Introduction

An estimated one million non-surgical root canal treatments are performed in the UK every year.[1] In most cases, non-surgical root canal treatment may be considered as routine and may be carried out in general dental practice or other primary care settings. However, experience levels, equipment availability or tooth-related complications such as access limitations, or canal sclerosis, may necessitate the need to refer patients onwards for management.[2] A survey in England of newly qualified dentists in vocational training reported that most expressed a lack of preparedness with regards to complex/molar endodontics.[3] In addition, the UK regulatory body, the General Dental Council (GDC), considers that dental practitioners have a duty of care to refer a patient onwards when it is in the patient's best interest.[4]

Radiographs of acceptable quality are essential for accurate diagnosis and treatment planning.[5, 6] They should accompany patient referrals to reduce the need for repeat radiographs and further radiation exposure; this also avoids delays and ensures correct allocation of cases via the referral triage system. There is no shortage of research evidence showing that the quality of radiographs, in primary dental care, is often poor.[7]

In clinical practice, every radiograph should be subjected to quality control and it has been recommended that a formal audit of radiograph quality, either prospectively or retrospectively, should be carried out approximately every six months.[6, 8] The quality guidelines[9] published by the National Radiological Protection Board (NRPB), now part of Public Health England, include a rating system (Table 1) and targets for radiographic quality (Table 2). The European Commission[7] has also published guidelines, which reflect those of the NRPB, on radiation protection and quality assurance in dental radiology. The latest, third edition of guidelines on selection criteria and quality assurance for all aspects of dental radiography,

including for endodontics, was recently published by the Faculty of General Dental Practice (UK).[10]

The aims of this prospective study were to assess the type and comparative quality of the radiographs accompanying endodontic referrals to a Health Authority Clinic. The results may inform on quality assurance and provide guidance on radiographic requirements accompanying endodontic referrals for the benefit of patients.

Materials and Methods

Patient selection

The Oxfordshire Priority Dental Service operates a clinic, one day a week, at The East Oxford Access Centre, Oxford, for the assessment and treatment of non-routine endodontic cases. General dental practitioners who wish to refer their patients for this service are required to provide a referral note and a radiograph.

Approval for this study was obtained from the Dental Directorate, Oxfordshire Primary Care Trust. Digital and conventional film radiographs accompanying the first 200 referrals received from 1 January 2012 onwards were collected. Patient confidentiality was strictly respected and no personal information was divulged.

Conventional film radiographs were evaluated under standardised and optimised conditions using a light-box (Kenro Ltd, Swindon, UK) and a Brynolf magnifier (JS Dental Inc, Ridgefield, Connecticut, USA) in a darkened room. Digital radiographs sent as an e-mail attachment or on a computer disc were viewed on a 22-inch professional widescreen, flat panel computer monitor (Dell P2210, Dell Inc., Round Rock, Texas, USA) calibrated for medical imaging;[11] those supplied printed on paper were viewed in ambient room light.

Assessor calibration

An initial, separate, 20 radiographs accompanying referrals were assessed jointly by two examiners, both experienced dentists with enhanced skills in endodontics, overseen by a Specialist in Endodontics and a Lecturer in Dental Maxillo-Facial Radiology. The variables assessed, inclusive of the three-category quality rating criteria (Table 1) based on NRPB guidelines[9] are shown in Table 3. The 'visible target area' referred to whether the radiographs showed the whole tooth including at least 2 mm beyond the apex; failure to satisfy this requirement would entail the need to take another radiograph. In addition, the quality of the digital radiographs, as a function of the size, was noted. Any digital radiographs which were equivalent to a conventional periapical film size (≤ 31 mm X 41 mm) were categorised as 'small'; those printed on A4 size (210 mm X 297 mm) paper were categorised as 'large' whilst any sizes in-between were assigned the 'medium' category. To ensure reproducibility, the assessor calibration exercise was repeated twice within a 3-month period, using a further 20 cases, to determine the inter- and intra-examiner agreement.

Statistical analysis

The anonymised data was recorded on a spreadsheet (Excel, Microsoft, Redmond, WA, USA) and analysed using SPSS statistical analysis software (IBM SPSS Statistics 20.0, SPSS Inc, Chicago, IL, USA) to calculate the Kappa, weighted Kappa and Confidence Intervals (CI). The frequency of the different variables for conventional and digital radiographs was calculated; the Chi-squared test and probability scores were used to assess whether the frequencies differed significantly from those observed.

Results

A total of 200 radiographs accompanying referrals were received from 42 practices. The vast majority (n=36, 86%) of these practices use digital radiography. Out of the 200 radiographs evaluated, 38 (19%) were conventional film and 162 (81%) were digital. All the conventional film radiographs submitted were un-mounted (n=38, 100%) whereas almost all the digital radiographs (n= 161, 99.5%) were in the printed form apart from one (n=1, 0.5%), which was provided on a computer disc.

The inter-observer variability had a Kappa score of 84% and weighted Kappa score of 88%. The intra-observer variabilities were 76% and 80%; both had a CI of 95%. The frequency and percentage of each variable for the conventional film or digital radiographs including the *P-values* as a measure of statistical chance are shown in Table 4.

The digital radiographs, categorized according to size (small, medium or large), were also assessed in relation to quality (Table 5). The 'small' radiographs were of better quality with 50% categorised as 'excellent', while 44% of the radiographs printed on A4 paper (large) were 'unacceptable'. Regardless of size, digital radiographs in the 'unacceptable' category (33%) exceeded the NRPB (2001) recommended maximum of 10%.

Discussion

The advent of digital radiography has led to increased adoption of this technology.[12, 13] It has been reported that 45% of practices in the UK employ digital radiography[14] as opposed to the 20% in a Swedish study[12] or an estimated 10 - 20% in USA.[15] In this study, a significantly higher number (85%), of referring general dental practitioners used digital radiography. However, it

was not possible to ascertain which digital system was used by each referring practitioner and this may have affected the quality of the radiographs.[13, 16, 17]

The number of 'excellent' scores for conventional film radiographs was over twice that of digital radiographs and this was unchanged even with the inclusion of the 'diagnostically acceptable' category. A more significant difference was noted with those considered 'unacceptable', which comprised of 33% digital, compared with 8% conventional film, radiographs; the difference may decrease as digital radiography becomes more common and expertise in its use improves. In addition, the relatively small number of practices still using conventional film radiography (14%) may mean the results are less relevant. However, it may also be true that practices which still use conventional film radiography may be very experienced with this format and are capable of producing good quality radiographs, and therefore, do not feel the need to adopt newer, digital technology.[18]

According to NRPB guidelines,[9] no more than 10% of radiographs should be rated 'unacceptable'. The 8% of conventional film radiographs rated 'unacceptable' in this study is within the NRPB guideline target and lower than the 19% reported in a similar study carried out in Sweden;[12] the difference may be because in the Swedish study,[12] 86% of radiographs were conventional film compared with only 19% in this study.

A major problem with comparing studies of radiograph quality is the criteria used and the rating system chosen; there is the inevitable element of subjectivity and this could lead to difficulties in achieving a high agreement score.[19] The number, experience and training of the assessors will also have an influence on the results. Instead of the NRPB three-category system[9] adopted in this study, other studies have chosen a two-category ('acceptable' and 'unacceptable')[12] or even four-category ('excellent', 'diagnostically acceptable', 'diagnostically

compromised' and 'unacceptable') system.[20] The four-category system was reported to be a more flexible and sensitive but the inter-observer agreements were reduced, although the Kappa scores were still rated as good or moderate despite there being 14 assessors.[20]

In this study, in 17% of the digital and 5% of conventional film radiographs, coverage did not include the apex and the surrounding 2 mm or 2 - 3 mm periapex as recommended by the guidelines of the European Society of Endodontology[21] and the European Commission[7] respectively. The higher percentage of insufficient coverage of the area of interest with digital radiographs may be dependent on the sensor used. Charged Couple Device (CCD) or Complementary Metal Oxide Semiconductor (CMOS) sensors are more bulky than conventional film whereas Photo-Stimulable Phosphor (PSP) plates resemble conventional film in size and shape.[6, 13, 17] The image quality of digital radiographs was also reported to be superior with a PSP plate system.[17]

Digital radiography sensors generally perform well in terms of spatial and contrast resolutions.[13, 22-24] However, the results from this study showed that only 39% of digital radiographs were judged to be of the correct density or contrast; 36% were too light and 25% were too dark. The greater percentage of conventional film radiographs which achieved the correct density and contrast (58%) may be due to automated processing largely superseding hand processing.

Since nearly all of the digital radiographs were supplied as hard copies, printing had significantly degraded image quality;[12, 25] most printers are not able to reproduce 256 shades of grey.[8] The choice of paper is also a factor;[25] in this study, only one digital radiograph was printed on photographic paper compared with one-third[12] or two-thirds[26] in other studies. In addition, the digital radiographs were printed in different sizes, ranging from that equivalent to a periapical

radiograph up to A4 size paper. The smaller printed digital radiographs were of better quality with 50% being rated as 'excellent' and 28% as 'diagnostically acceptable'. Of the largest, A4 size, 44% of the prints were 'unacceptable'; hence, if digital radiographs accompanying referrals have to be printed, a smaller size would be more appropriate. However, it may be argued that the quality of digital radiographs in the form of paper copies is too poor to justify the use of printed copies.[12, 25] Therefore, within the parameters of information governance, digital radiographs should, ideally, be provided electronically via a secure image/mail web portal or computer disc to prevent quality degradation and to permit manipulation of the image to maximise the diagnostic information obtainable. In the future, software for digital radiography may include tools that will automatically optimize image quality without the need for manual manipulation.[24] Since digital radiographic image quality is also dependent on the computer display performance and viewing conditions,[6, 14, 27] these factors should be included in any quality assurance programme. Only if it is not possible to supply an electronic copy with referrals, then digital radiographs should be printed on radiographic film or photographic paper to ensure limited loss of quality.[25]

If the quality of the radiographs is considered 'unacceptable' or the periapical area of interest is not included, then a repeat radiograph would be necessary; in this study, this would apply to 33% of digital compared with 8% of conventional film radiographs. Given the very high percentage of repeat radiographs necessary with digital radiographs, it would negate the advantages of digital radiography including a reduction in radiation exposure.[28-30] The poorer quality of digital radiographs confirmed the need for quality control[6, 31] to facilitate correct diagnosis, to avoid the need for repeat radiographs and unnecessary radiation exposure. Furthermore, the results of this study support the recommendation of regulatory bodies, such as

the GDC, that radiography and radiation protection be amongst the topics to undertake as part of compulsory continuing professional development requirements.[32]

Conclusions

The use of digital radiography is increasing as exemplified by the greater number accompanying referrals. The quality of digital radiographs was significantly lower compared with conventional film radiographs and the percentage of 'unacceptable' digital radiographs was above the target as recommended by the NRPB guidelines. Digital radiographs printed on paper were of reduced quality so unless they are supplied in electronic form, the inability to optimise the images using the appropriate computer software negates the benefits of using a digital system.

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Table 1. Subjective quality criteria (based on NRPB 2001 guidelines).

Rating	Quality	Basis
1	Excellent	No errors of patient preparation, exposure, positioning, processing or handling
2	Diagnostically acceptable	Some errors of patient preparation, exposure, positioning, processing or handling, but which do not detract from the diagnostic utility of the radiograph
3	Unacceptable	Errors of patient preparation, exposure, positioning, processing, or handling, which render the radiograph diagnostically unacceptable

Table 2. Recommended minimum targets for quality (based on NRPB 2001 guidelines).

Rating	Quality	Percentage of radiographs taken
1	Excellent	Not less than 70%
2	Diagnostically acceptable	Not greater than 20%
3	Unacceptable	Not greater than 10%

Table 3. Variables and features assessed

Variables			
Type	Digital		Film-based
Sharpness	Yes		No
Angulation	Correct		Incorrect
Density/Contrast	Light	Correct	Dark
Visible target area	Yes		No
Errors	Yes		No
Repeat radiograph	Yes		No
Image size	Small	Medium	Large
Format	Printed on paper	Disc/E-mail	Film
Overall quality	1	2	3

Table 4. Frequency and percentage of variables for digital and conventional film radiographs (n=200)

Variable	Digital (%) n=162	Conventional Film (%) n=38	*P-value*
Density/Contrast			
Light	59 (36)	8 (2)	-
Correct	63 (39)	22 (58)	-
Dark	40 (25)	8 (21)	0.084
Sharpness			
Yes	93 (57)	38 (100)	-
No	69 (43)	0 (0)	0.000
Area			
Yes	135 (83)	36 (95)	-
No	27 (17)	2 (5)	0.053
Errors			
Yes	23 (14)	7 (18)	-
No	139 (86)	31 (82)	0.332
Quality			
1	43 (27)	21 (55)	-
2	65 (40)	14 (37)	-
3	54 (33)	3 (8)	0.001
Angulation			
Yes	155 (96)	37 (97)	-
No	6 (4)	1 (3)	0.000
Digital radiograph size			
Small	32 (20)	-	-
Medium	69 (42)	-	-
Large	61 (38)	-	0.000

Table 5. **Quality ratings (1, 2, 3) in relation to digital radiograph size (Small, Medium, Large)**

Digital radiograph size	Number of images (%)	p-Value
Small (n=32)		
1	16 (50)	-
2	9 (28)	-
3	7 (22)	0.000
Medium (n= 69)		
1	21 (31)	-
2	28 (40)	-
3	20 (29)	0.000
Large (n=61)		
1	7 (12)	-
2	27 (44)	-
3	27 (44)	0.000