

Implementation of Digital Radiography during Root Canal Treatments in Saudi Endodontic and General Dental Practice

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ABSTRACT

Objective: To report usage of full-digital-radiography (FDR) during root-canal-treatments (RCTs) in Saudi dental-practice and to explore factors and measures that obstacle/contribute to better implementation.

Methods: Following a pilot study, questions on demography, types of radiographic systems used during RCTs, advantages and disadvantages of FDR, reasons of not using it and measures that increase its implementation were included. The sample size was calculated considering the total number of general dentists (GDs) in Saudi Arabia and a 50-60% expected response rate. The questionnaire was emailed to 550 GDs and all endodontists in Saudi Arabia (185). A solo a reminder was emailed two months later. Data were analyzed by the Chi-square test at $P=0.05$.

Results: Most participants (64.9%) used FDR for RCTs ($P<0.001$); with all endodontists (100%) and 52% of GDs ($P<0.001$). While all who were working in governmental-academia (100%) used FDR, 69.2% in private-academia did so ($P<0.001$); with no difference between private and governmental-clinics (60.6 and 69.2%). As the weekly-performed RCTs increased and participants' experience decreased, FDR usage increased ($P<0.05$). While high-cost was the main FDR disadvantage, faster-workflow, better image-quality and less-radiation were the main advantages ($P<0.001$). The majority (76.1%) of FDR none-users were doing so because of unavailability. Participants reported lower-cost and better undergraduate-education as most effective measures that increase FDR implementation in dental-practice.

Conclusion: FDR was adopted to good extent in Saudi dental-practice. Financial aspects were the main concern that should be addressed to increase FDR implementation in private practice. Endodontists showed better perception towards FDR and suggested more attention to educational aspects.

Keywords: Digital, endodontics, questionnaire, root canal, radiography, radiology, survey

HIGHLIGHTS

- FDR was fully adopted in endodontic specialized Saudi Practice
- FDR usage in general dental practice was accepted, to some extent, though efforts should be exercised to improvement its implementation, especially on educational measures.
- There was significant different perception between endodontists and GDs towards FDR

INTRODUCTION

Techniques and equipment of radiographic imaging have witnessed significant refinements and development since the x-ray was discovered by Wilhelm Roentgen in 1895 (1). He took the first ever radiograph; the exposure time to the x-rays was 15 minutes (2). Only after 14 days, Otto Walkhoff made the first dental radiograph. In the same year, Morton, made the first dental radiograph in the United

States (2). One year later, Edmund Kells made the first intraoral radiograph on a patient. He used to expose his hands to x-rays every day, for years, by holding the plates and trying to adjust the quality of the beam, for better images. This continuous exposure, unfortunately, led to the development of cancer in his hand which was amputated later. This demonstrated the harmful effects of x-rays. However, Kells kept working on x-ray usage and used it in 1899 to determine tooth length during RCTs (2). Rollins published the first paper on the potential dangers of x-rays and proposed the use of filters to suspend the dangerous parts of the X-ray beam, the use of collimation, and the practice of covering patients with lead to prevent X-ray penetration (3, 4). Also, Rollins highlighted the importance of setting safe and harmful doses' limits (4, 5). In 1913, Coolidge developed the first X-ray tube. Later on, in 1923, Coolidge and Victor X-ray Corporation developed the first x-ray

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machine. In 1957 a variable kilo-voltage dental X-ray machine was introduced, followed by the long-cone head in 1966 (2).

However, with some drawbacks of film-based radiography (FBR) and the demand for easier manipulation and documentation of radiographs and information exchange, the digital radiography (DR) imaging systems were introduced in the mid-1980s (6). Digital sensors have many advantages over films, such as: reduction of radiation, elimination of undesirable variables associated with processing of conventional films (especially the hazardous chemicals); easy transmission, archiving and retrieving images from databases and facilitating usage of all-electronic patients' records (7, 8).

In spite of these advantages, reports showed poor implementation of DR in dental practice (9-11). A relatively recent study revealed very poor implementation of DR in Indian dental practice; as only 13% were using it (12). On the other hand, DR was better adopted, to some extent, in New Zealand as 58.0% of dentists were using it (13). These conflicting findings necessitate the conduct of new research to explore the up-to-date popularity of this paramount tool. This is especially true as many of the drawbacks of earlier DR equipment have been resolved, such as: the reduction of the bulky images' receptors, better images' resolution and advanced computer technology (1). Therefore, DR is expected to gain significant popularity in recent dental practice (14). In addition, different practice environments and regulations may affect implementation of DR in different countries. Up to this date, there has been no study on adoption of DR in Saudi dental practice.

The objective of the current study was to report the extent to which DR is used during RCTs in Saudi dental practice and the influencing factors and to explore measures that may result in better adoption.

MATERIALS AND METHODS

Ethical Consideration and Sampling: This study was conducted in 2018 (June to December) after obtaining an official ethical approval from the Research Ethics Committee (REC) at Taibah University College of Dentistry (No: TUCD-REC.15.12.2016). The study was designed as an online questionnaire, in which participants' identities were not requested. Therefore, the study was executed without the need for participants' consent form and according to the World Medical Association's Helsinki Declaration.

Pilot Study and Survey's Formation & Conduction: A pilot questionnaire was distributed electronically to staff members at Taibah University College of Dentistry and a group of dentists (n=50) to ensure that the questions were relevant and easily understood. The final online questionnaire constituted questions related to the following four main aspects:

- A. Demographic & General Information: this included the gender & category of participants (GDs, endodontists, others), participants experience, type of practice (government and private), number of RCTs performed per week.
- B. Types of Radiography systems used during RCTs & Reasons; whether participants were using film-based radiography

(FBR), semi-digital radiography (SDR) or fully-digital radiography (FDR) during RCTs and the reasons for doing so.

- C. Advantages and Disadvantages of using FDR.

- D. Measures that may increase implementation of FDR

Using the StatCalc programme, the sample size was calculated taking into consideration the expected and the minimum accepted response rate; 60 and 50%, respectively, and the total number of GDs in Saudi Arabia. A sample size of 375 GDs would give a 99.9% confidence level. It was determined, however, to send the survey to 550 GDs to enable reliable statistical comparison between subgroups by reducing the number of expected cells that count less than five in cross-tabs tables. The sample of GDs was selected, from the Saudi Dental Register, randomly using the systematic sampling method. The final questionnaire was emailed to the 550 selected GDs and all endodontists (185) working in Saudi Arabia using the Google-Drive website. The email explained the aims of the study and confirmed that participants' responses would remain anonymous. An e-mail reminding questionnaire completion was sent two months after the first sent-out.

Statistical analysis

Responses were collected as an excel sheet which was converted into SPSS data sheet using the SPSS 20 for Windows software (SPSS Inc, Chicago, USA). Data were analyzed using the Linear-by-Linear Association and Chi-square tests at $P=0.05$.

RESULTS

Response rates and participants' gender & classification

Of the 735 recipients, 401 responded to the questionnaire; 276 (68.8%) were GDs, 99 (24.7%) were endodontists, 6 (1.5%) were students or residents in endodontic postgraduate programmes, and 20 (5%) were others (other specialties). Nine respondents were not performing RCTs. The response rates were:

- Overall: $401/735=54.6\%$
- Non-endodontists response: $302/550=54.9\%$
- Endodontists response rate: $99/185=53.5\%$.

The percentage of male participants (67.8%) was significantly greater than female ones (32.2%) ($P<0.001$) (Table 1). Overall, significantly most participants (64.9%) were using FDR for RCTs followed by 24.2% using FBR, and 11.2 who were using SDR ($P<0.001$). There was no significant difference between the percentage of early respondents who were using FDR (63.1%) and that of the late respondents (66.9%) ($P=0.493$). The percentage of male clinicians who were using FDR (71.1%) was significantly greater than that of females (52%). All endodontists (100%) were adopting FDR, which was significantly greater than the percentage of GDs (52%) who were doing so ($P<0.001$).

Participants' experience & FDR usage

Overall, the highest percentage of GDs and endodontists (40.1 and 34.6%, respectively) had more than 15 years' experience,

TABLE 1. Types of radiographic systems used according to participants' gender and classifications

Early & late responses	Type of radiographic system used: No (%)			
	FBR	SDR	FDR	Total
Early responses (69.8)	70 (25.5)	31 (11.3)	173 (63.1)	(100)
Late response (30.2)	26 (22)	13 (11)	79 (66.9)	(100)
Total (100)	96 (24.5)	44 (11.2)	252 (64.3)	392 (100)
Respondents' gender	Type of radiographic system used: No (%)			
	FBR	SDR	FDR	Total
Female (32.2)	45 (36)	15 (12)	65 (52)	127 (100)*
Male (67.8)	49 (18.6)	27 (10.3)	187 (71.1)	263 (100)*
Total (100)	96 (24.5)*	44 (11.2)*	252 (64.3)*	392 (100)
Respondents' classification	Type of radiographic system used: No (%)			
	FBR	SDR	FDR	Total
GDs	90 (33.3)	39 (14.4)	141 (52.2)	270 (100)*
Endodontists	0 (0)	0 (0)	98 (100)	98 (100)*
Endo postgrads	2 (33.3)	0 (0)	4 (66.7)	6 (100)*
Others	4 (22.2)	5 (27.8)	9 (50)	18 (100)*
Total	96 (24.5)	44 (11.2)	252 (64.3)	392 (100)

(*) The percentage was calculated from the total number of the sample not the sum of subgroups

TABLE 2. Usage of FDR according to participants experience and classifications

Respondents' classification	Experience of respondents (Years)				Total
	Up to 3	3.1 to 7	7.1 to 15	More than 15	
General dentists	15.7 (66.7)	11.7 (59.4)	32.5 (57.3)	40.1 (39.8)	100 (52.2)
Endodontist	11.5 (100)	26 (100)	27.9 (100)	34.6 (100)	100 (100)
Total	13.9 (74.5)	15.6 (75.8)	31 (68.3)	39.5 (52.9)	100 (64.3)

The values in brackets represent the percentages of respondents who were FDR within each corresponding subgroup

which were significantly greater than other experience' groups ($P < 0.001$) (Table 2). The trend of using FDR significantly increased as participants' experience decreased ($P = 0.023$). The highest percentage who used FDR were within those who had up to 7 years' experience ($\approx 76\%$).

Work's sector & usage of FDR

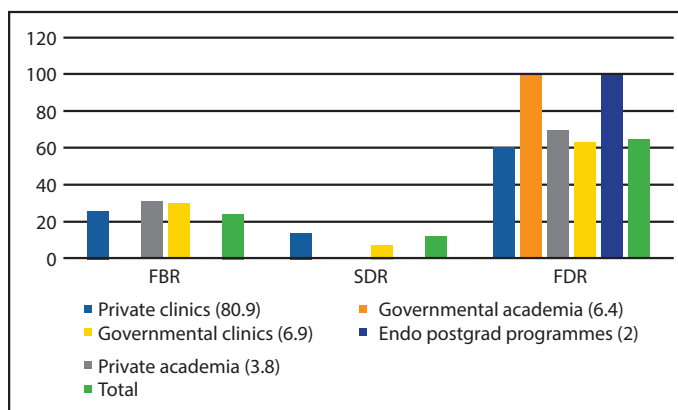
The majority (80.9%) were working in the private sector ($P < 0.001$). While all those who were working in the governmental academic (100%) used FDR, 69.2% in private academia did so so ($P < 0.001$) (Fig. 1). There was no significant difference between the private and governmental clinics about the use of FDR (60.6 and 69.2%) ($P = 0.583$).

Number of weekly RCTs & usage of FDR

While the highest percentage of respondents (32.9%) performed 7-12 RCTs per week, the lowest percentage (17.5%) performed 1-3 RCTs ($P < 0.001$) (Fig. 2). As the number of weekly RCTs increased, the trend of using FDR increased; with a significantly the highest percentage (75.3%) within those who used to do more than 12 RCTs per week ($P < 0.001$).

Disadvantages of using FDR

Significantly most participants (61.5%) reported the high-cost as the main disadvantage of using FDR systems ($P < 0.001$);

**Figure 1.** Types of radiographic systems used according to work's sectors

with no significant differences between GDs and endodontists (60.4 and 65.3%, respectively) ($P = 0.056$) (Table 3).

Advantages of using FDR

Faster workflow, better image-quality and less radiation (26.5, 22.7 and 22.2%, respectively) were significantly the most common reported advantages of using FDR ($P < 0.001$) (Table 4). Overall, there were significant differences between GDs and endodontists ($P < 0.001$). While the highest percentage of en-

TABLE 3. Disadvantages of using FDR and the correlation with participants' classifications and the radiographic systems they used

Respondents' classification	Disadvantages of using DI					
	Difficulty of software use	High cost	Greater radiation	Need for special training	Other	Total
General dentists	6.7	60.4	15.6	11.9	5.6	100
Endodontist	6.1	65.3	12.2	11.2	5.1	100
Endo postgrads	33.3	33.3	0	0	33.3	100
Others	0	66.7	5.6	16.7	11.1	100
Total	6.6	61.5	14	11.7	6.1	100
Type of radiographic system used	Disadvantages of using DI					
	Difficulty of software use	High cost	Greater radiation	Need for special training	Other	Total
FBR	7.3	60.4	6.3	25	1	100
SDR	0	52.3	27.3	11.4	9.1	100
Digital	7.5	63.5	14.7	6.7	7.5	100
Total	6.6	61.5	14	11.7	6.1	100

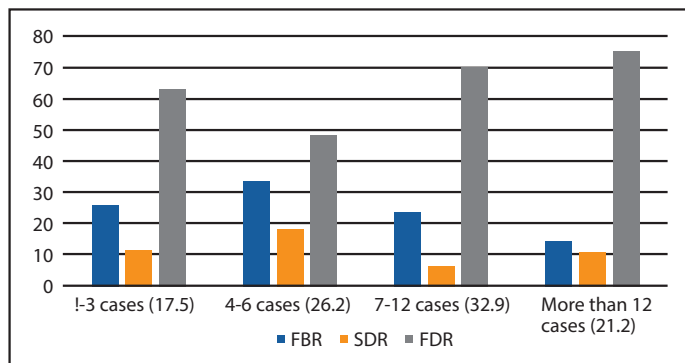


Figure 2. Association of radiographic systems types and number of weekly RCTs

dentists (34.7%) reported less radiation as the main advantage, the highest percentages of GDs reported faster workflow and better images-quality (25.9% each). Similarly, there were significant differences among users of different radiography systems in reporting the main advantages of FDR. While the

highest percentages of FBR and SDR systems users (27.1 and 31.4%, respectively) reported better images-quality as the main advantage, the highest percentage of FDR system users (30.2%) reported faster workflow (P=0.030).

Reasons for not using FDR

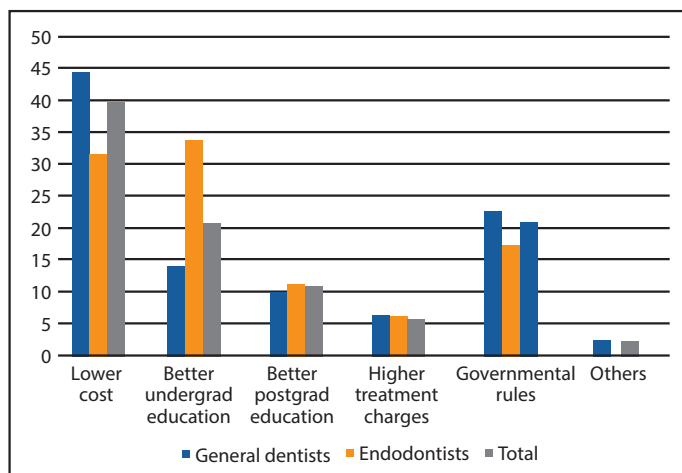
The majority of FDR non-users (76.1%) were not using it because of unavailability followed by high-cost (18.3%) (P<0.001) (Table 5). There were no significant differences between males and females (P=0.148). On the other hand, all non-users in governmental practice reported unavailability for not using FDR which was significantly different from the 80% who were working in private practice and reported the same reason (P=0.004). Within non-users' groups, all (100%) who had up to three Years' experience did not use FRD because of unavailability which was significantly greater than those who had 7 to 15 or more than 15 years' experience (59.1 and 83.8%, respectively) (P=0.012). Also, most of those who had 3.1 to 7 years' experience (66.7%) did not use FDR because of high-cost (P=0.012).

TABLE 4. Advantages of using FDR the correlation with participants' classifications and the radiographic systems they used

Respondents' classification	Advantages of using FDR						
	Less radiation	Better image quality	Faster workflow	Better archiving & documentation	Better reducibility	Other	Total
General dentists	15.9	25.9	25.9	14.1	8.9	9.3	100
Endodontist	34.7	12.2	30.6	11.2	11.2	0	100
Endo postgrads	33.3	33.3	33.3	0	0	0	100
Others	44.4	27.8	11.1	11.1	0	5.6	100
Total	22.2	22.7	26.5	13	8.9	6.6	100
Type of radiographic system used	Advantages of using FDR						
	Less radiation	Better image quality	Faster workflow	Better archiving & documentation	Better reducibility	Other	Total
FBR	18.8	27.1	18.8	8.3	12.5	14.6	100
SDR	11.4	31.4	22.7	15.9	13.6	4.5	100
Digital	25.4	19.4	30.2	14.3	6.7	4	100
Total	22.2	22.7	26.5	13	8.9	6.6	100

TABLE 5. Reasons for not using FDR and its association with participants gender and experience and work' sector

Respondents' gender	Reasons for not using FDR				
	No advantages	Difficult use	Unavailable	High cost	Total
Males	5.3	0	71.1	23.7	100
Females	0	6.5	80	12.9	100
Work sector	Reasons for not using FDR				
	No advantages	Difficult use	Unavailable	High cost	Total
Private clinics	3.5	3.5	80	12.3	100
Private academic	0	0	0	100	100
Governmental clinics	0	0	100	0	100
Respondents' experience (Years)	Reasons for not using FDR				
	No advantages	Difficult use	Unavailable	High cost	Total
Up to 3	0	0	100	0	100
3.1 to 7	0	0	33.3	66.7	100
7.1 to 15	0	0	59.1	40	100
More than 15	5.4	5.4	83	5.4	100
Total	2.8	2.8	76.1	18.3	100

**Figure 3.** Measures may contribute to better usage of FDR**Measures contribute to better implementation of FDR**

The highest percentage (39.7%) reported that lower-cost will result in better implementation of FDR in dental practice followed by better undergraduate education and governmental rules (20.6 and 20.9%, respectively) (Fig. 3) ($P < 0.001$). Overall, there were significant differences between GDs and Endodontists ($P < 0.05$). While the highest percentage of GDs (44.4%) reported the lower-cost factor, the highest percentage of Endodontists (33.7%) reported better undergraduate education ($P = 0.001$).

DISCUSSION

Radiographic imaging is an essential tool in endodontics, as the diagnostic imaging tasks include three main areas; 1) diagnosis (diagnosis of radicular and peri-radicular diseases) and estimation of cases' difficulty (interpretation of root canals systems' morphologies); 2) therapeutic procedures, such as determination of radiographic root canals' lengths and confirmation of obturation extension; and 3) evaluation the short and long-term outcomes of endodontic treatments (15, 16). It is well-known that endodontic treatments cannot be performed without the assistance of radiography (17).

Most previous studies reported poor usage of FDR in dental practice which ranged from 13% of GDs in India, 14% of GDs in Norway, 26% of members of the American Academy of Pediatric Dentistry to 36% of GDs in Hawai'i (9-12). Only one study reported quite acceptable adoption of FDR by GDs in New Zealand (58.0%) (13). The current study showed better implementation in Saudi dental practice as 64.9% were using FDR for RCTs. This can be attributed to different reasons and factors. While the current study was conducted recently (late 2018), the majority of previous studies were conducted many years ago. Tay et al, 12 years ago, expected increased demand for FDR in dental practice with time (14). The awareness of dental practitioners (general or specialists) also may have increases because of easier knowledge dissemination nowadays compared to past times. For example, in New Zealand, while only about one in three dentists was using FDR in 2008 (14), the figure significantly increased within only 5 years (2013) to become almost half of clinicians (13). Another possible reason is the good implementation of FDR in undergraduate curricula in Saudi dental institutes, especially the governmental ones. Interestingly, as it will be discussed later, all those who were working in the governmental academic (100%) were using FDR. Also, many of the drawbacks of earlier FDR equipment have been resolved (1). For example, the bulky images' receptors became smaller, images' resolution improved, and the advanced computer technology, which, in turn, have resulted in higher processing speeds and better data storage and archiving solutions (1). The faster workflow with FDR, due to markedly reduced exposure time and elimination of the time needed for chemical processing accompanied with FBR, can be an additional reason (1). FDR has also many advantages over FBR, which may explain the improved implementation of FDR in the current study compared to those in previous ones. Of these are: significant reduction of radiation, elimination of undesirable variables associated with processing of conventional films (especially the hazardous chemicals); easy transmission, archiving and retrieving images from databases and communication systems and facilitation usage of an all-elec-

tronic patient record (7, 8). The current study results were generally consistent with those obtained by Ting et al (13). In that, faster workflow, better Images' quality and less radiation (26.5, 22.7 and 22.2%, respectively) were the most common and important advantages of using FDR. Only 13% reported better archiving of images. Interestingly, the highest percentages of FBR and SDR systems users (27.1 and 31.4%, respectively) reported better images' quality as the main advantage. This may be due to the problem they encounter when trying to interpret images obtained by conventional films. By contrast, FDR users become familiar with the good quality of radiographic images and consider it as a normal outcome. Consequently, the highest percentage of them (30.2%) reported faster workflow as the most advantageous of FDR systems.

The perception of FDR importance was significantly different between GDs and endodontists. While the highest percentage of endodontists (34.7%) reported less radiation as the main advantage, the highest percentages of GDs reported faster workflow and better images quality (25.9% each). This reflects the better awareness of endodontists towards the priority of reducing radiation's risk and hazards rather than working quickly or enhancing the quality of radiographic images. However, some may argue that radiation reduction may not be really achieved, because practitioners may have the tendency to take more intraoral radiographs because of the easy radiographic acquisition and processing. This may explain the current study results as increased radiation was reported as the second most important disadvantage of using FDR, especially within those who were using SDR. This could be due to the tendency of taking more radiographs as FDR systems offer easy radiographic acquisition and processing within very short time compared to the traditional FBR. Berkhout et al addressed this aspect by comparing the number of radiographs taken in dental practices equipped with FDR versus FBR (18). They concluded that effective dose reduction after converting from FBR to FDR is less than 25% owing to the greater numbers of radiographs taken when FDR systems were used, though FDR requires 50-80% less radiation per exposure than films (18). However, previous studies revealed different and conflicting results regarding the correlation between the number of radiographs taken and the radiographic systems used.

While Berkhout et al found that FDR systems users took significantly greater number of radiographs compared to FBR users (18), Anissi & Geibel found that FBR users took significantly more radiographs than FDR users (19). Muathe & Eaton could not find a significant link in this regard (20). Nevertheless, there was agreement among participants of the current study (GDs and endodontists as well as FDR users and non-users) on high-cost being the most important disadvantage of FDR (61.5%). These findings were consistent with those reported in previous studies (13, 19). This group of participants, the highest percentage (61%), might be willing to adopt FDR systems should they were able to afford them, or should FDR systems were available in the first instance. Such a speculation can be confirmed by the results of the question related to reasons reported by participants for not using FDR. While, the majority of participants (77%) were not using FDR systems because they were unavailable at the practices they work in,

only 18.3% reported clearly the high-cost reason. These findings were consistent with those obtained in previous studies which investigated some aspects of endodontics in Saudi dental practices (21, 22). Unavailability was the main barrier for not using dental-dam and endodontic rotary instruments (21, 22). Nevertheless, 45 % of the dentists who were using FBR, in a previous study, clearly object shifting to FDR systems (19). It could have been better that the current study asked participants whether they will consider using FDR in a future work. This can be considered as one limitation of the study, which should be addressed properly in the future. Yet, there were agreements among participants on the reasons for not using FDR regardless their gender, type of practice (private, academic or government) or years of practice experiences.

Many reasons and factors may affect the decision of GDs to/not to adopt FDR. The percentage of male participants (67.8%) was significantly greater than female ones (32.2%). This was an expected consequence which reflects the greater percentage of males than that of females in Saudi Dental Register. This also confirms the reliability and randomization of the study's sampling method, hence the representation of the results. This also was consistent with previous studies concerned with FDR implementation (9, 12, 13). Also, the percentage of male clinicians who were using FDR (71.1%) was significantly greater than that of females (52%). While these findings were consistent with those obtained by Gupta & Rai (12), Berkhout et al found no correlation between gender and using of FDR (18). None of previous studies explained the impact of participants' gender on their decision to/not to adopt FDR. An additional statistic comparison, of the current study's responses, revealed a greater percentage of males (26%) who believe in reducing radiation as a main advantage of FDR than that of females (18.1%). Nevertheless, currently it is difficult to explain the greater usage of FDR among males than females, which suggests further in-depth research work.

While all endodontists (100%) were using FDR, a significantly lower percentage of GDs (52%) were doing so. This can be an expected result as endodontists are expected to be more aware of all advantages that FDR provide as well as eliminating of FBR disadvantages. Also, endodontists are expected to provide high-quality RCTs with better long-term outcomes, hence high-quality radiographs during treatment procedures are crucial. Previous studies showed that digital images perform at least as well as conventional radiographs, and sometimes better (10, 23). However, the quality of FDR is affected by knowledge and experience in FDR techniques and parameters of radiographs acquisition, hence comprehensive knowledge of FDR principles and improved technical skills are required (24, 25). It is well documented that endodontists perform significantly greater number of RCTs than GDs do (26, 27). While the majority of endodontists' time, if not all, is devoted to endodontics, the GDs are generally involved in a range of general dentistry procedures. Moreover, it is generally accepted that RCTs' procedures usually involve taking many radiographs (diagnostics, working length determination, gutta percha cone fit, pos-obturation and follow up and others). Therefore, saving time offered by FDR usage is paramount in endodontic specialized practices, which gives rise to all endodontists us-

ing FDR compared to only 52% of GDs. The latter justification is consistent with the results regarding the positive strong correlation of weekly performed RCTs and the adoption of FDR. As the number of weekly RCTs increased, the trend of using FDR increased; with a significantly the highest percentage (75.3%) within those who used to do more than 12 RCTs. Again, with greater number of RCTs hence more time devoted to endodontics, saving time required for radiographs acquisition is important. Anissi & Geibel found positive, but not significant, correlation between the increased number of patients and the trend towards taking more radiographs (19).

In terms of participants' experience, the significantly highest percentage of GDs and endodontists (40 and 34.6%, respectively) had more than 15 years experience. This can be considered as normal results and can be explained by the fact that dentists even after 15 years of practice, they usually still have a long way before stop practicing dentistry or specialized endodontics. In addition, recently graduates are interest in postgraduate studies programmes. Only one previous study did not find a correlation between the type of radiographic system used and the clinicians' experience in practice (9). By contrast, the trend of using FDR, in the current study, significantly increased as participants' experience decreased; with the highest percentage of FDR users being within the groups of dentists who had up to 7 years' experience (=76%). These findings were consistent with those obtained in most of previous studies (10, 13, 19). Nevertheless, none of the previous studies explained the impact of clinicians' experience on their decision to/not to adopt certain types of radiographic system. Old age GDs may resist adopting new technologies in dental practice. On the other hands, freshly graduated dentists are more exposed to new technologies and are already familiar with them. In addition, the increased implementation of FDR in Dental Schools' curricula could have impact (28). Freshly graduated or young GDs might be exposed to the literature more than old GDs.

The current study results were consistent with those of previous studies conducted in Saudi Arabia and showed that most of participants (80.9%) were working in the private sector (21, 22, 26, 27). Hence, great attention should be exercised towards this sector in terms of continuous education programmes and clinical audit. This is especially true as the percentage of those who were using FDR for RCTs within this sector (60.6%) was less than that of other sectors. Unlike the current study results, Mauthe & Eaton found that private GDs were more likely to use FDR than their mainly NHS counterparts (20). Such differences may be due to different work environments, economics and regulations as well as different factors related to clinicians. Nevertheless, whether FDR is used for other dental procedures rather than RCTs in Saudi dental practice, is an interesting aspect that should be further investigated. This can be considered as another limitation of the current study. On the other hand, the FDR systems are entirely implemented in governmental academic clinics. As mentioned earlier, this could contribute to the relatively good adoption of FDR systems reported in the current study compared to previous studies. However, more attention is needed in private academic clinics as the percentage of using FDR (69.2%) was significantly lower

than that of governmental academics. Equipment cost might be the major obstacle for better implementation of FDR systems in this sector.

High cost was apparent as the main obstacle of better implementation in Saudi dental practice. This is especially true regarding the general practice and was confirmed when participants were asked about factors and measures that can contribute to better implementation in dental practice. The highest percentage (39.7%) reported lower-cost of FDR as a main factor, followed by better undergraduate education and governmental rules (20.6 and 20.9%, respectively). These results were consistent with those obtained in another study regarding implementation of other techniques in Saudi dental practice (unpublished data). Nevertheless, this reflects the better understanding of endodontists compared to GDs. While the highest percentage of endodontists (33.7%) reported better undergraduate education as a main measure to better implementation of FDR in Saudi dental practice, the highest percentage of GDs (44.4%) reported lower-cost factor. It is generally accepted that the specifications and characteristics of undergraduate curricula reflect on dentists' performance and preferences during postgraduation practice. Nevertheless, GDs need to change their misperception regarding the real cost of FDR systems, as they are not that expensive as they think. Bansal stated that lower-cost is one important advantage of FDR systems because they save money from films' cost, reduce requirement for storage, and lesser staff is required to maintain the services and archiving sections (25). FDR also allows lesser films waste and lesser films per exam.

One may argue that the response rate obtained in this study (54.6%) is relatively low and that respondents may not be representative of the target population. This can be considered as one limitation, especially when the response rate is compared to those obtained in previous studies (18). However, it was similar to that of the study by Ting et al (55.2%) (13) and was better than those obtained by Brady (20.4%) (11), Russo et al (32%) (10), and Anissi & Geibel (27.7%) (19). Also, the response rates obtained by online questionnaires are usually lower than those reported in self-administrated ones (29). This may affect the results if the response rate is very low in the first instance. While a 70%–80 range is generally preferred (30), good response rates alone do not guarantee the validity of questionnaire studies' results (31). Asch et al stated that more attention should be given to assessments of bias, and less to specific response rate thresholds (32). In addition, the lowest level of non-response bias could have been obtained with a 43% response rate (33). Low response rates associated with a randomized and systematic sampling method are usually better than high response rates without randomization (34). More importantly, the none response bias can be a concern only when responders and non-responders differ on the variables of interest (35, 36). This can be achieved statistically by comparing those who responded after the first questionnaire sent out (early responses) and those who responded after the reminder (late responses), because the latter represent those who did not respond to the questionnaire (36). There was no significant difference between the percentage of early respondents who were using FDR (63.1%) and that of the late respondents (66.9%) ($P=0.493$). Neverthe-

less, though efforts were exercised to cover all relevant aspects, new aspects arose and necessitate future works to investigate them in-depth, such as why more male clinicians use FDR than females do and do clinicians take more or less radiographs during RCTs should they use FDR or FBR? Another important aspect is whether the current study findings can/cannot be applied on a global scale. It is quite accepted that dental communities are different worldwide in terms of clinical environments and set-ups, undergraduate training curricula, authorities' regulations as well as socio-economic conditions. These may reflect on questionnaire studies' results. Therefore, further research work in other countries to investigate aspects included in this study as well as other aspects that have arose from the current study is of great importance.

CONCLUSION

FDR was adopted to good extent in Saudi dental practice. Financial aspects were the main concern that should be addressed properly to increase implementation of FDR in private general practice. Endodontists showed better perception towards FDR and suggested more attention on educational aspects.

Disclosures

Conflict of interest: None declared.

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REFERENCES

- Petrikowski CG. Introducing digital radiography in the dental office: an overview. *J Can Dent Assoc* 2005; 71(9):651.
- Kfir A, Basrani B. General Principles of Radiology in Endodontics. In: Bettina Basrani, editors. *Endodontic Radiology*. John Wiley & Sons; 2012. p. 3–54.
- Rollins W. X-light kills. *Boston Medical and Surgical Journal* 1901; 144:173.
- Kathren RL, William H. Rollins (1852-1929): x-ray protection pioneer. *J Hist Med Allied Sci* 1964; 19:287–94.
- Rollins W. Some conclusions from experiments on guinea pigs which are of importance in the treatment of disease by x-light. *Boston Medical and Surgical Journal* 1902; 146:430.
- Sonoda M, Takano M, Miyahara J, Kato H. Computed radiography utilizing scanning laser stimulated luminescence. *Radiology* 1983; 148(3):833–8.
- Naoum HJ, Chandler NP, Love RM. Conventional versus storage phosphor-plate digital images to visualize the root canal system contrasted with a radiopaque medium. *J Endod* 2003; 29(5):349–52.
- Wenzel A, Gröndahl HG. Direct digital radiography in the dental office. *Int Dent J* 1995; 45(1):27–34.
- Wenzel A, Møystad A. Decision criteria and characteristics of Norwegian general dental practitioners selecting digital radiography. *Dentomaxillofac Radiol* 2001; 30(4):197–202.
- Russo JM, Russo JA, Guelmann M. Digital radiography: a survey of pediatric dentists. *J Dent Child (Chic)* 2006; 73(3):132–5.
- Brady DT. Digital radiography: a survey of dentists in Hawai'i. *Hawaii Dent J* 2007; 38(4):10–3.
- Gupta R, Rai R. The adoption of new endodontic technology by Indian dental practitioners: a questionnaire survey. *J Clin Diagn Res* 2013; 7(11):2610–4.
- Ting NA, Broadbent JM, Duncan WJ. Dental radiography in New Zealand: digital versus film. *N Z Dent J* 2013; 109(3):107–14.
- Tay KI, Wu JM, Yew MS, Thomson WM. The use of newer technologies by New Zealand dentists. *N Z Dent J* 2008; 104(3):104–8.
- Versteeg KH, Sanderink GC, van Ginkel FC, van der Stelt PF. Estimating distances on direct digital images and conventional radiographs. *J Am Dent Assoc* 1997; 128(4):439–43.
- Nair MK, Leven MD, Nair PU. Radiographic Interpretation. In: Hargreaves KM, Berman LH, editors. *Cohen's Pathways of The Pulp*. Canada: Elsevier; 2016. p. 33–70.
- Cotti E, Campisi G. Advanced radiographic techniques for the detection of lesions in bone. *Endod Top* 2004; 7:52–72.
- Berkhout WE, Sanderink GC, Van der Stelt PF. Does digital radiography increase the number of intraoral radiographs? A questionnaire study of Dutch dental practices. *Dentomaxillofac Radiol* 2003; 32(2):124–7.
- Anissi HD, Geibel MA. Intraoral radiology in general dental practices - a comparison of digital and film-based X-ray systems with regard to radiation protection and dose reduction. *Rofo* 2014; 186(8):762–7.
- Mauthe PW, Eaton KA. An investigation into dental digital radiography in dental practices in West Kent following the introduction of the 2006 NHS General Dental Services contract. *Prim Dent Care* 2011; 18(2):73–81.
- Madarati AA. Why dentists don't use rubber dam during endodontics and how to promote its usage?. *BMC Oral Health* 2016; 16:24.
- Madarati AA, Habib AA. Modalities of using endodontic nickel-titanium rotary instruments and factors influencing their implementation in dental practice. *BMC Oral Health* 2018; 18(1):192.
- van der Stelt PF. Principles of digital imaging. *Dent Clin North Am* 2000; 44(2):237–v.
- Hellén-Halme K. Quality aspects of digital radiography in general dental practice. *Swed Dent J Suppl* 2007; (184):9–60.
- Bansal GJ. Digital radiography. A comparison with modern conventional imaging. *Postgrad Med J* 2006; 82(969):425–8.
- Madarati A, Sammani A, Zafar MS, Bani-Younes H, Aly Ahmed HM. Usage of NiTi rotary files systems for root canal retreatment procedures: Experience and practice of dental practitioners and endodontists. *ENDO - Endodontic Practice Today* 2016; 10(4):213–23.
- Madarati AA. Preferences of dentists and endodontists, in Saudi Arabia, on management of necrotic pulp with acute apical abscess. *BMC Oral Health* 2018; 18(1):110.
- Brownstein SA, Murad A, Hunt RJ. Implementation of new technologies in U.S. dental school curricula. *J Dent Educ* 2015; 79(3):259–64.
- van Gelder MM, Bretveld RW, Roeleveld N. Web-based questionnaires: the future in epidemiology?. *Am J Epidemiol* 2010; 172(11):1292–8.
- Brennan DS, Ryan P, Spencer AJ, Szuster FS. Dental service rates: age, period, and cohort effects. *Community Dent Health* 2000; 17(2):70–8.
- McCull E, Jacoby A, Thomas L, Soutter J, Bamford C, Steen N, et al. Design and use of questionnaires: a review of best practice applicable to surveys of health service staff and patients. *Health Technol Assess* 2001; 5(31):1–256.
- Asch DA, Jedrzejewski MK, Christakis NA. Response rates to mail surveys published in medical journals. *J Clin Epidemiol* 1997; 50(10):1129–36.
- Hovland EJ, Romberg E, Moreland EF. Nonresponse bias to mail survey questionnaires within a professional population. *J Dent Educ* 1980; 44(5):270–4.
- Lydeard S. The questionnaire as a research tool. *Fam Pract* 1991; 8(1):84–91.
- Tan RT, Burke FJ. Response rates to questionnaires mailed to dentists. A review of 77 publications. *Int Dent J* 1997; 47:349–54.
- Parashos P, Morgan MV, Messer HH. Response rate and nonresponse bias in a questionnaire survey of dentists. *Community Dent Oral Epidemiol* 2005; 33(1):9–16.