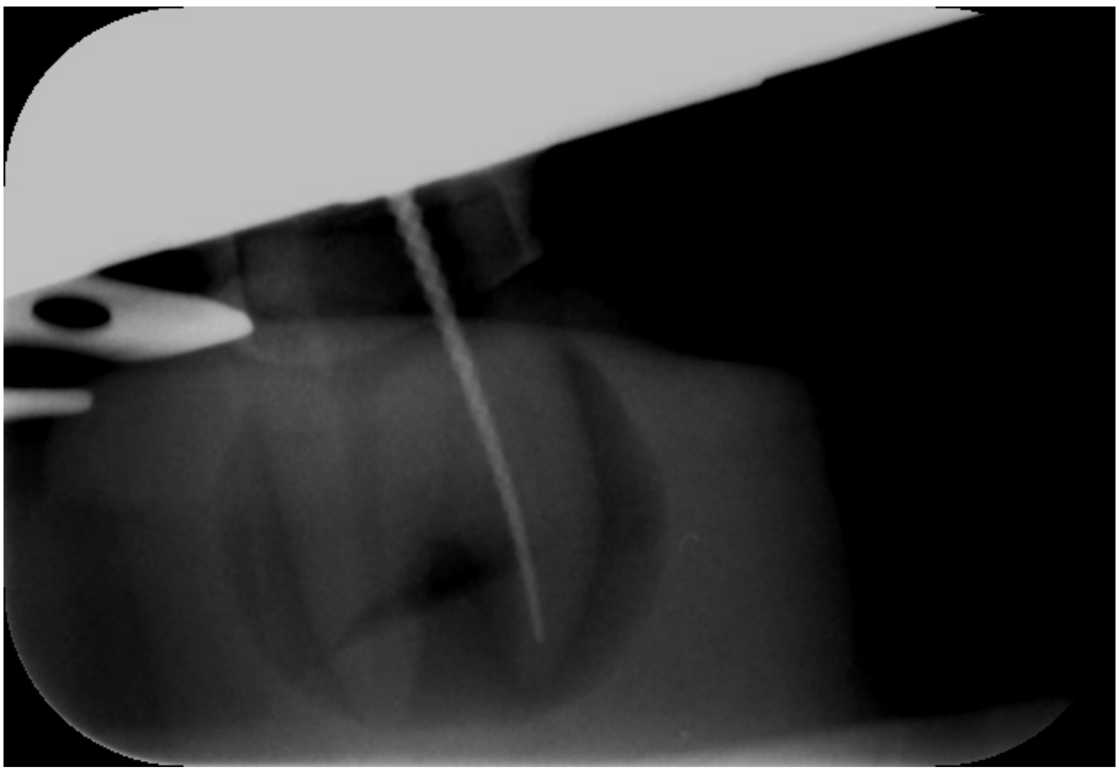

Figure 4: Cone Cut

Missed apices is a technical error that is caused by missalignment of the PID, incorrect placement of the film, severe angulation of the PID, or a cone cut.

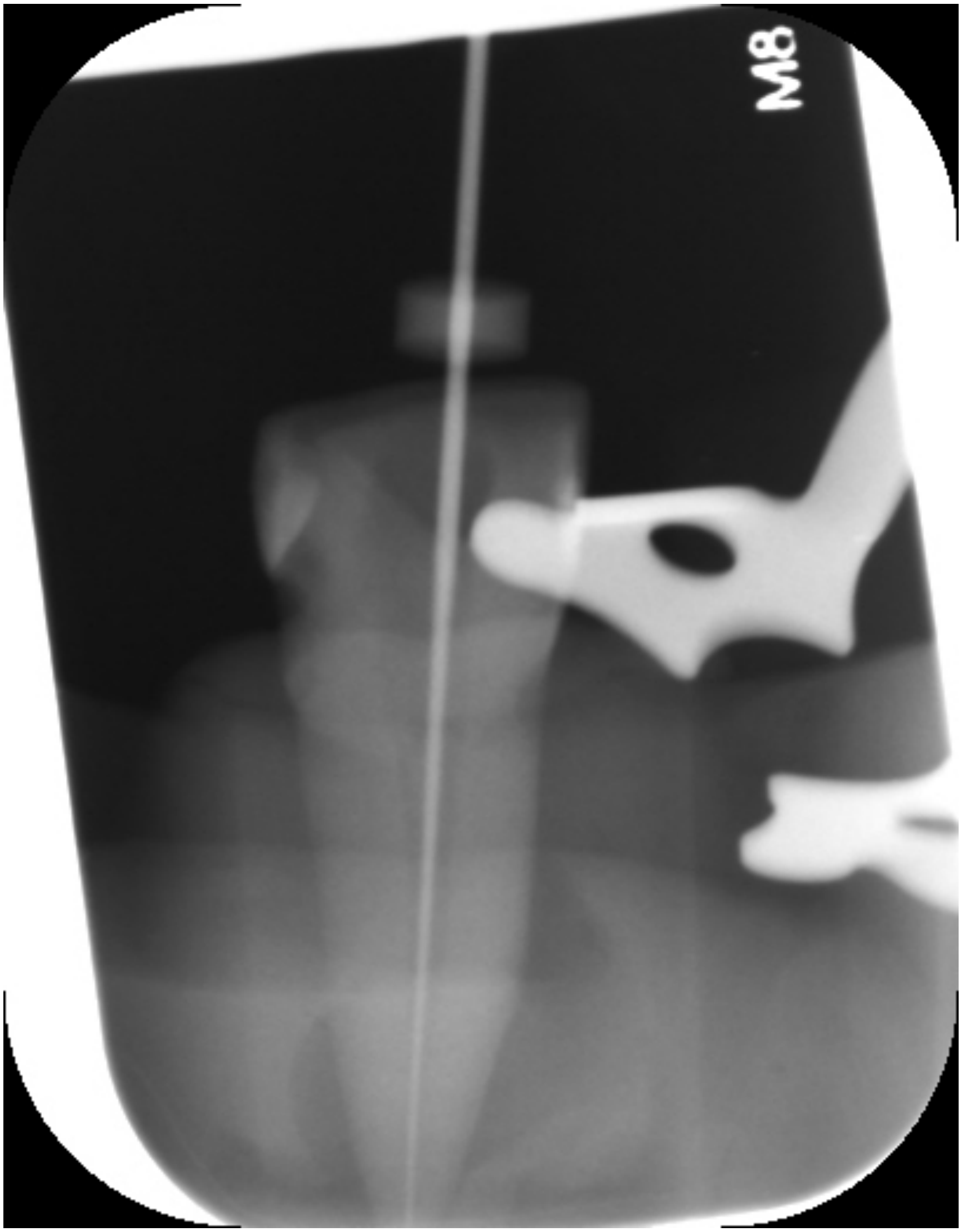

Figure 5: Missed Apex

Missed apices due to cone cut is defined as missing apices of the roots due to the lack of exposure of the apical area of the radiograph.

Figure 6: Missed apex Due to Cone Cut

Radiographs were extracted from the server and renamed randomly with numbers from 1-1,475. Each radiograph was evaluated for cone cuts, missing apex, and missing apex due to a cone cut. The four groups of teeth evaluated were anterior teeth with circular collimation, anterior teeth with rectangular collimation, posterior teeth with circular collimation and posterior teeth with rectangular collimation.

The radiographic evaluation was completed using digital radiographic images on computer monitors. The monitors were calibrated so that all images would be of the same quality. Evaluation of the radiographs was completed by a board certified endodontic faculty, an endodontic resident, and a dental student. Evaluators were calibrated by looking at radiographs of four anterior and four posterior teeth prior to the data collection. Evaluators were statistically cross referenced to maintain consistency in the evaluation process. Identity of student operators was confidential.

Statistical Analyses

The number of radiographs was strongly skewed thus the log-transformed values were analyzed. A repeated-measures mixed-model ANOVA was used to compare the two collimators, after adjusting for difference due to tooth location (anterior vs. posterior) and accounting for the correlation between the two sets of radiographs taken by each student. All analyses were performed using SAS software (JMP Pro version 10.0.1 and SAS version 9.3, SAS Institute, Inc., Cary NC). Significance was determined using an alpha=0.05 cutoff.

Results

Results are presented in two sections: the analysis of the number of radiographs taken, and the analysis of the ratings of the radiographs. In each section the primary comparison is between the two collimators. First, the number of radiographs were compared in the two collimators after taking into account the differences that may be due to tooth location (anterior vs. posterior) and considering that students took radiographs on two occasions thus these two outcomes are related.

Number of Radiographs

Sixty students participated in this study. All except two took each of their radiographs using one collimator, either circular or rectangular. Two teeth were imaged by 23 of the 60 students. Table 1 shows that there were 21 teeth imaged using the rectangular collimator and 21 teeth imaged using the circular collimator. The number of radiographs taken by each student ranged between 6 and 105 and was thus strongly skewed. So, the log-transformed counts were analyzed and then back-transformed to geometric means for reporting purposes. The geometric mean of the number of radiographs taken of anterior teeth in a rectangular collimator was 11.37 (95% CI = 9.8 to 13.2). Approximately twice as many were taken of posterior teeth (geometric mean = 22.98, 95% CI = 18.7 to 28.3).

Tooth	n	Median	Mean	95% CI		Range	
	Rectangular						
Anterior	21	12	11.37	9.79	13.20	6	27
Posterior	21	22	22.98	18.67	28.29	11	78
	Circular						
Anterior	21	9	9.65	8.62	10.79	6	16
Posterior	21	21	20.14	17.41	23.30	12	35

Table 1: Number of Radiographs Taken Using Each Collimator

The repeated-measures mixed-model ANOVA indicated that there were significantly more radiographs taken of posterior teeth ($P < .0001$). Posterior teeth were imaged an average of 22.0 times (95% CI = 19.6 to 24.6) as versus anterior teeth which were imaged an average of 10.7 times (95% CI = 9.7 to 11.8). After adjusting for this difference and taking into account that the number of images taken on the two occasions was strongly correlated ($r = 0.60$), no significant difference between the two collimators ($P = 0.0901$) was found. There were nominally more images taken in the rectangular collimator (mean = 16.5, 95% CI = 14.6 to 18.6) as compared to the circular collimator (mean = 14.3, 95% CI = 12.6 to 16.1). Although this is 15% more (ratio = 1.15, CI= 0.98 to 1.36), this difference was not significant.

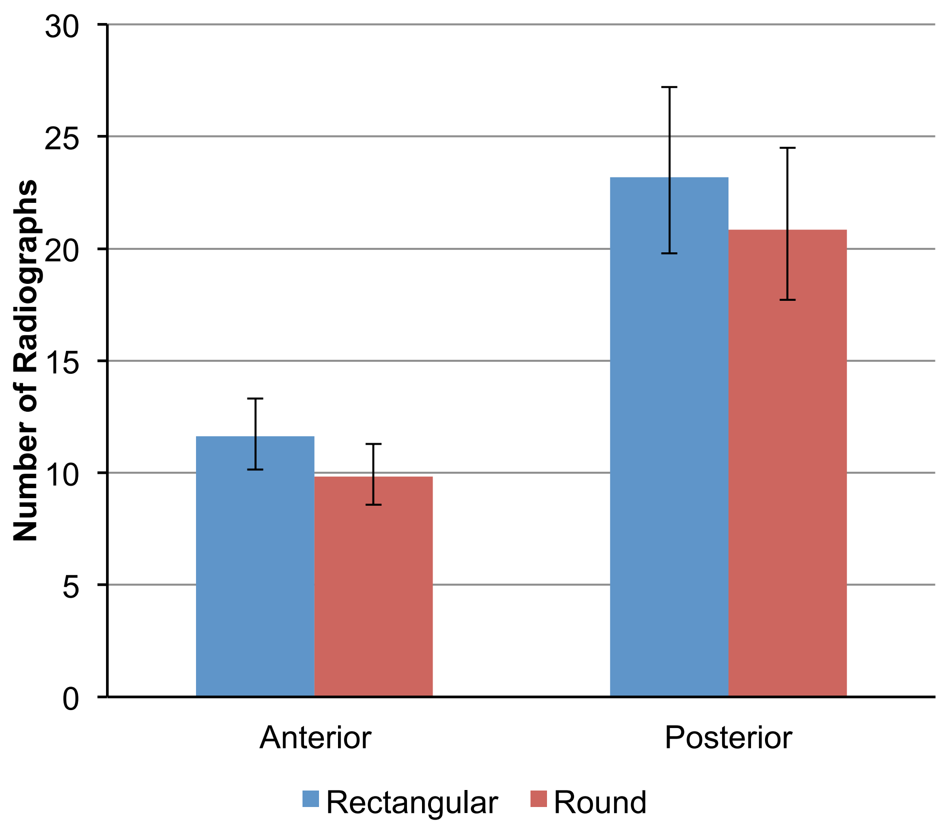

Figure 7: Number of Radiographs

Ratings of the Quality of the Radiographs

The analysis of the quality of the radiographs is presented in three sub-sections corresponding to the three ratings. In each sub-section, the reliability of the ratings is presented and then the results of the logistic regression analysis. Rating reliability is described by measures of agreement, including Kappa. The repeated-measures logistic regression focuses on the primary question—collimator differences—after adjusting for differences due to anterior versus posterior position and rater differences.

Cone Cuts

The primary outcome variable was the instance of a cone cut on radiographs. Table 2 shows the agreement between a resident observation of a cone cut and a faculty observation of a cone cut. The resident indicated the presence of a cone cut 40.0% of the time (580/1451) and the faculty rater indicated the presence of a cone cut 38.5% of the time (559/1451). Comparing the resident and faculty, there was 96.3% agreement (1398/1451) with Kappa = 92.3 (95% CI = 90.3 to 94.4). For 16 teeth, the first rater did not indicate a cone cut and the second rater did. For 37 teeth the first rater did indicate a cone cut and the second rater did not.

	Faculty		
Resident	No	Yes	Total
No	855	16	871
Yes	37	543	580
Total	892	559	1451

Table 2: Agreement on Cone Cuts between Resident and Faculty

The student indicated the presence of a cone cut 40.7% of the time (591/1451). Comparing the resident and student, there was 92.5% agreement (1342/1451) with Kappa = 84.4 (95% CI = 81.6 to 87.2). For 60 teeth, the first rater did not indicate a cone cut and the second rater did. For 49 teeth the first rater did indicate a cone cut and the second rater did not. Comparing the faculty and student, there was 92.1% agreement (1337/1451) with Kappa = 83.6 (95% CI = 80.7 to 86.5). For 73 teeth, the first rater did not indicate a cone cut and the second rater did. For 41 teeth the first rater did indicate a cone cut and the second rater did not.

A repeated-measures logistic regression was used to compare the rectangular and circular collimators, after adjusting for anterior-posterior and rater differences. There was a significant difference on the proportion of radiographs with cone cuts (P = .0003). Table 3 shows, if equal numbers of circular vs. rectangular and posterior vs. anterior teeth had been rated, cone cuts would be observed in 19% of radiographs taken with a circular collimator and 59% in radiographs taken with a rectangular collimator. There was no significant difference between posterior and anterior (P = 0.1960), but there was a significant rater difference (P = 0.0172). The resident's cone cut percentage was 37% (95% CI = 30.3 to 44.3), faculty 35.4% (28.8 to 42.6), and student 37.9% (31.4 to 44.9).

	Position		
Collimator	Posterior	Anterior	combined
Circular	18.0% (9.9 to 30.7)	20.4% (13.5 to 29.6)	19.2% (12.8 to 27.8)
Rectangular	52.8% (41.7 to 63.6)	64.5% (51.5 to 75.6)	58.7% (50.1 to 66.9)
combined	33.2% (24.7 to 42.9)	40.6% (32.6 to 49.1)	

Table 3: Logistic Regression Results, Cone Cut Percentages (95% CI)

Missed Apex

One of the two secondary outcome variables was the instance of a missed apex on radiographs. Table 4 shows the agreement between a resident observation of a missed apex and a faculty observation of a missed apex. The resident indicated the presence of a cone cut 13.8% of the time (200/1451) and the faculty rater indicated the presence of a cone cut 13.3% of the time (193/1451). Comparing the resident and faculty, there was 98.3% agreement (1426/1451) with Kappa = 92.6 (95% CI = 89.8 to 95.5). For 9 teeth, the first rater did not indicate a missed apex and the second rater did. For 16 teeth the first rater did indicate a missed apex and the second rater did not.

	Faculty		
Resident	No	Yes	Total
No	1242	9	1251
Yes	16	184	200
Total	1258	193	1451

Table 4: Agreement on Missed Apex between Resident and Faculty

The student indicated a missed apex 12% of the time (174/1451). Comparing the resident and student, there was 96.7% agreement (1403/1451) with Kappa = 85.3 (95% CI = 81.2 to 89.3). For 11 teeth, the first rater did not indicate a missed apex and the second rater did. For 37 teeth the first rater did indicate a missed apex and the second rater did not. Comparing the faculty and student, there was 96.8% agreement (1404/1451) with Kappa = 85.3 (95% CI = 81.3 to 89.4). For 14 teeth, the first rater did not indicate a missed apex and the second rater did. For 33 teeth the first rater did indicate a missed apex and the second rater did not.

There was no evidence for a collimator difference when considering missed apex (P = .0986) nor was there a difference between anterior and posterior (P = 0.1400). There was a difference due to rater (P = 0.0274). If there had been equal numbers of anterior and posterior and equal numbers of circular and rectangular, then the resident percentage would be 11.9% (8.8 to 15.9), faculty 11.5% (8.3 to 15.6), and student 10.3% (7.6 to 13.8).

Collimator	Position: Posterior	Anterior	combined
Circular	10.7% (6.2 to 17.8)	7.1% (3.7 to 13.2)	8.8% (5.6 to 13.4)
Rectangular	17.4% (11 to 26.5)	11.5% (5.9 to 21.4)	14.2% (9.9 to 20)
combined	13.7% (9.6 to 19.3)	9.1% (5.7 to 14.3)	

Table 5: Logistic Regression Results, Missed Apex Percentages (95% CI)

Undiagnostic Due to Cone Cut

The remaining secondary outcome was the instance of an undiagnostic radiograph due to a cone cut. Table 6 shows the agreement between a resident and faculty observation of an undiagnostic radiograph due to a cone cut. The resident indicated the presence of a cone cut 3.0% of the time (43/1451) and the faculty rater indicated the presence of a cone cut 2.9% of the time (42/1451). Comparing the resident and faculty, there was 99.5% agreement (1444/1451) with Kappa = 91.5 (95% CI = 85.3 to 97.8). For three teeth, the first rater did not indicate undiagnostic due to cone cut and the second rater did. For four teeth the first rater did indicate undiagnostic due to cone cut and the second rater did not.

Resident	Faculty: No	Yes	Total
No	1405	3	1408
Yes	4	39	43
Total	1409	42	1451

Table 6: Agreement on Undiagnostic between Resident and Faculty

Comparing the resident and student, there was 99% agreement (1437/1451) with Kappa = 83.2 (95% CI = 74.6 to 91.9). For seven teeth, the first rater did not indicate undiagnostic due to cone cut and the second rater did. For seven teeth the first rater did indicate undiagnostic due to cone cut and the second rater did not. Comparing the faculty and student, there was 99% agreement (1436/1451) with Kappa = 81.8 (95% CI = 72.8 to 90.8). For eight teeth, the first rater did not indicate undiagnostic due to cone cut and the second rater did. For seven teeth the first rater did indicate undiagnostic due to cone cut and the second rater did not.

The repeated measures logistic regression showed no evidence for an anterior vs. posterior difference (P > 0.9) and no rater difference (P > 0.9). The resident percentage was 2.3% (1.4 to 3.8), faculty 2.2% (1.4 to 3.6), and student 2.3% (1.3 to 3.9). There was no significant difference due to collimator type (P = 0.0631), as shown in Table 7.

	Position		
Collimator	Posterior	Anterior	combined
Circular	0.9% (0.3 to 2.4)	1.9% (0.6 to 5.8)	1.3% (0.6 to 3.1)
Rectangular	5.5% (3.8 to 8.0)	2.8% (1.1 to 6.7)	4.0% (2.3 to 6.6)
combined	2.3% (1.4 to 3.8)	2.3% (1.1 to 4.6)	

Table 7: Undiagnostic Due to Cone Cut Percentages (95% CI)

Additional Analyses: Relationships between the Ratings

Whether there was a cone cut was related to whether there was a missed apex (Table 8). If the radiograph has a cone cut, the likelihood of a missed apex was 20%, as versus 8% if there was no cone cut.

	Missed Apex			
Cone Cut	No	Yes	Total	%Yes
No	2405	218	2623	8.3
Yes	1381	349	1730	20.2
Total	3786	567	4353	13.0

Table 8: Relationship between Cone Cut and Missed Apex

There was a relationship between cone cut and undiagnostic due to cone cut (Table 9). If there is no cone cut, then it was impossible to be undiagnostic due to cone cut. However, it is interesting to note that only 7% of the radiographs with a cone cut failed to be diagnostic.

	Undiagnostic			
Cone Cut	No	Yes	Total	%Yes
No	2623	0	2623	0.0
Yes	1602	128	1730	7.4
Total	4225	128	4353	2.9

Table 9: Relationship between Cone Cut and Undiagnostic Due to Cone Cut

Similarly, there was a relationship between a missed apex and undiagnostic (Table 10). In only one instance (therefore, with only one rater) was a radiograph undiagnostic due to cone cut and no missing apex.

	Undiagnostic			
Missed Apex	No	Yes	Total	%Yes
No	3785	1	3786	0.0
Yes	440	127	567	22.4
Total	4225	128	4353	2.9

Table 10: Relationship between Missed Apex and Undiagnostic Due to Cone Cut

Discussion

During endodontic therapy, dentists usually like to take angled radiographs to separate superimposed structures. This requires moving the X-ray cone in a mesial or a distal direction, which is not aligned with the positioning indicating device. If part of the radiographic film did not get exposed to the X-ray beam it appears white and does not include any diagnostic information. When collimation is added to the X-ray cone, it restricts the beam causing further difficulties in exposing the radiographic film.

The rectangular collimator was used for many years to constrict the beam to a size more consistent with the radiographic film. It minimizes radiation to critical sensitive areas in the body. Because of the added difficulties in alignment of the positioning indicating device to the film in angled radiographs, one would think that more radiographs would be exposed due to the increased possible number of undiagnostic radiographs. However, the results of this study showed that the number of radiographs was not statistically significant between the circular and the rectangular collimators during simulated endodontic therapy. The main difference in the number of exposed radiographs was between anterior and posterior teeth. The results showed that the number of exposed radiographs were doubled in posterior teeth. This is mainly due to the fact that there is more tooth anatomy to consider when someone is treating a multi-rooted molar versus a single rooted anterior tooth.

Looking at the results from cone-cuts, there was a statistically significant difference in the amount of cone-cuts present. As seen in the results section, for the circular collimator a cone cut was present in 19% of the exposed radiographs, while for the rectangular collimator a cone cut was present in 59% of the exposed radiographs.

This has importance especially when exposing radiographs with the need for high quality diagnostic films without cone cuts. The results show that using a circular collimator would result in a decrease of about 40% in the chance of having a cone cut.

In a study by Horton et al, while examining 3,801 dental radiographs to detect cone cuts, 50% of the films were exposed with circular collimation while the other half was exposed with rectangular collimation. A total of 156 cone cuts were detected. Only four of the cone cuts resulted from the circular collimation. The four cone cuts (2.6%) using the circular collimation required retakes while 29 (18%) of the rectangular cone cuts required retakes (34). In comparison, herein showed that 1.3% of the circular collimation and 4% of the rectangular collimation required retakes due to cone cuts of the apices.

Similar results were also found by Parks. When evaluated dental students exposed full mouth series on manikin heads, rectangular collimation produced more cone cuts than circular collimation. Another study by Sewerin et al, showed that the use of circular collimation produced 21.9% cone cuts while the use of rectangular collimation produced 28.7%. All of these study results match the results herein, in that there were more cone cuts observed using the rectangular collimation than the round collimation (35,32).

When looking at the missed apices on the radiographs, there was no statistical difference between the circular collimator and the rectangular collimator. Even though it is statistically insignificant, the number of the missed apices almost doubled when using the rectangular collimator, 8.8% for the circular collimator to 14.2% for the rectangular collimator.

The circular collimator can be used to reduce missed apices in radiographs but the difference is not significant. This insignificant reduction could lead to significant reduction in radiation over a long period of patient exposure to X-rays.

The most important aspect of the study was the missed apices due to cone cut. These are the radiographs that dentists must retake, thus repeating patient exposures during endodontic therapy until a radiograph that shows the anatomy at the apices of the teeth in treatment is obtained. The difference between the circular collimator and the rectangular collimator was not significant. However, the results were marginally significant. The circular collimator produced 1.3% radiographs that were undiagnostic due to cone cut, whereas the rectangular collimator produced 4%. The number of undiagnostic radiographs was tripled by using a rectangular collimator. That means that the patient during dental treatment would actually get triple the amount of radiation by using the rectangular collimator during endodontic therapy.

Technical errors seemed to occur more often with radiographs taken during the endodontic treatment rather than pre/post treatment radiographs. Future study could be prepared to evaluate the use of rectangular collimation in pre/post treatment radiographs while circular collimation is used for radiographs during the treatment. There are add on devices such as the Rinn Universal Collimator (Dentsply, Elgin,IL) that could easily be attached and detached from the circular collimator. These devices may solve the problem of reducing radiation when taking pre/post treatment radiographs and achieving high quality in treatment radiographs.

In this study the raters were a dental student, an endodontic resident, and a board certified endodontic faculty. The inter-rater differences were insignificant except for the missed apices where the student detection was 10.3%, the endodontic resident detection was 11.5% and the faculty detection was 11.5%. Although this number was statistically significant, the difference was less than 2%.

There are many things that could improve the study. In the future, a clinical study repeating the same criteria could be conducted that would allow recommendation for patient treatment during in vivo endodontic procedures. In this study the students had the choice of selecting teeth with simple anatomy for the simulation while in real life there is no control over the complexity of the anatomy of the teeth. Moreover, when students were aligning the X-ray tube to expose radiographs, all the patient difficulties were subtracted. This includes patient's physical ability to open their mouth and patient oral anatomy, preventing placement of film in an ideal area. Adding teeth morphology and difficulties associated with treating patients will result on an overall multiplication of the errors especially when rectangular collimators are used.

In summary, this study shows that there were more cone cuts during endodontic treatment using rectangular collimation when compared to circular collimation. In order to expose high quality radiographs avoiding cone cuts, a traditional circular collimator may be indicated for use during endodontic therapy.

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Appendix

Disagreements on Cone Cut

Setting=Rect Posterior=0

Student	Radiograph	Al_Ali	Archer	Rachael
13000	**32**	1	1	0
13005	**73**	1	0	1
13005	**75**	1	0	1
13005	**81**	1	0	1
13050	**402**	1	0	0
13050	**405**	1	1	0
13095	**509**	1	0	0
13095	**513**	1	0	0
13115	**238**	1	1	0
13115	**240**	1	1	0
13115	**241**	1	1	0
13115	**248**	0	0	1
13125	**526**	0	0	1
13135	**546**	0	0	1
13145	**608**	1	0	1
13145	**609**	0	0	1
13185	**651**	1	0	1
13185	**653**	0	1	0
13270	**911**	1	0	0

13305	**1012**	0	0	1
13305	**1015**	1	0	1
13345	**1113**	1	1	0
13345	**1116**	1	1	0
13515	**1264**	1	1	0
13515	**1269**	0	0	1
13525	**1289**	0	0	1
13525	**1290**	0	0	1
13525	**1293**	0	1	1
13525	**1294**	0	0	1
13525	**1295**	0	0	1
13525	**1296**	0	0	1
13525	**1298**	0	0	1

Setting=Rect Posterior=1

Student	Radiograph	Al_Ali	Archer	Rachael
13000	**3**	0	0	1
13000	**10**	0	0	1
13000	**11**	1	0	1
13000	**13**	0	0	1
13000	**14**	0	0	1
13000	**15**	0	0	1
13000	**16**	0	0	1
13000	**23**	0	0	1

13000	**25**	0	0	1
13005	**67**	0	1	0
13005	**68**	0	1	1
13065	**419**	1	1	0
13065	**432**	1	1	0
13065	**445**	1	0	0
13075	**446**	1	1	0
13075	**455**	0	1	1
13075	**466**	0	0	1
13075	**467**	0	0	1
13115	**180**	1	0	1
13115	**183**	1	0	1
13115	**186**	1	0	1
13115	**199**	0	1	0
13115	**214**	0	1	1
13135	**551**	1	0	0
13135	**557**	1	1	0
13135	**558**	1	1	0
13135	**559**	1	1	0
13135	**561**	1	1	0
13205	**698**	1	1	0
13205	**708**	1	0	1
13305	**1031**	0	1	1
13305	**1036**	0	0	1

13345	**1127**	0	1	1
13405	**1155**	0	0	1
13405	**1161**	0	0	1
13405	**1163**	0	1	1
13405	**1165**	0	0	1
13405	**1166**	0	0	1
13405	**1167**	0	0	1
13405	**1171**	0	0	1
13405	**1172**	0	0	1
13420	**1181**	0	0	1
13430	**1197**	1	0	1
13430	**1202**	1	0	1
13455	**1206**	1	0	0
13455	**1216**	1	0	1
13455	**1220**	1	0	0
13515	**1274**	0	0	1
13515	**1275**	1	0	1
13525	**1311**	0	0	1
14080	**1389**	1	1	0
14080	**1390**	1	1	0
14080	**1393**	1	1	0
14080	**1417**	1	0	1
14080	**1423**	1	0	1
14440	**1431**	0	1	0

14440	**1434**	0	1	1
14440	**1441**	0	1	1

Setting=Circular Posterior=0

Student	Radiograph	Al_Ali	Archer	Rachael
13010	**316**	1	1	0
13010	**317**	1	1	0
13010	**318**	1	1	0
13010	**320**	1	1	0
13010	**321**	1	1	0
13010	**322**	1	0	0
13010	**324**	1	1	0
13010	**326**	1	1	0
13030	**362**	1	0	1
13030	**363**	1	0	0
13030	**364**	1	0	0
13030	**368**	1	0	0
13035	**370**	1	0	0
13070	**120**	0	0	1
13070	**122**	1	0	1
13070	**123**	0	0	1
13120	**274**	0	1	0
13155	**612**	0	0	1
13155	**620**	1	0	1

13200	**675**	1	1	0
13200	**678**	0	1	0
13210	**719**	0	0	1
13215	**759**	0	0	1
13215	**760**	0	0	1
13215	**763**	1	0	1
13230	**798**	1	0	0

Setting=Circular Posterior=1

Student	Radiograph	Al_Ali	Archer	Rachael
13040	**379**	1	1	0
13040	**380**	1	1	0
13040	**392**	1	1	0
13085	**133**	0	0	1
13085	**135**	0	0	1
13085	**136**	0	0	1
13085	**139**	1	0	0
13130	**298**	0	0	1
13140	**564**	1	1	0
13140	**569**	0	1	0
13140	**573**	1	1	0
13190	**671**	1	1	0
13230	**821**	0	0	1
13290	**964**	0	0	1

13290	**965**	0	0	1
13290	**966**	0	0	1
13290	**996**	1	0	1
13315	**1058**	1	1	0
13340	**1091**	0	0	1
13500	**1238**	0	0	1
13500	**1245**	0	0	1
13500	**1252**	0	0	1

Disagreements on Missed Apex

Setting=Rect Posterior=0

Student	Radiograph	Al_Ali	Archer	Rachael
13095	**509**	1	0	0
13115	**239**	1	1	0
13115	**242**	1	1	0
13115	**246**	1	0	0
13115	**247**	1	1	0
13367	**1130**	1	1	0
13367	**1132**	1	1	0
13515	**1261**	1	1	0
13525	**1288**	0	0	1

Setting=Rect Posterior=1

Student	Radiograph	Al_Ali	Archer	Rachael
13065	**417**	0	1	0

13065	**444**	1	1	0
13115	**155**	0	0	1
13115	**168**	1	0	0
13115	**183**	1	0	0
13135	**558**	1	1	0
13205	**708**	1	1	0
13205	**711**	1	1	0
13430	**1195**	1	1	0
13515	**1272**	0	1	0
13515	**1273**	1	1	0
13515	**1279**	0	1	0
13525	**1301**	1	1	0
13525	**1312**	1	1	0
13525	**1320**	0	1	0
14080	**1403**	1	0	1
14080	**1407**	1	1	0
14080	**1408**	1	1	0
14080	**1410**	1	0	0
14080	**1418**	1	1	0
14080	**1421**	0	1	0
14080	**1422**	0	1	0
14080	**1424**	0	1	1
14080	**1427**	0	1	0
14440	**1434**	0	1	1

14440	**1446**	1	0	1

Setting=Circular Posterior=0

Student	Radiograph	Al_Ali	Archer	Rachael
13035	**371**	1	0	0
13200	**675**	1	1	0
13200	**680**	1	1	0
13225	**775**	1	0	0
13235	**828**	1	1	0

Setting=Circular Posterior=1

Student	Radiograph	Al_Ali	Archer	Rachael
13012	**344**	1	0	1
13012	**354**	1	0	0
13130	**292**	1	0	1
13130	**295**	0	0	1
13140	**568**	1	1	0
13140	**570**	1	1	0
13140	**572**	1	0	0
13140	**588**	1	0	1
13230	**820**	0	0	1
13240	**865**	1	0	0
13290	**964**	0	0	1
13290	**965**	0	0	1

13290	**966**	0	0	1
13290	**973**	0	0	1
13315	**1059**	1	0	0
13340	**1092**	0	0	1
13340	**1096**	1	1	0
13340	**1101**	1	1	0
13340	**1102**	1	1	0
13340	**1104**	1	1	0

Disagreements on Undiagnostic Due to Cone Cut

Setting=Rect Posterior=0

Student	Radiograph	Al_Ali	Archer	Rachael
13367	**1130**	1	1	0
13367	**1131**	1	1	0
13515	**1265**	1	0	0

Setting=Rect Posterior=1

Student	Radiograph	Al_Ali	Archer	Rachael
13065	**410**	0	0	1
13065	**444**	1	1	0
13115	**151**	0	1	0
13115	**152**	0	1	0
13135	**558**	1	1	0
13525	**1301**	1	1	0
14080	**1391**	0	0	1

14440	**1434**	0	1	1
14440	**1446**	1	0	1

Setting=Circular Posterior=0

Student	Radiograph	Al_Ali	Archer	Rachael
13200	**675**	1	0	0

Setting=Circular Posterior=1

Student	Radiograph	Al_Ali	Archer	Rachael
13290	**964**	0	0	1
13290	**965**	0	0	1
13290	**966**	0	0	1
13290	**996**	1	0	1
13340	**1091**	0	0	1

Vita

Dr. Tareq AlAli was born June 23, 1981 in Kuwai. Dr. AlAli received a Doctor of Dental Surgery from Virginia Commonwealth University in 2007. Dr. AlAli earned a Certificate in Advanced Education in General Dentistry from Virginia Commonwealth University in 2008. He then joined Kuwait University as a scholarship holder to study Endodontics for a year prior to enrolling in the Advanced Specialty Program in Endodontics at Virginia Commonwealth University School of Dentistry. Dr. AlAli is a member of the AAE, ADA, Kuwaiti Dental Association, and Virginia Dental Association. Dr. AlAli will return to teach Endodontics at Kuwait University upon graduation. He will graduate from VCU with a Master of Science in Dentistry and a Certificate in Endodontics.