RESEARCH

A comparison between bitewing radiographs taken with rectangular and circular collimators in UK military dental practices: a retrospective study

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Objectives: The aim of this study was to determine any increase in the incidence of cone cut errors that adversely affected diagnostic yield resulting in more retakes using rectangular collimation with film holders in bitewing radiography. Comparisons were also made with other positioning errors that occurred when bitewings were taken with circular collimation, with and without film holders.

Methods: A preliminary questionnaire was used to determine the year that rectangular collimation was adopted by military dental practice. 3 time-framed subsets, each of 1000 bitewing radiographs, were identified: subset 1, films taken with circular collimators without film holders; subset 2, films taken with circular collimators with film holders; and subset 3, films taken with rectangular collimators with film holders. Each subset was assessed for positioning errors of cone cut, horizontal overlap, vertical distortion and film centring. The χ^2 test was used to test significant differences amongst the three subsets.

Results: 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, but the actual number considered “rejects” was very small, only 0.1% (1 in 1000 films) in subset 2 and 0.3% (3 of 1000 films) in subset 3, when assessed for diagnostic yield.

Conclusions: This study provides evidence that rectangular collimation did not significantly affect the diagnostic yield of bitewing radiographs despite the presence of cone cut. Therefore, all practitioners should adopt rectangular collimation.

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Keywords: bitewing radiography; rectangular collimation; circular collimation; cone cut

Introduction

In October 1988 a technical report of the Commission on Dental Products¹ recommended that restriction of the X-ray beam cross-section to conform to the size of the image receptor should be used for periapical and bitewing (BW) radiography. This recommendation was subsequently reinforced by the European Commission in 2004.² The field size is one of the most important factors in both dose reduction and influencing the frequency of retakes.³ Historically a circular collimator has been used to expose a rectangular intraoral film. As

a result, about 60% more skin than necessary is exposed.⁴ The interproximal examination is considered the least difficult of the intraoral techniques, yet the results of incorrect alignment of the film, teeth and X-ray beam are frequently seen on the finished radiograph.⁵ Most universities in a North American study in 2002 used rectangular collimators only in their radiology clinics because they feared that members of the non-radiology faculties would produce an unacceptably high number of technical errors.⁶ Anecdotal reports suggest that rectangular collimation may result in more retakes with a possible net increase in patient dosage.^{7,8} The potential benefit from the routine use of rectangular collimation far outweighs any modest increase in individual dose since it offers dose reduction in the

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order of 60%⁹ and nearer 80% once the 2007 International Commission on Radiation Protection (ICRP) tissue weighting factors are considered.¹⁰ The most frequent cause of film rejection was positioning error, and re-exposure rates were higher for those in training than for qualified staff.¹¹

The main concern was whether any rejected films had just been discarded. Military dental records held by the Defence Dental Services (DDS) are well maintained and are considered to be a highly reliable source of complete data since all films are accounted for. This study was carried out to determine any increase in the incidence of cone cut errors which adversely affected diagnostic yield, resulting in more retakes, when rectangular collimation was used with film holders in BW radiography. Size 2 films taken with rectangular collimation were compared with films taken with circular collimation with film holders. Horizontal angulation errors, vertical angulation errors and centring errors were also assessed and analysed. A similar comparison was made between BWs taken with circular collimation without film holders and with film holders. Retakes were also recorded.

The specific research questions were:

1. What effect did the introduction of film holders have on the incidence of positioning errors when a circular collimator was used?
2. Did the incidence of positioning errors, and specifically cone cut, increase after the introduction of rectangular collimation?
3. Did the number of retakes due to cone cut error increase after the introduction of rectangular collimation?
4. Did practitioners improve their technique over time?

Materials and methods

Ethical considerations

Permission was given by DDS clinical services for this anonymous observational, retrospective study of BW radiographs of military personnel spanning 33 years. Ministry of Defence research ethics committee approval was not required.

Preliminary study

A questionnaire was sent to dental practitioners employed by the DDS in July 2007 to determine the date that

rectangular collimation was adopted into military practice. Practitioners were asked to qualify their answers by three levels of memory recall: "definite", "almost certain" and "a guess". The findings would set the time frame used in the main study for subset 3.

Main study

Data collection: Radiographs from 285 patient records were scanned for later analysis. These yielded 250 sets of digitized images that met the inclusion criteria. Three discrete subsets were identified that reflected the change from the use of round collimation with BW tabs (subset 1) to round collimation with film holders (subset 2) and then to rectangular collimation (subset 3, see Table 1).

Exclusion criteria were:

- service personnel born after 1972, owing to lack of data;
- BWs taken with a size 1 or 3 film;
- films cropped with scissors; and
- images that were unreadable despite digital enhancement.

This cohort of patients provided 6 pairs of BWs (2 pairs for each of the 3 subsets of 1000 films, a total of 3000 films).

Image acquisition: Patient records were given a three digit reference number followed by the subset number (Figure 1). The transparency unit of the Epson Perfection 4490 Photo Scanner (Seiko Epson Corporation, the Netherlands) was used to scan the two pairs of BWs from each subset. A bespoke black opaque mask was secured to the scanner bed since digital images of masked films are of higher quality.¹² This scanner was used to digitize the conventional films in 24-bit colour at 300 dots per inch since the diagnostic intention was caries detection.¹³ Each JPEG image was saved to a Sony laptop computer (Model FE41E, Sony Corporation, Europe). An example of a complete set of films is shown in Figure 1.

Image analysis: The screen images were viewed at the default resolution, approximately 1:4 in normal ambient light as advocated by Cederberg et al,¹⁴ whilst appreciating that some report a lowered diagnostic yield when radiographs were viewed in this way.¹⁵ A display ratio of 1:1 and 1:2 result in better diagnostic

Table 1 Description of inclusion criteria for the three subsets and the arrangement of the films within each dental record

Subset	Description of inclusion criteria	Arrangement of films
1	Bitewing radiographs taken with circular collimation without film holders between 1974 and 1997	Subsets 1 and 2 were a cluster of four pairs of size number 2 films, which were in date sequence
2	Bitewing radiographs taken with circular collimation with film holders in or before 1997	
3	Bitewing radiographs taken with rectangular collimation with film holders between 2001 and 2007	Subset 3 were the two most recent pairs of bitewing radiographs taken

Figure 1 An example of a complete set of film images from the same patient at different times. These show radiographs taken (a) without a film holder (subset 1) and (b) with a film holder (subset 2) using a circular collimator, and (c) with a film holder using a rectangular collimator (subset 3)

validity with respect to caries detection,¹⁶ but the default setting was suitable for assessing positioning errors.

The positioning errors analysed were:

1. cone cut errors;
2. horizontal overlap errors;
3. vertical distortion errors; and
4. film centring errors.

Numerical codes were described for each positioning error based on the European guidelines.² Observer guides to show the positioning error analysis table (PEAT) codes for each subset were devised (Figure 2). Similar codes were used to analyse subsets 2 and 3. There was only one observer in this study.

Code 0 indicated that no error was present. Only the first three positioning errors listed were amenable to graded or comparative codes. Codes 1 and 2 were very minor and minor errors, respectively, that did not affect the diagnostic yield. A code 3 cone cut error indicated a major error where a moderate to large area of film was blank, resulting in reduced or no diagnostic yield. These films were later re-evaluated for diagnostic yield to determine any “rejects”. A “reject” was a film considered to be of no diagnostic value and thus a potential “retake”. Code 3 in horizontal and vertical angulation errors were major errors that all resulted in no diagnostic yield.

Centring errors were:

- code 1 — film positioned too far posteriorly;
- code 2 — film was not centred, but with a horizontal occlusal plane; and
- code 3 — the occlusal plane was not horizontal.

These centring errors were not mutually exclusive and if more than one error was seen then both were recorded (Table 2). Films rejected for other reasons such as handling and processing errors were not considered.

The assigned PEAT codes were recorded for each subset and the χ^2 test was used to test the significance of differences amongst the three subsets.

Results

Preliminary study: questionnaire

The DDS mandated use of rectangular collimation in June 1997. 61% of the 241 dentists employed worldwide were polled. The response rate was 71% (105/148). All respondents were using rectangular collimation. By July 2007, at least 43% of DDS practitioners had adopted rectangular collimation. With respect to the date they recalled adopting this technique, there was a cluster of “definite” and “almost certain” in 1997 (Figure 3).

Main study

Comparison of circular collimation with and without film holders: The null hypothesis that “the incidence of all cone cut errors is not affected by the use of a film holder” was rejected since the P -value was < 0.001 . Similar analyses of the three other positioning errors gave the same P -value, indicating that the use of film holders had reduced the number of all positioning errors. There was a significant decrease in cone cut errors from 21.7% to 3.3% (Table 3), a significant reduction in centring errors from 60.9% to 36.6% and a significant reduction in vertical distortion errors from 88.8% to 52.5%. For horizontal overlap, the overall incidence reduced from 68.2% to 65.8%, but the major (code 3) errors reduced significantly from 11.6% to 3.4%.

Comparison of circular collimation with rectangular collimation: The null hypothesis that “the incidence of all cone cut errors was not affected by the change to rectangular collimation” was rejected since $P < 0.001$. Cone cut errors had significantly increased from 3.3% to 20.9% when rectangular collimation was used with film holders. There was an increase in centring errors from 36.6% to 46.5%, a decrease in horizontal overlap errors from 65.8% to 51.2% and an increase in vertical distortion errors from 52.5% to 62.6%.

Major cone cuts accounted for 15.2% of the three graded major positioning errors when circular collimation was used with film holders and 39.1% of the major positioning errors when rectangular collimation

Radiographic examples of the PEAT codes used for subset 1 observer's guide

Code = 0	Code = 1	Code = 2	Code = 3
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Code	Presence and degree of any cone cut
0	No evidence of cone cut
1	Very minor/insignificant cone cut
2	Minor cone cut not affecting the diagnostic value
3	Major cone cut resulting in reduction or loss of diagnostic yield

Code = 0	Code = 1	Code = 2	Code = 3
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Code	Centring of film in the mouth
0	Centred and horizontal
1	Positioned too far posteriorly
2	Not centred but still parallel to the occlusal plane
3	Occlusal plane not horizontal

Code = 0	Code = 1	Code = 2	Code = 3
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Code	Degree of overlap in the horizontal plane
0	No overlaps or one overlap that is just discernable
1	One minor overlap only
2	Overlap of more than one contact but of diagnostic value
3	Major overlap(s) resulting in poor/no diagnostic yield

Code = 0	Code = 1	Code = 2	Code = 3
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Code	Degree of distortion in the vertical plane
0	No obvious distortion
1	Minor vertical separation of cusps of upper 5 and/or lower 6 and 7
2	Obvious vertical separation of buccal & lingual cusps lower 6 and 7
3	Obvious distortion of crowns/restorations

Figure 2 A complete positioning error analysis table (PEAT) for subset 1. Similar tables were devised for subsets 2 and 3

Year of adoption of rectangular collimation				
Year	A guess	Almost certain	Definite	
1980	1			
1981				
1982				
1983				
1984				
1985				
1986	1	1		
1987				
1988				
1989				
1990	1			
1991				
1992		1		
1993	1			
1994				
1995	3	1		
1996	2	3		
1997	2	8	8	
1998	3	7	2	
1999		3	1	
2000	2	3	4	
Totals	16	27	15	58

Figure 3 Data to show the year of adoption of rectangular collimation. 58 of the respondents had graduated and joined the Defence Dental Service (DDS) before 1998. They were asked to qualify the strength of their memory recall in one of three categories. (One outlier in 1980 and two in 1986 are not shown)

was used with film holders (Table 3). Incorrect horizontal angulation accounted for 46.3% of the major positioning errors when rectangular collimation was used. Although the incidence of major cone cut errors (code 3) had increased, the actual number of films considered "rejects" reduced from 7 to 1 in subset 2 and from 27 to 3 in subset 3 when diagnostic yield was further assessed (Table 4).

Rectangular collimation errors from 2001 to 2007

Further analysis to determine if the incidence of all cone cut errors had changed between 2001 and 2007

Table 2 Numerical data to show centring errors per film of all subsets

	Code 0	Code 1	Code 2	Code 3	Codes 1 + 2	Codes 1 + 3	Total
Subset 1	391	119	129	269	18	74	1000
Subset 2	634	242	39	58	10	17	1000
Subset 3	535	280	63	68	28	26	1000

(Table 5) gave a *P*-value of 0.351, which was not statistically significant.

Discussion

For caries diagnosis the usual practice in the UK is to take only one horizontal posterior BW on each side centring on the maxillary first molar. Correct anatomical coverage dictates that the film should cover the distal surfaces of the canine and the mesial surfaces of the most posterior erupted teeth.²

Film holders have apparently made it easier for the operator to assess whether the occlusal plane is horizontal and many more films have been properly centred. Interestingly, the incidence of positioning the film too far posteriorly increased with the transition from BW tabs to film holders. The authors had expected an increase in the actual number of films with no overlaps and were surprised that the difference was only 2.4%. There was a significant positive shift in the combined incidence of overlaps of several contacts and major overlaps when film holders were introduced. In our study, the number of major vertical distortion errors, while still small, doubled with the change to rectangular collimation. It was also noted that many films were still of some diagnostic value despite a major cone cut error owing to the compensating effects of other positioning errors.

In Patel's study of 1979¹⁷ logging frequency of errors in intraoral radiographs, cone cut error occurred in 2.7% of 6763 exposures and accounted for 33.9% of all errors and 46.6% of positioning errors in BWs taken using circular collimation and film holders. In our study, the frequency of all cone cut errors in BWs taken using circular collimation and film holders (subset 2) was 2.0%. This compared favourably with Patel's study, although he looked only at radiographs taken by junior dental students, in whom a higher rate of error might be expected.

In 1983, Horton et al¹⁸ found that the number of cone cuts was greater with rectangular collimation than with circular collimation, but that the total numbers of cone cuts in either technique were not great and therefore should not be a contraindication to the use of rectangular collimation on these grounds. A significant increase in the number and severity of cone cut films was noted when changing from circular to rectangular collimation by Sewerin et al¹⁹ in 1985. This was considered of minor importance as retakes were not elicited. They also commented that comparing frequencies of cone cut errors from different studies was almost meaningless because there were too many variables, such as beam area, focus to film differences, film holding systems and experience of operators.

In 1991, Parks²⁰ found that film placement errors appeared to remain constant regardless of the technique used or the operator's skill. He found that the number and types of error and retakes with the use of

Table 3 Positioning errors by type

PEAT codes	Type of positioning error							Number of films
	Cone cut errors		Horizontal overlap		Vertical distortion		Centring errors	
	Minor 1 + 2	Major 3	Minor 1 + 2	Major 3	Minor 1 + 2	Major 3	Centring errors*, all combinations	
Subset 1	167	50	566	116	747	141	609	1000
Subset 2	26	7	624	34	520	5	366	1000
Subset 3	182	27	480	32	616	10	465	1000

*Centring errors were not assessed for potential rejects in this study. Not all films with major cone cut errors were rejected, whereas all major angulation errors were rejected owing to no diagnostic yield. PEAT, positioning error analysis table

rectangular collimator techniques were not significantly different from the errors and retakes with circular collimation. This was reflected in our study with respect to potential "retakes" owing to major cone cuts and major horizontal overlaps. No evidence was found to show that practitioners had improved their technique using rectangular collimation over time. This supported Parks' findings and echoed a study by Mupparapu et al²¹ in 2007, which showed that re-exposure rate (albeit of students) did not significantly improve during their year-long rotation in the radiology clinic.

In 1995, Potter et al²² investigated horizontal and vertical angular deviations and alignment errors using different BW techniques. They found that the mean total angular alignment error for the standard BW tab technique was 6.2 degrees. The mean alignment error for both the Kwik bite (Hawe-Neos Dental, Gentilo, Switzerland) and the Rinn XCP (Densply Rinn, Elgin, IL) film-holding devices was less than 1.8 degrees. This indicated the superiority of using an intraoral positioning device for acquiring BW radiographs. This was reinforced in our study (Table 3). No comment could be made on the potential effects of any additional aligning ring since this detail was not recorded in the patient records. The former does not appear to offer any distinct advantages.²²

With rectangular collimation using E-speed film, the dose to the skull was less than half (47%) of that measured by Kircos et al²³ with circular collimation. 64% of the thyroid dose attributable to internal scatter can be eliminated by rectangular collimation. A study by Farman and Parks²⁴ in 1990 showed that the use of rectangular position indicating devices had increased

from 12% in 1985 to 31% in 1990 in United States¹ dental hygiene programmes. A study by Geist and Katz⁶ of doses in the North American dental schools in 2002 revealed that only 10 schools (15%) used rectangular collimators exclusively. In 2003, Tugnait et al²⁵ reported that rectangular collimation was not widely used in England and Wales. In 2005, Stavrianou²⁶ reported that in Greece only 29% of the dentists nationally used a rectangular collimation system. This figure was somewhat lower than the 36% found in a single county, Orebro, in Sweden.

The PEAT codes were primarily devised as a research tool. They helped to standardize the viewing method and minimize both intra- and interobserver error. In the wider clinical setting, the PEAT codes could be used within a radiographic quality assurance programme. In the research arena, PEAT codes would allow easier comparison between future studies from different investigators.

The images were stored in JPEG format since it offered the lowest file sizes, could easily be converted to greyscale and was DICOM (Digital Imaging and Communications in Medicine) compatible. It was appreciated that JPEG is a lossy compression technique and that some degradation of quality is inevitable and irreversible. A reduction in file size to approximately 7% can be used without significant deterioration in the accuracy of caries detection.²⁷ A compression ratio of 1:21 appears to be acceptable when deciding on whether to restore a tooth, but detection of small lesions is hampered.²⁸ The default compression used was not known but, since analysis was only done on positioning errors, it was not expected to affect this study adversely. The file size ranged from 45 to 58 kB.

Table 4 Table to show the number of radiographs considered to be rejects. Type and frequency of three major positioning errors that were considered "rejects" owing to very little or no diagnostic yield

Error	Subset	Number	Percentage of errors	Percentage of films
Cone cut	1	32	11.1	3.2
Horizontal overlap	1	116	40.1	11.6
Vertical distortion	1	141	48.8	14.1
Total		289	100	28.9
Cone cut	2	1	2.5	0.1
Horizontal overlap	2	34	85.0	3.4
Vertical distortion	2	5	12.5	0.5
Total		40	100	4.0
Cone cut	3	3	6.7	0.3
Horizontal overlap	3	32	71.1	3.2
Vertical distortion	3	10	22.2	1.0
Total		45	100	4.5

Table 5 Numerical data of cone cut errors in years 2001–2007, during which rectangular collimation was used. In 2007, data were available only for the first 4 months and hence totals are expressed in percentages for comparison

	2001	2002	2003	2004	2005	2006	2007
PEAT code 1	6	13	17	17	18	16	7
PEAT code 2	4	12	13	12	16	29	3
PEAT code 3	1	2	6	3	4	9	2
Film totals	64	124	164	182	198	202	66
	2001 (%)	2002 (%)	2003 (%)	2004 (%)	2005 (%)	2006 (%)	2007 (%)
PEAT code 1	9.4	10.5	10.4	9.3	9.1	7.9	10.6
PEAT code 2	6.3	9.7	7.9	6.6	8.1	14.4	4.5
PEAT code 3	1.6	1.6	3.7	1.6	2.0	4.4	3.0
% totals	17.3	21.8	22.0	17.5	19.2	26.8	18.1

PEAT, positioning error analysis table

Rectangular collimation is not yet in routine use. Evidence to support its use may encourage other clinicians to adopt this practice, which is equally applicable to digital radiography. Further studies to determine the extent of adoption of the routine use of rectangular collimation for intraoral radiography worldwide would be of value to demonstrate the extent to which operators are keeping all exposures as low as reasonably practicable (ALARP). Theoretical knowledge and practical skill are closely related.²⁹ If dental educational facilities require their students to employ dose-reducing strategies throughout their training, it is likely that the students will continue to use them as practising dentists.⁶

In conclusion, this study showed that the introduction of rectangular collimation resulted in a significant increase in cone cut errors. Minor cone cuts did not affect diagnostic yield and not all major cone cuts were considered “rejects”. The introduction of film holders significantly improved the quality of the radiographs with respect to the positioning errors of cone cut,

horizontal and vertical angulation errors and film centring errors. It was not possible to identify any improvement in operator technique over time. The benefits of significant dose reduction when using rectangular collimation far outweigh the inconvenience of a less than perfect film. There is little justification for the continued use of circular collimation with film-holding devices when taking the BW projection. All practitioners should adopt rectangular collimation.

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