RESEARCH ARTICLE

Creation of a dental X-ray unit with a contactless exposure control switch

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Objective: A new dental radiographic unit (DXRU) with a contactless switch for adjusting exposure conditions and a foot-pedal exposure switch was developed to prevent bacterial or viral contamination from patients and was compared with a conventional DXRU with a panel push-button switch with respect to user friendliness.

Methods: 45 fourth-year dental school students carried out intraoral radiography using both types of DXRU. Errors regarding dose shortages of X-rays were compared and a questionnaire completed.

Results: 22 (49%) of the 45 students failed to provide the correct radiographic exposure and the number of errors was 32 for the conventional DXRU, and 4 (9%) students failed to provide the correct radiographic exposure and the number of errors was 4 for our new DXRU, at the first stage ($p < 0.001$). At the second stage, the number of students who failed to provide the correct radiographic exposure and the number of errors decreased to 12 and 16, respectively, for the conventional DXRU ($p < 0.05$). 37 (82%) of the 45 students preferred our DXRU because of its contactless switch and the push-pedal exposure switch.

Conclusions: These data suggested that our new contactless mechanism should be used for other DXRUs for contamination control.

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Introduction

There are many opportunities for iatrogenic transmission of infected materials in dental treatment compared with medical treatment. The saliva and blood of patients, as well as dental instruments in contact with the patient, are the main sources of cross-infection. Such transmission can be extended to surrounding walls, the dental chair and the air by tooth preparation. One must use disposable materials in contact with the mouth and use sterilized material for infection control. In addition the basis of disinfection methods is autoclaving and gaseous sterilization. Guidelines concerning infection prevention have been published previously.¹

However, large pieces of apparatus, such as the dental radiographic unit (DXRU), are wiped with disinfectant because the disinfection method described above cannot be used. The DXRU is readily infected by saliva and blood during intraoral radiography because detectors such as a film, an imaging plate [*i.e.* photo-stimulable storage phosphor (PSP) plate] and a charge-coupled device sensor are positioned in the mouth.²⁻⁸ During the radiographic procedure, an operator locates the detector in the patient's mouth with his/her hand and sets the X-ray head or cone. The exposure button is pushed after such a placement. A control button for adjusting the radiographic conditions is sometimes used by operators with their hands, which may be contaminated by patients' saliva and/or blood. Thus, a patient's

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saliva and/or blood can be transferred easily onto the X-ray cone, control button or exposure button. Hence, an infection source could develop if the disinfection method is not adequate. Some clinical facilities have adopted infection-control methods in which the X-ray cone and exposure button are covered and a disposable cover is exchanged for each patient. However, most dental clinics use disinfectants such as alcohols. The disinfectant method is unsuitable for a DXRU with a mechanical exposure button because the liquid can penetrate the movable parts.

We wanted to improve the DXRU to decrease the chance of bacterial or viral transmission as much as possible. As a result, a new DXRU was created. It was composed of a contactless switch and a foot-pedal exposure switch instead of a push-button switch. The convenience of use of this newly created DXRU was compared with a conventional DXRU by dental students who had not taken a radiograph previously.

Methods and materials

A new dental radiographic unit with a contactless control switch

A new contactless panel switch for adjusting exposure conditions was developed to prevent viral or bacterial contamination. It was based on a commercially available DXRU (ALULA™; Asahi Roentgen Ind. Co., Ltd, Kyoto, Japan). The DXRU had a fixed tube current (6 mA) and a selectable tube voltage (60 or 70 kV). The exposure time could be changed from 0.01 to 1.60 s independently and could also be preset for children and adults as well as for eight locations (four sites in the upper jaw and four sites in the lower jaw). Exposure conditions were adjusted by a control panel with a push-button switch (including an irradiation switch). The exposure condition adjusting switch and irradiation switch were exchanged for a new control panel with a contactless switch and foot-pedal exposure switch, respectively (Figure 1a,b).

The contactless switch contained a light-modulation reflective-type photosensor, which reacted by a finger being placed between 10 and 15 mm from it. Thus, the operator could adjust the exposure conditions just by “hovering” his/her finger over the sensing area of the sensor. The panel dimensions had a width of 180.0 mm, a height of 152.0 mm and a thickness of 38.5 mm.

Conventional dental radiographic unit

A commercially available DXRU (Intra™; Planmeca, Helsinki, Finland) was used as a comparison for our newly developed DXRU. The conventional DXRU was selected because it is in widespread use all over the world and is equipped with a control panel including an irradiation switch quite similar to the previous type of the new DXRU. The unit could be set independently at a tube voltage of 60 or 70 kV, an exposure time from 0.1 to 3.2 s and a tube current from 2 to 8 mA. The exposure-condition control switch and irradiation switch

were of the finger-push-button type covered by a plastic sheet (Figure 1c).

Methods

45 fourth-year dental students participated in the research. The students had attended a dental radiology class in the first half of their fourth-year studies. However, they had not taken radiographs using even human simulators such as a manikin. It was the first time they had used a DXRU. They were well briefed on the usage of the two DXRUs by an instructor just before the experiment began and compared our new DXRU with a conventional DXRU with regard to simulation of intraoral radiography. 28 exposures were made to simulate the full mouth (14 series) of two patients; only the exposure time was altered, whereas the X-ray cone was kept fixed. The exposure time ranged from 0.2 to 0.4 s for the upper jaw and from 0.10 to 0.25 s for the lower jaw. Each side of the jaw was exposed alternately by changing the DXRUs. Students were divided into two groups: one group (Group A) started exposures using our new DXRU and the other group (Group B) started exposures using the conventional DXRU. In Group A, (1) seven exposures using a new DXRU and (2) seven exposures using a conventional DXRU were made for the upper jaw at the first stage and (3) seven exposures using the new DXRU and (4) seven exposures using the conventional DXRU were made for the lower jaw at the second stage. In Group B, the exposures were made in the order (2), (1), (4) and (3).

A questionnaire was distributed after the exposures. The items on the questionnaire included a comparison of our new DXRU with the conventional DXRU, sex and the use of smartphones and tablet personal computers. A “free comment” section was also available in the questionnaire (Table 1).

Evaluation items

The number of exposure errors (*i.e.* exposure interruptions before the end of a set time) was counted for each DXRU. An error message could not be displayed in our new DXRU, so the dose was measured and the error determined by a shortage of X-ray dose. The conventional DXRU could display a message if an error occurred (including shortage of X-ray dose) so an error could be detected by this message. The errors were judged and the number of exposures was counted by an instructor supervising the experiment. The prevalence of errors in 28 exposures for both DXRUs was compared. The prevalence of errors for the first and second exposures was compared. A χ^2 -test was used for statistical evaluations.

Results

22 (49%) of the 45 students failed to provide the correct X-ray dose at the first-exposure stage, and there were 32 errors when using the conventional DXRU. In the second stage, 12 (27%) students failed to provide the

Figure 1 (a) Our new contactless switch panel [the arrow shows the mode button (periapical or occlusal) and the broken arrow shows the location button (upper or lower)]. (b) A foot-pedal switch for irradiation. (c) A conventional switch panel (the arrow shows the irradiation button and the broken arrow shows the exposure-adjusting button).

correct X-ray dose and the number of errors was 16. The number of students who failed to provide the correct X-ray dose at the second stage decreased significantly compared with that at the first stage ($p < 0.05$).

For our new DXRU, at the first stage, only 4 (9%) students failed to provide the correct X-ray dose and the number of errors was four. However, no student failed to provide the correct X-ray dose at the second stage. Thus, our new DXRU was superior to the conventional DXRU with respect to the number of students who failed to provide the correct X-ray dose and the number of errors ($p < 0.001$) (Table 2). When using our new DXRU, four students failed to provide the correct X-ray dose only once. However, at the first stage when using the conventional DXRU, 15 students failed to provide the correct X-ray dose once, 4 students failed twice, and 3 students failed three times. Two of four students who failed to provide the correct X-ray dose when using our new DXRU also failed when using the conventional DXRU.

With regard to the order of DXRU use, 12 (52%) of 23 students in the group starting with our new DXRU failed to provide the correct X-ray dose, and the number of errors was 22 using the conventional

DXRU. 14 (64%) of 22 students in the group starting with the conventional DXRU failed to provide the correct X-ray dose, and the number of errors was 26 using the conventional DXRU. There was no difference in the order of use between the two groups.

As a result of completion of the questionnaire after carrying out intraoral radiography, 37 (82%) of 45 students wished to use our new DXRU, and 8 students wished to use the conventional DXRU (Table 3), and this difference was significant ($p < 0.01$). The main reason why the students preferred our new DXRU was that they could adjust the exposure conditions using a contactless switch (35 students) and use a foot-pedal switch (27 students). Most of the students who liked our new DXRU used a smartphone (32 of 37 students), and all 6 students using tablet personal computers hoped to purchase our new DXRU. The free-comment section of the questionnaire was limited to matters relating to our new DXRU. 39 students described the improvement of our DXRU and 44 students described its advantages. 15 comments stated that the contactless switch was too sensitive and that the position of the switch was not clear. Five students claimed it was non-reactive. The largest number of comments regarding the advantages of our new DXRU focused on its usefulness for infection control (19 students), and the second largest

Table 1 The questionnaire

What is your sex?	
1. Male	2. Female
Do you use a tablet computer?	
1. Yes	2. No
Do you use a smartphone?	
1. Yes	2. No
Which is preferable to use for adjusting exposure conditions?	
1. Non-contact switch	2. Panel push-button switch
Which is preferable to use for exposure?	
1. Foot-pedal exposure switch	2. Panel push-button switch
Which type will you purchase in the future?	
1. New type	2. Conventional type
Further comments:	

Table 2 Comparison of errors when using each type of dental radiographic unit

No. errors	New dental radiographic unit		Conventional dental radiographic unit	
	First stage	Second stage	First stage	Second stage
0	41	45	23	33
1	4	0	15	9
2	0	0	4	2
3	0	0	3	1

Numbers are the total errors during the first and second trials.

Table 3 Comparison of the selected dental radiographic unit for purchase (*n* = 45)

Dental radiographic unit	Sex		Smartphones		Tablet personal computers	
	Male	Female	Available	None	Available	None
New	22	15	32	5	6	31
Conventional	3	5	6	2	0	8

Dental radiographic unit	Exposure condition adjusting switch ^a		Exposure switch ^b	
	Contactless	Panel push-button	Foot pedal	Panel push-button
New	35	0	27	7
Conventional	2	6	3	5

^aTwo students were non-respondent.
^bThree students were non-respondent.

number of comments was on the good sensitivity of the sensor (13 students).

Discussion

The number of errors when using the conventional DXRU was clearly more than that when using our new DXRU because the students were not accustomed to pushing a button and releasing their fingers. The conventional DXRU had a circuit that enabled emission of a sound for preventing an inadequate dose of X-rays, but some students interrupted the exposure because of their lack of judgement. The time required to continue pushing the button was measured as 1.2 s for an exposure time of 0.1 s for the lower anterior teeth and 1.5 s for an exposure time of 0.4 s for the upper molar teeth. The actual exposure time was determined by measuring the time that the beep sounded or that an irradiation switch shone. Thus, the actual exposure time was longer than the time needed for recording. This phenomenon could be because most young people are familiar with touch-screen technology such as smartphones, and their reaction time is based on the use of a touch screen. This finding might suggest that the button switch should be replaced with a new design because some students failed many times.

Conversely, errors were barely seen when using a foot-pedal exposure switch. The measurement times required for exposure were 1.4 s for an exposure time of 0.1 s and 1.7 s for an exposure time of 0.4 s, which were similar readings to those observed using a push-button switch. Most students did not understand how long it takes for a machine to work although they were told that they should keep the exposure button pushed while the beep sounded, and there was no problem with a foot pedal because foot pedal operations were considerably slower than those using the hand.

A simulated full-mouth exposure was undertaken continuously. The dental radiologists within our department could not imagine that so many mistakes could occur by simply pushing a button. Our findings suggested that mere explanation was not sufficient even if an operation was

very simple, and that training was indispensable because the number of errors at the second stage decreased significantly compared with that observed at the first stage. When this applies to dental treatment, training that simulates actual manipulation will be very important.

With regard to the preference of DXRU, most dental radiologists in our department had negative feelings about our new DXRU because a contactless switch was novel, and they felt it was easier to use a push-button panel. However, most students clearly liked our new DXRU. Thus, the opinion of the fourth-year dental students should be reflected in the development of a new product. Our new DXRU could not assess a shortage of X-ray dose, and many students highlighted this feature. Hence, we developed a display circuit to show such dose shortages, and it will be incorporated in a new control panel.

There is appreciable potential for cross-contamination of equipment and surfaces with saliva and/or blood when taking dental radiographs. Such cross-contamination during intraoral radiography was reported over 40 years ago.⁸ It was stated that transference was observed in 77% of patients and that the radiographic equipment and the operator’s hand were the vectors for transfer. Saliva and blood could be easily transferred by an operator’s hand onto an X-ray tube head, extension cones, control panels and exposure buttons. It was reported that many anaerobic and aerobic microbes were observed in a sleeve and trigger switch, respectively, during a radiographic procedure.⁷ In addition, *Staphylococcus epidermidis* was observed in an X-ray cone and button, and *Streptococcus mitis* was observed in an X-ray button.⁴ Although digital radiographic systems have decreased the chances of cross-contamination during film processing, another problem can occur. Perforation of the plastic sheath for direct digital radiography occurs at a high frequency.² It has been reported that a plastic barrier sheath of the PSP plate must be disinfected during an exchange with a barrier envelope,^{4,9} and that gas sterilization of the PSP plate is a potential solution,³ although a barrier envelope of the PSP plate is effective for reducing contamination.⁵ It is also reported that ethanol disinfection degrades PSPs though it eliminates all micro-organisms.¹⁰ And it is said that most general dental clinics (62%) continue to use films in, for example, Belgium.¹¹ Nevertheless, the X-ray tube, control panel and exposure button are contaminated if a digital system is used. Our new DXRU with a contactless control panel and a foot-pedal exposure switch can prevent contamination by touching a control panel and exposure button. Thus, our new DXRU is very useful for preventing cross-contamination.

At first, we aimed to develop a contactless switch including an irradiation switch but a contactless control panel could not legally involve an irradiation switch in Japan. We used a foot-pedal irradiation switch instead and a good result was obtained. Finally, we would like to develop a contactless irradiation switch. However, even now, it is always necessary to change the exposure time at the time of irradiation in intraoral radiography,

and there must be a cross-contamination problem with the adjusting switch. The new contactless switch contributes to preventing the cross-contamination. Now, we hope that manufacturers will adopt the exposure

control panel with a contactless switch on the DXRU to prevent infectious contamination and to decrease the error of exposures because this new control panel has few errors of exposures and is applicable to any unit.

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