The use of radiographic imaging technologies by general dentists in Ontario, Canada

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Objective. The aim of this study was to determine the prevalence of 2-dimensional and 3-dimensional digital imaging technologies, the methods used by general dentists to limit patient exposure to ionizing radiation, and the impact of dentists' education on imaging technologies and patient dose-reducing techniques.

Study Design. A cross-sectional, web-based survey of all general dentists in Ontario was conducted.

Results. Responses from 1332 (14.7%) of the 9052 registered general dentists in Ontario were included in the analysis. Approximately 89% reported using digital intraoral technology, 81.1% reported owning panoramic imaging systems, 71.2% reported making referrals for cone beam computed tomography (CBCT), and 9.5% reported including CBCT in their practices. CBCT was most commonly used for dental implant treatment planning (85.8%), followed by endodontics (45.4%), evaluation of pathology (39.6%), and surgical assessment for impacted teeth or difficult extractions (36.8%). Approximately 32.7% used only collimators with a long focal point−receptor distance and 8% used only rectangular collimation; 86.9% reported using a thyroid collar when imaging patients. Differences in educational backgrounds correlated with differences in the use of imaging and dose-reducing techniques.

Conclusions. There is widespread adoption of digital imaging technologies by general dentists in Ontario, including CBCT. Greater implementation of long and/or rectangular collimation could markedly reduce the ionizing radiation dose to patients. Changes in dental education curricula and continuing education course offerings may address these issues. (Oral Surg Oral Med Oral Pathol Oral Radiol 2021;131:475−484)

Imaging technologies in dentistry have changed markedly in the past 25 years. In the case of 2-dimensional (2-D) intraoral and panoramic imaging, these systems have migrated from film-based receptors to charge-coupled device, complementary metal-oxide semiconductor, and photostimulable phosphor type digital receptors. The introduction of 3-dimensional (3-D) imaging in the form of cone beam computed tomography (CBCT) has both augmented and changed how oral and maxillofacial pathoses are diagnosed.

Radiographic imaging has significant benefits for the diagnosis and management of oral diseases and conditions. However, it is well known that ionizing radiation can have harmful effects on biologic tissues.[1] Although numerous guidelines have been proposed or enacted regarding the use of 2-D and 3-D radiographic imaging so that the benefit-to-risk ratio is optimal for patients,[2-7] all have 2 similar principles: justification and optimization. Justification of radiographic imaging requires a reasonable probability that information obtained from imaging will alter management. If a radiographic investigation is justified, optimization is reflected by the "as low as reasonably achievable" (ALARA) principle to limit patient dose. The modified phrase "as low as diagnostically acceptable" (ALADA) has also been added to the radiologic glossary to reinforce the idea that patient dose should be limited to the lowest amount of radiation needed to achieve a diagnostically acceptable image. In addition to prescription of imaging, numerous technical modifications have been recommended in dentistry to ensure application of the ALARA/ALADA principle. Examples of these are use of the fastest/most sensitive image receptor compatible with the diagnostic task, rectangular collimation, long focal point−receptor distance (FRD); use of protective aprons and thyroid collars, when appropriate; and limiting the volume of the irradiated tissue to the region of interest.[3]

Current dental education programs in Canada have a requirement that graduating dentists understand the principles of justification and optimization. Both domestic students and internationally trained dental graduates (who must undertake a series of assessment examinations or undergo further schooling at a Canadian university) are made aware of these principles as a component of the educational programs. Before den-

Statement of Clinical Relevance

Digital 2- and 3-dimensional imaging technologies are now commonly used by general dentists. However, dose reduction methods, such as long focal point−receptor distance and rectangular collimation, are not. Modifications in education programs and continuing education courses may help address this new reality.

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tists can own and operate a CBCT unit in Ontario, Canada, they must complete a 2-day continuing education (CE) course that includes the principles of justification and optimization as they apply to CBCT.

Bohay et al.[8-11] investigated dental radiographic imaging practices in Ontario, Canada's most populous province, at a time when 2-D film imaging practices predominated.[8-11] In the subsequent 26 years, and with the advent of new imaging technologies, little is known about how these changes have been adopted by general dentists. Although dose reduction has accompanied the introduction of some digital 2-D imaging technologies, the widespread adoption of 3-D imaging may have resulted in the opposite effect. Given that the methods general dentists use to reduce patient exposure to ionizing radiation are highly variable,[12-17] the objectives of this study were to determine the prevalence of adoption of 2-D and 3-D digital imaging technologies, the methods used by general dentists to limit patient exposure to ionizing radiation in Ontario, Canada, and the impact of dentists' education on the use of imaging technologies and patient dose-reducing techniques.

MATERIALS AND METHODS

This cross-sectional study was conducted through an electronic survey platform. The invitation to participate in the study was sent in 4 e-mail waves in April, May, and June 2019, to all general dentists registered with the Royal College of Dental Surgeons of Ontario, the body that regulates dentists in the province. As of July 17, 2019, 9052 general dentists were registered.

The eligibility criteria for participation in this study were (1) having a general dentist license in Ontario; (2) not holding a concurrent dental specialist permit; and (3) being still in clinical practice.

Table I shows the survey questions, the number of respondents for each question, and the responses by dentists. Five questions were aimed at collecting dentist demographic and dental education information, including attendance at CE courses on imaging practices. Four questions asked about imaging technology used by general dentists in their practices: intraoral imaging receptors used, ownership of a film-based or digital panoramic system, referral for CBCT imaging, and ownership of a CBCT system. One question investigated the clinical scenarios where a dentist would order CBCT. Nine scenarios were included in the question from which the respondents could indicate whether or not they used CBCT for that scenario. A 10th option of "other" was included that allowed the respondents to add any further situations in which they used CBCT. Six questions asked about CBCT use. Four questions investigated the frequency of CBCT use for treatment planning of dental implants, endodontic therapy, tooth extractions, and orthodontic care. With regard to the frequency of CBCT use, the respondents could select from 3 options: every case, select cases, or no cases. (Each of these questions had an option that allowed identification of respondents who did not conduct these types of dental treatment. Respondents who chose these options were not included in the data shown in this table.) One question investigated the field-of-view (FOV) size of the CBCT machine owned by dentists. Three questions investigated patient-dose optimization techniques: the use of short or long FRD, round or rectangular collimation, and lead apron and/or thyroid collar.

Data analysis was performed by using the Statistical Package for Social Sciences software, version 25.0 (SPSS Inc., Chicago, IL). Proportions of general dentists were calculated from the survey questions to determine the prevalence of adoption of 2-D and 3-D digital imaging technologies and the methods used by general dentists in Ontario to limit patient exposure to ionizing radiation. Ninety-five percent confidence intervals (95% CIs) were calculated for each percentage and proportion based on the sample size and known population of 9052 registered dentists. Inferential statistical calculations were made by using χ^2 analysis. Independent variables revolved around the education of the dentists, including year of graduation, location of dental training, and when the dentists had last taken a CE course in oral and maxillofacial radiology. Dependent variables included use of digital intraoral imaging receptors, ownership of a panoramic imaging machine, referrals made for CBCT imaging, ownership of a CBCT machine, and use of a long FRD collimator, rectangular collimation, and a lead apron and/or thyroid collar. All inferential statistical analyses were 2-tailed and interpreted at the 5% level of significance.

Ethical approval was obtained on April 1, 2019, from the University of Toronto Health Sciences Research Ethics Board (protocol number 37237), Toronto, Ontario, Canada.

RESULTS

Survey respondents

Of the 9052 dentists invited to participate in the study, 1340 provided their responses. Eight responses were identified as either duplicate or completed by a dental specialist, and these were discarded. The remaining 1332 responses were included in the analysis (14.7% response rate).

Table I shows the dentists' responses to the survey questions. Of the respondents, 62.4% were males (95% CI 59.9%−64.9%) with mean age being 50.2 years (95% CI 49.6−50.9). The median year of dental school graduation was 1995 (95% CI 1994−1996), and 69.1% (95% CI 66.7%−71.3%) graduated from a Canadian dental school. These data are similar to the Ontario Dental Association's demographic data of their 8070 general dentist members: 58.2% males (95% CI

Table I. Survey instrument questions regarding the radiographic imaging practices of general dentists in Ontario, Canada, and the responses of the dentists

Question	*Number of respondents*	*Responses (95% confidence intervals)*
You are?	1291	Male = 62.4% (59.9%−64.9%) Female = 37.6% (35.1%−40.1%)
What is your age?	1270	Mean = 50.2 (49.6−50.9)
What was the year of graduation of your initial degree (DDS/DMD/BDS) in any jurisdiction?	1278	Median = 1995 (1994−1996)
From where did you receive your initial* dental training (DDS/DMD/BDS)?	1296	University of Toronto = 39.7% (36.2%−42.2%) Western University = 17.4% (15.5%−19.3%) Another Canadian university = 12% (10.4%−13.6%) U.S. university = 9.5% (8.0%−11%) Another international university = 21.5% (19.4%−23.6%)
Have you taken a continuing education course involving imaging practices, prescription, or guidelines?	1278	Within the last year = 17.7% (15.8%−19.6%) Between 1 and 5 years ago = 39.9% (37.4%−42.4%) Between 6 and 10 years ago = 12.1% (10.5%−13.7%) Over 10 years ago = 9.3% (7.8%−10.8%) Never = 21% (18.9%−23.1%)
What type of intraoral imaging system do you use? (Check ALL that apply.)	1287	Digital sensor (CCD, CMOS) = 70.3% (68.0%−72.6%) Photostimulable phosphor plate (PSP) = 23.2% (21.1%−25.3%) Film = 14.5% (12.7%−16.3%) Unknown = 0.6% (0.2%−1.0%)
Do you have a panoramic machine in your practice?	1331	Digital machine = 70% (67.7%−72.3%) Film machine = 9.5% (8%−11.0%) Both digital and film machines = 1.6% (1%−2.2%) None = 18.7% (16.8%−20.6%) Unknown = 0.2% (0.1%−0.3%)
Do you refer for CBCT imaging?	1328	Yes = 71.2% (68.9%−73.5%) No = 28.8% (26.5%−31.1%)
Do you have a CBCT machine in your practice?	1331	Yes = 9.5% (8%−11%) No = 90% (88.5%−91.5%) Unknown = 0.5% (0.1%−0.9%)
What do you use/refer for CBCT for? (Check ALL that apply.)†	967	Implants = 85.8% (83.7%−87.9%) Endodontic treatment = 45.4% (42.4%−48.4%) Pathology = 39.6% (36.7%−42.5%) Impacted teeth/difficult extractions = 36.8% (33.9%−39.7%) Temporomandibular joint dysfunction = 21.7% (19.2%−24.2%) Trauma = 14.6% (12.5%−16.7%) Orthodontics = 7.2% (5.7%−8.7%) Periodontal assessment = 3.5% (2.4%−4.6%) Caries = 0.9% (0.3%−1.5%) Other = 0.6% (0.1%−1.1%) (5 respondents mentioned use for airway analysis and 1 for unexplained pain in the jaws)
How often do you use/refer for a CBCT for implants?‡	666	Every case = 31.1% (27.7%−34.5%) Select cases = 67.1% (63.7%−70.5%) No cases = 1.8% (0.8%−2.8%)
How often do you use/refer for a CBCT for endodontic treatment?‡	832	Every case = 1.0% (0.4%−1.6%) Select cases = 47.1% (43.9%−50.1%) No cases = 51.9% (48.7%−55.1%)
How often do you use/refer for a CBCT for tooth extraction?‡	919	Every case = 0.3% (0.1%−0.5%) Select cases = 38.4% (35.4%−41.4%) No cases = 61.3% (58.3%−64.3%)
How often do you use/refer for a CBCT for orthodontic treatment planning?‡	390	Every case = 0.8% (0.1%−1.5%) Select cases = 26.4% (22.1%−30.7%) No cases = 72.8% (68.5%−77.1%)
If you have a CBCT machine in your office, the largest field of view size is:	124	$\leq$ 5 cm = 5.6% (1.6%−9.6%) $>$ 5 cm to 8 cm = 71.8% (63.9%−79.7%)

(*continued*)

Table I. Continued

Question	*Number of respondents*	*Responses (95% confidence intervals)*
		> 8 cm = 12.1% (6.6%−17.8%)
		Unknown = 10.5% (5.1%, 15.9%)
What type of collimator length (focal point-receptor distance) do you use?	1283	Long = 32.7% (30.3%−35.1%)
		Short = 48.1% (45.6%−50.6%)
		Both = 11.1% (9.5%−12.7%)
		Unknown = 8.1% (6.7%−9.5%)
What type of collimation do you use for intra-oral imaging?	1295	Rectangular = 8% (6.6%−9.4%)
		Round = 84.4% (82.6%−86.2%)
		Both = 2.2% (1.5%−2.9%)
		Unknown = 5.4% (4.3%−6.5%)
What patient protection equipment do you use when taking intra-oral radiographs?	1327	Lead apron = 12.7% (11%−14.4%)
		Thyroid collar = 0.5% (0.1%−0.9%)
		Lead apron and thyroid collar = 86.4% (84.7%−88.1%)
		Unknown = 0.4% (0.1%−0.7%)
		None = 0%

*"Initial" was used if a dentist had graduated from an international university and gone through an equivalency program at a Canadian university to receive the license to practice dentistry in Canada.
†An option "I don't use CBCT" was given. Respondents who chose this option were not included in the data shown in the table.
‡Options that allowed identification of respondents who did not conduct these types of dental treatment were given. Respondents who chose these options were not included in the data shown in this table.

57.8%−58.6%), with a mean age of 47.5 years (95% CI 47.3−47.7), median year of dental school graduation of 1999 (95% CI 1998−1999), and graduation from a Canadian dental school (66.9% [95% CI 66.6%−67.2%]). With regard to CE in imaging practice, 17.7% (95% CI 15.8%−19.6%) of the respondents had attended a course within the previous year; 39.9% (95% CI 37.4%−42.4%) had attended a course 1 to 5 years ago; 12.1% (95% CI 10.5%−13.7%) had attended a course 6 to 10 years ago; 9.3% (95% CI 7.8%−10.8%) had attended a course over 10 years ago; and 21% (95% CI 18.9%−23.1%) had never taken such a course.

2-D imaging technology

The majority of the surveyed general dentists used digital imaging modalities for both intraoral and panoramic imaging. Approximately 89% (95% CI 87.4%−90.6%) of dentists in this sample used digital intraoral radiography; 8% (95% CI 6.6%−9.4%) of dentists used multiple intraoral imaging receptor types; and 81.1% (95% CI 79.2%−83.0%) operated a panoramic imaging system in their practices.

CBCT imaging

Of the general dentists in this sample, approximately 75.7% (95% CI 73.5%−77.9%) used CBCT imaging in their practices. Of all of the survey respondents, 71.2% (95% CI 68.9%−73.5%) made referrals for CBCT imaging; and 9.5% (95% CI 8%−11%) operated a CBCT system in their practices. These 2 figures are not mutually exclusive because some dentists who had a CBCT system in their offices still made referrals to other facilities for CBCT imaging of some patients. Treatment planning for dental implants was the most common reason for using CBCT imaging, followed by endodontic treatment, evaluation of pathological lesions, and impacted teeth/difficult extractions. Of dentists who placed dental implants, approximately 31.1% (95% CI 27.7%−34.5%) used CBCT imaging for treatment planning for every case; 67.1% (95% CI 63.7%−70.5%) used it for treatment planning for only select cases; and 1.8% (95% CI 0.8%−2.8%) did not use CBCT imaging for treatment planning implant cases. Of the dentists who provided endodontic treatment, approximately 1% (95% CI 0.4%−1.6%) used CBCT imaging for treatment planning for all cases; 47.1% (95% CI 43.9%−50.1%) used it for select cases; and 51.9% (95% CI 48.7%−55.1%) did not use this technology for endodontic treatment planning. Of the dentists who performed extractions, approximately 0.3% (95% CI 0.1%−0.5%) used CBCT imaging for treatment planning for all of the teeth they extracted; 38.4% (95% CI 35.4%−41.4%) used it for extraction of some teeth; and 61.3% (95% CI 58.3%−64.3%) did not use it for treatment planning for tooth extraction. Of the dentists who provided orthodontic treatment, approximately 0.8% (95% CI 0.1%−1.5%) used CBCT imaging for treatment planning for all orthodontic cases; 26.4% (95% CI 22.1%−30.7%) used it for select cases; and 72.8% (95% CI 68.5%−77.1%) did not use these images for orthodontic treatment planning.

Of the dentists who owned a CBCT device in their practices, approximately 5.6% (95% CI 1.6%−9.6%) used a system with a FOV size of 5 cm (diameter) or less; 71.8% (95% CI 63.9%−79.7%) greater than 5 cm and 8 cm or less; and 12.1% (95% CI 6.6%−17.8%) greater than 8 cm. Approximately 10.5% (95% CI 5.1%−15.9%) did not know the FOV sizes of their systems.

Physical methods for reducing patient dose

Approximately 48.1% (95% CI 45.6%−50.6%) of the surveyed general dentists used only a short FRD for collimation (i.e., 20 cm distance from the x-ray source to the distal end of the aiming device; a long FRD involves a 40 cm distance), and 84.4% (95% CI 82.6%−86.2%) used only a round (7 cm diameter) collimator. Approximately 86.4% (95% CI 84.7%−88.1%) used both a lead apron and a thyroid collar for their patients during the imaging examination.

Impact of dentist education

Tables II through VIII show the correlation between education-related independent variables and the use of digital intraoral imaging systems, ownership of panoramic machines, referrals for CBCT imaging, ownership of CBCT machines, use of only long FRD collimation, use of only rectangular collimation, and use of thyroid collars. Dentists who had graduated more recently ($P < .001$) or dentists who had trained internationally ($P = .006$) were more likely to use digital intraoral imaging systems (see Table II). These same 2 groups of dentists were also more likely to own panoramic imaging machines ($P < .001$ and $P = .027$, respectively), as shown in Table III.

Dentists trained internationally ($P = .050$) were more likely to make referrals for CBCT imaging (see Table IV). Dentists trained in Canada ($P = .001$) and dentists who had taken a CE course in radiology within the past 5 years ($P < .001$) were more likely to own CBCT machines (see Table V).

Dentists trained in countries other than the United States and Canada ($P = .013$) were more likely to use only long collimation (see Table VI). Dentists who had graduated before 1993 ($P = .002$), had trained internationally ($P = .003$), or had taken a CE course in radiology within the past 5 years ($P = .006$) were more likely to use rectangular collimation (see Table VII). Dentists who had trained in Canada ($P = .001$) or had not taken a CE course in radiology within the past 5 years ($P = .045$) were more likely to use thyroid collars during imaging (see Table VIII).

DISCUSSION

The response rate of 14.7% (1332 respondents) was comparable with those reported by 2 recent survey studies involving general dentists in Ontario.[18,19] Overall, the demographic information collected for this study was comparable with data from the Ontario Dental Association member database, although the demographic was composed mostly of older males with Canadian dental training. Despite the differences, we believe that this study's sample of dentists is generalizable to all general dentists in Ontario.

Digital intraoral and panoramic imaging receptor technologies had been widely adopted by this sample of general dentists. The advantages of digital imaging include faster image acquisition time, reduction of chemical waste, and ease of image transfer.[3] Furthermore, as much as a 52% reduction in the radiation dose to the patient can be achieved with a photostimulable phosphor plate receptor and a 76% reduction with a solid-state detector, compared with F-speed film.[20] The findings of this study indicated that the advantages of digital imaging outweigh its chief disadvantage, that is, cost, in the practices of most dentists. Our findings align with those of recent studies in Turkey, South Korea, New Zealand, and The Netherlands,[13,21-23] all of which reported that the majority of general dentists used digital imaging. Of the dentists who operated a panoramic system in their offices, the rate of 81.1% was a notable increase from the 50.5% reported previously.[8]

The use of CBCT imaging was common among our sample of general dentists, with 75.7% reporting that they used CBCT. The majority of these respondents made referrals to other clinics for a CBCT study because less than 10% reported having a CBCT system in their practices. In Ontario, CBCT ownership and

Table II. Use of digital intraoral imaging receptors compared to solely film by general dentists in Ontario stratified by education demographics. Expected counts for chi-square analyses are given in brackets after the observed counts.

Education demographic	*Use of digital receptors*	*Use of solely film*	*Chi-Square tests*
Graduated between 2009 and 2019	253 (234)	10 (29)	$\chi^2 = 45.129$
Graduated between 1993 and 2008	426 (410)	34 (51)	$p < 0.001$
Graduated before 1993	416 (451)	91 (56)	$n = 1230$
Graduated from Canadian dental school	747 (763)	110 (94)	$\chi^2 = 10.131$
Graduated from USA dental school	113 (106)	6 (13)	$p = 0.006$
Graduated from another international dental school	249 (240)	21 (30)	$n = 1246$
Taken a continuing education (CE) course in radiology in the past five years	633 (632)	77 (79)	$\chi^2 = 0.090$
No CE course in radiology in the past five years	459 (461)	59 (57)	$p = 0.764$
			$n = 1228$

Table III. Ownership of panoramic imaging machines among general dentists in Ontario, Canada, stratified by educational demographic characteristics*

Educational demographic	*Panoramic machine in practice*	*No panoramic machine in practice*	*χ^2 test*
Graduated between 2009 and 2019	246 (221)	26 (51)	$\chi^2 = 39.980$
Graduated between 1993 and 2008	402 (386)	74 (90)	$P < .001$
Graduated before 1993	387 (428)	141 (100)	n = 1276
Graduated from Canadian dental school	709 (726)	185 (168)	$\chi^2 = 7.209$
Graduated from U.S. dental school	107 (100)	16 (23)	$P = 0.027$
Graduated from another international dental school	235 (225)	42 (52)	n = 1294
Taken a CE course in radiology in the past 5 years	609 (596)	126 (139)	$\chi^2 = 3.747$
No CE course in radiology in the past 5 years	425 (438)	116 (103)	$P = .053$
			n = 1276

CE, continuing education.
*Expected counts for χ^2 analyses are given in brackets after the observed counts.

Table IV. Referral for cone-beam computed tomography (CBCT) imaging by general dentists in Ontario stratified by education demographics. Expected counts for chi-square analyses are given in brackets after the observed counts.

Education demographic	*Refer for CBCT imaging*	*Does not refer for CBCT imaging*	*Chi-Square tests*
Graduated between 2009 and 2019	203 (194)	69 (78)	$\chi^2 = 1.823$
Graduated between 1993 and 2008	334 (338)	140 (136)	$p = 0.402$
Graduated before 1993	372 (377)	156 (151)	n = 1274
Graduated from Canadian dental school	625 (638)	269 (256)	$\chi^2 = 5.989$
Graduated from USA dental school	99 (88)	24 (35)	$p = 0.050$
Graduated from another international dental school	198 (196)	77 (79)	n =1292
Taken a continuing education (CE) course in radiology in the past five years	532 (524)	203 (211)	$\chi^2 = 0.903$ $p = 0.342$
No CE course in radiology in the past five years	377 (385)	162 (154)	n = 1274

Table V. Ownership of cone-beam computed tomography (CBCT) imaging machines by general dentists in Ontario stratified by education demographics. Expected counts for chi-square analyses are given in brackets after the observed counts.

Education demographic	*CBCT machine in practice*	*No CBCT machine in practice*	*Chi-Square tests*
Graduated between 2009 and 2019	27 (25)	246 (248)	$\chi^2 = 0.591$
Graduated between 1993 and 2008	44 (43)	428 (429)	$p = 0.744$
Graduated before 1993	44 (48)	483 (479)	n = 1272
Graduated from Canadian dental school	100 (83)	793 (810)	$\chi^2 = 13.459$
Graduated from USA dental school	9 (11)	114 (112)	$p = 0.001$
Graduated from another international dental school	11 (25)	263 (249)	n =1290
Taken a continuing education (CE) course in radiology in the past five years	98 (67)	633 (664)	$\chi^2 = 38.109$ $p < 0.001$
No CE course in radiology in the past five years	18 (49)	523 (492)	n = 1272

operation are regulated such that general dentists must obtain certification through a multiday CE program before they can own and operate a CBCT device in their practices. This is likely the reason for most general dentists in Ontario making referrals to other clinics for CBCT imaging.

CBCT was reported to be used in a variety of clinical situations by the respondents, with treatment planning for dental implants being the most common. Approximately 85.8% used CBCT for implant treatment planning. The next most common clinical situations included endodontic treatment planning (45.4%), investigation of pathologic entities of the jaws (39.6%), and surgical treatment planning for impacted teeth/difficult extractions (36.8%). Only 3 previous studies were identified that investigated the prevalence of CBCT imaging and clinical situations where

Table VI. The use of only long focal point-receptor distance collimation by general dentists in Ontario, Canada, stratified by educational demographic characteristics*

Educational demographic	*Sole use of long collimation*	*Does not solely use long collimation*	*χ^2 tests*
Graduated between 2009 and 2019	90 (84)	173 (179)	$\chi^2 = 1.688$
Graduated between 1993 and 2008	138 (148)	324 (314)	P = .430
Graduated before 1993	166 (162)	341 (345)	n = 1232
Graduated from Canadian dental school	263 (276)	592 (579)	$\chi^2 = 8.638$
Graduated from U.S. dental school	32 (38)	87 (81)	P = .013
Graduated from another international dental school	108 (89)	167 (186)	n = 1249
Taken a CE course in radiology in the past 5 years	234 (229)	479 (484)	$\chi^2 = 0.355$
No CE course in radiology in the past 5 years	162 (167)	357 (352)	P = .551
			n = 1232

CE, continuing education.
*Expected counts for χ^2 analyses are given in brackets after the observed counts.

Table VII. The use of only rectangular collimation by general dentists in Ontario, Canada, stratified by educational demographic characteristics*

Educational demographic	*Sole use of rectangular collimation*	*Does not solely use rectangular collimation*	*χ^2 tests*
Graduated between 2009 and 2019	15 (21)	251 (245)	$\chi^2 = 12.148$
Graduated between 1993 and 2008	26 (36)	435 (425)	P = .002
Graduated before 1993	57 (41)	459 (475)	n = 1243
Graduated from Canadian dental school	58 (68)	807 (797)	$\chi^2 = 11.760$
Graduated from U.S. dental school	6 (9)	113 (110)	P = .003
Graduated from another international dental school	35 (22)	241 (254)	n = 1260
Taken a CE course in radiology in the past 5 years	69 (56)	650 (663)	$\chi^2 = 7.621$
No CE course in radiology in the past 5 years	28 (41)	496 (483)	P = .006
			n = 1243

CE, continuing education.
*Expected counts for χ^2 analyses are given in brackets after the observed counts.

Table VIII. The use of thyroid collars by general dentists in Ontario stratified by education demographics. Expected counts for chi-square analyses are given in brackets after the observed counts.

Education demographic	*Uses thyroid collar*	*Does not use thyroid collar*	*Chi-Square tests*
Graduated between 2009 and 2019	236 (237)	36 (35)	$\chi^2 = 3.748$
Graduated between 1993 and 2008	406 (415)	70 (60)	p = 0.153
Graduated before 1993	469 (458)	56 (67)	n = 1273
Graduated from Canadian dental school	796 (776)	94 (114)	$\chi^2 = 14.482$
Graduated from USA dental school	104 (107)	19 (16)	p = 0.001
Graduated from another international dental school	225 (242)	53 (36)	n =1291
Taken a continuing education (CE) course in radiology in the past five years	627 (639)	107 (95)	$\chi^2 = 4.014$
No CE course in radiology in the past five years	481 (469)	58 (70)	p = 0.045
			n = 1273

it is used by general dentists.[21,22,24] A survey of dentists in Turkey in 2011 found that approximately 30% of dentists made referrals for CBCT imaging, and the 2 most common reasons were implant planning (70%) and diagnosis of cysts/tumors (54%).[21] A survey of dentists from The Netherlands in 2015 found that 8.4% of dentists used CBCT imaging, although it was not clear if this percentage reflected the proportion of dentists who owned a CBCT system or made referrals for CBCT imaging.[22] A survey of all the dental clinics in Norway that had registered CBCT machines in 2015 reported that the most common use of CBCT imaging was for planning implant placement.[24] These results are similar to those of our investigation with respect to clinical situations where dentists use

CBCT imaging. Our survey, which showed appreciably higher use, was conducted more than 4 years after the Dutch study and 8 years after the Turkish study and may simply reflect the greater prevalence of CBCT use in general dental practice.

A small but concerning percentage of this sample reported that they used CBCT imaging for diagnosing caries and periodontal disease. These are clinical situations where guidelines recommend against the use of CBCT.[5-7] A small number also reported using CBCT imaging for all endodontic cases, all teeth that are to be extracted, and all orthodontic cases. Guidelines recommend the use of CBCT imaging only for select cases in these situations.[5-7,25-27] Our results indicate that some general dentists may not be using CBCT according to the established guidelines. For dental implant placement, the American Academy of Oral and Maxillofacial Radiology recommends CBCT imaging as the modality of choice for dental implant site assessment.[25] Only 31.1% of general dentists who reported using CBCT imaging for treatment planning for dental implants used it for every case. These results, in consideration of the American Academy of Oral and Maxillofacial Radiology guidelines, indicate that general dentists may be underutilizing CBCT imaging for implant placement. However, the European Commission Report No. 172 on radiation protection (prepared by the SEDENTEXCT project) states that cross-sectional imaging (including CBCT) may not be required in all implant cases.[5] Further studies are recommended to clarify the role of CBCT in implant treatment planning and to further assess CBCT use by general dentists with more precise determination of the appropriateness of the use of this modality in clinical situations.

The large majority of general dentists in this sample who owned a CBCT unit had devices with a FOV size of 8 cm or less. This is not surprising because in Ontario general dentists may only acquire and interpret CBCT volumes of 8 cm or less in the largest dimension. Given that the large majority of clinical situations for CBCT use, as reported by general dentists, requires a limited or small FOV, the high prevalence of CBCT machines with small FOVs aligns with both provincial regulation and the ALARA (As Low As Reasonably Achievable) principle.

The wide adoption of digital 2-D imaging and CBCT imaging has implications for the training of dental students and CE offerings for general dentists. Historically, dental education has focused on film and 2-D imaging. This study recommends that educational programs be made more comprehensive to reflect the increased use of digital imaging and the common use of CBCT imaging.

Tables II through V show that differences in education among dentists correlate with differences in the use of these technologies. Ownership of digital intraoral units and panoramic machines was more common among dentists who had graduated more recently and internationally trained dentists. Previous studies in Turkey and New Zealand also showed a similar trend—that recent graduates were more likely to use digital intraoral technologies.[21,23] Dentists who graduated more recently likely were exposed to newer technologies during their schooling and, thus, more readily incorporated them in their practices.

The differences in dental education in various countries may reflect variations in the availability of technologies used in these countries' schools and how these technologies are incorporated into their curricula. A study conducted in Ontario in the early 1990s also found that differences in the locations of schools correlated with ownership of a panoramic unit; schools that focused more on panoramic imaging correlated with more graduates owning a machine.[9] Referral for CBCT imaging and ownership of CBCT machines correlated with the location of the respondents' dental schools but not with the year of graduation. Canadian-trained dentists were more likely to own CBCT devices and less likely to make referrals for CBCT imaging compared with internationally trained dentists. This inverse relationship can be explained by the fact that dentists who own CBCT machines are less likely to make referrals for CBCT because they can conduct this imaging in their own practice settings. Dentists who own CBCT units are more likely to have taken the mandatory 2-day CE course on CBCT within the last 5 years to be able to own and operate a CBCT machine in Ontario.

Specific optimization techniques can be used in dental imaging to reduce the dose of ionizing radiation to patients. The exit portal of a rectangular collimator is approximately one-third the size of a round collimator and can reduce patient dose by up to 5-fold.[3] Use of a long (40 cm) collimator can reduce patient dose by 10% to 25% compared with the use of short collimation (20 cm).[3] The use of thyroid collars is recommended for all patients when the thyroid collar does not interfere with the primary beam.[3] This is because the thyroid gland is a radiosensitive organ and is located in an anatomic site that is struck by scattered radiation during oral and maxillofacial radiographic exposures. Proper use of thyroid collars can significantly reduce patient dose during imaging.[3] One guideline states that use of the lead apron may not be necessary if all other recommendations for reducing patient dose during dental imaging are adhered to because dose to the abdomen has been shown to be negligible.[3]

Previous studies have investigated the use of physical methods by general dentists to reduce patient dose.[12-17] Rectangular collimation has been infrequently used, with reports ranging from 5% to 29%.[12,13,15-17] Surveys from Turkey and Korea reported that 8.7% and 16.9% of dentists used lead aprons, respectively.[12,13] In contrast, 100%

and 99% of dentists in New York and Michigan used lead aprons, respectively.[14,15] Only 3.7% of dentists in Turkey used thyroid collars, but in New York and Michigan, 60% and 49% did, respectively.[12,14,15] The results of these studies showed that the physical methods used by general dentists to reduce patient dose were highly variable and, in some jurisdictions, not implemented at all by all dentists. Interestingly, when general dentists in Sweden attended a 1-week CE course on ionizing radiation protection, they were twice as likely to use techniques that reduce patient dose after the course.[16]

The present study similarly revealed that not all dose-reducing methods were being used by general dentists. Although most used lead aprons and thyroid collars when exposing patients to ionizing radiation, 12.7% reported only using a lead apron without a thyroid collar, and only 8% used rectangular collimation. This latter figure is unchanged from previous data collected in Ontario during the 1990s.[9] Approximately 32.7% of general dentists in this sample used only a long collimator. Further implementation of long and rectangular collimation could reduce patient dose during radiographic imaging.

Tables VI through VIII show that educational differences correlate with differences in the use of dose-reducing methods. Dentists trained in countries other than the United States and Canada were more likely to use only the long collimation technique and rectangular collimation. Although rectangular collimation is taught in Canadian dental schools as a technique to reduce patient dose, few schools routinely use it in their clinics. It is possible that more international schools use rectangular collimation, resulting in the implementation of this technique by greater numbers of dentists from those countries, but data on collimation used in the schools of the surveyed dentists was not collected in this project. Dentists in this study who had graduated more recently were actually less likely to use rectangular collimation. It is possible that educational programs are now focusing less on this technique than in the past, leading to dentists not using rectangular collimation. A study conducted in Michigan in 1992 also showed that the location of dental training correlated with the use of rectangular collimation.[15] The use of thyroid collars was more common among Canadian-trained dentists in the present study, which, again, may reflect differences in education.

The effect of CE courses in radiology was not clearly demonstrated in this study. Dentists who had taken a CE course in radiology within the last 5 years were more likely to use rectangular collimation, possibly because CE courses in radiology reinforce the importance of dose-reducing techniques. However, an inverse relationship was seen for the use of thyroid collars, and no significant effect was seen with the use of long collimation. A study conducted in Sweden in 1996 found that dentists who had attended a 1-day CE course were more likely to use low-dose imaging techniques.[16] The study from Michigan found no correlation with dental training and the use of thyroid collars but did find that the location of schooling and fewer years in practice correlated with the use of film holders.[15] A previous study conducted in Ontario in the early 1990s found significant differences in the following areas, depending on the school of dental training: speed of film, film holder use, and use of the parallel film periapical technique.[9] These findings seem to reinforce the need for focusing on patient dose–reducing techniques in both dental education and CE courses.

As with all survey-type studies, social desirability bias is likely to have occurred because some dentists would be inclined to answer what they believe to be the correct response and not necessarily what they actually do in their dental practices. Nonresponse bias is also a limitation of this study because this was a voluntary survey. Data from the sample in this investigation were generally similar to data from the Ontario Dental Association, although they were slightly biased toward older, male, Canadian-trained dentists. Causality in the relationship between differences in dentist education and the use of imaging technologies or dose-reducing techniques could not be determined because this was a cross-sectional study, and in such research, temporal association cannot be demonstrated. Despite these limitations, we believe that the data set is robust enough for the conclusions and implications of the study to remain unaltered.

CONCLUSIONS

Digital imaging and CBCT imaging technologies have been widely adopted by general dentists in Ontario, which is Canada's largest province and largest dental care market. Long and rectangular collimators are not widely used and represent an area in which their implementation can potentially reduce patient dose during dental imaging examinations. Differences in the educational backgrounds of dentists correlated with differences in the use of imaging technology and patient dose–reducing techniques during radiographic procedures. Modifications to dental curricula, combined with increases in the scope of CE course offerings, are needed to ensure that general dentists have the background knowledge to utilize imaging technologies effectively and safely and to increase awareness and appropriate use of patient dose–reducing techniques during image acquisition.

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PRESENTATION

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