

Research article

Efficacy of a newly designed angulation-adjustable film holder for reducing cone-cutting errors and saving time in horizontal tube-shift technique by dental students

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ABSTRACT

Objectives: To compare the cone-cutting error frequency and the X-ray cone alignment time in the horizontal tube-shift technique between the newly designed angulation-adjustable and the extension cone paralleling (XCP) holders, by dental students.**Materials and methods:** Two film holders were assigned for a random test. The mandibular left first molar position of a laboratory phantom head was used. Intraoral periapical radiography was performed horizontally at right-angle, 20° mesial-, and 20° distal projections by fifth-year dental students (n = 41). The cone-cutting error frequency and the X-ray cone alignment time were measured and analyzed statistically at a significant level of $p < 0.05$.**Results:** Using the two holders at right angle caused no significant difference ($p > 0.05$) in the cone-cutting error frequency or the X-ray cone alignment time. At the horizontal tube-shift angles, some significantly greater frequencies of cone-cutting errors at both 20° mesial (43.9%) and 20° distal (73.2%) shifts were detected in the XCP group, but none in the angulation-adjustable group. For X-ray cone alignment time at both 20° mesial and 20° distal shifts, the XCP group spent a significantly longer time ($p < 0.05$) than the angulation-adjustable group.**Conclusions:** The usages of the angulation-adjustable holder in the horizontal tube-shift technique resulted in none of the cone-cutting error and a significant reduction of time for the X-ray cone alignment, when compared to those of the XCP instrument.**Clinical significance:** The angulation-adjustable holder effectively reduced cone cutting error and treatment time, both of which were beneficial to the patients and the dental personnel.

1. Introduction

Intraoral periapical radiographs are essential for all stages of endodontic therapy, because they provide important information for diagnostic investigations, treatment decisions, and outcome assessments [1, 2]. High-quality radiographic images are necessary for dental clinicians to achieve diagnostic validity [3]. With its simplicity, reproduction, less dimension distortion [4], and less overlapping between the tooth root apex and the zygomatic process [1], the paralleling technique produces the most accurate periapical radiographs for endodontic purposes [5]. In addition, it is able to standardize the dental radiographic images, when a film-holding device is co-used [6].

A minimum of the standard (right angle) and an altered angulation in the intraoral periapical radiography is required to obtain the maximum information for endodontic diagnosis [1]. According to the buccal object rule [7], the X-ray beam's horizontal axis alteration to mesial or distal direction helps to identify the superimposed or multiple root canals, the anatomical landmarks or pathologic lesions, the apical root curvature [1], the external or internal root resorption [8], and the vertical or horizontal root fractures [9]. Capabilities in the root canal separations of the horizontal tube-shift technique on the posterior teeth have been evaluated at several angulations, such as 20° [10, 11], 25° [12, 13, 14], 30° [15], and 40° angulations [16].

The intraoral film-holding devices for the paralleling technique are commercially available with numerous designs, and their advantages/

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disadvantages have been evaluated [17, 18, 19, 20, 21]. To the best of our knowledge, the film holders mostly comprise a film-holding portion and a right-angle beam aiming rod (with or without an aiming ring). In the horizontal tube-shift technique, the X-ray cone needs to be aligned at the desired angles to separate the superimposed objects [10, 11, 12, 13, 14, 15, 16], and at the correct beam projection to cover the entire intraoral film that will prevent cone-cutting errors [22]. These errors may lead to lower quality radiographs, and image-retaking procedures, particularly among undergraduate dental students who have less radiographic experience, which may cause increased treatment time and the risk of radiation exposure. The radiographers' performances have been reported to affect the intraoral radiograph quality or cause some technical errors [23, 24, 25, 26, 27]. However, data on the relationships between the horizontal tube-shift technique and the technical errors are scarce.

Usages of the horizontal tube shift technique need a precise angulation to identify the superimposed root canals of each tooth [10, 11, 12, 13, 14, 15, 16]. A film-holder with a beam-aiming rod that is adjustable to 20° or 40° in a horizontal axis, has recently been developed. It was reported that the 20°-angle effectively separated the multirooted premolars and molars [10, 11], while the 40°-angle was the alternative for identifying other additional canals of the premolars [16]. This holder was speculated to enable a better horizontal tube-shift radiography, with decreased cone-cutting errors and treatment time. Hence, the aim of this study was to compare the cone-cutting error frequency and the X-ray cone alignment time in the horizontal tube-shift technique between the newly designed angulation-adjustable and the extension cone paralleling (XCP) holders, by dental students.

2. Materials and methods

This study protocol was approved by the Naresuan University Ethics Committee (IRB Number 0571/60). The fifth-year dental students ($n = 41$) in the 6-year program participated in this research project, after they had studied the intraoral radiographic technique series and practiced a full-mouth oral radiography for patients in their third- and fourth-years, respectively. Among them, clinical knowledge and skills of using the paralleling technique with film-holders were expectedly similar. Before this investigation, all instructions, demonstrations, and laboratory training procedures were set up for each student by an instructor.

After all necessary informed consent forms had been obtained, a laboratory phantom head was prepared with all maxillary and mandibular permanent teeth (third molars included) for intraoral periapical radiography using the paralleling technique. Two types of the X-ray film holders were used, that is, the one with the extension cone paralleling instrument (XCP; Dentsply Rinn, York, PA, USA) for posterior teeth with a stabilized aiming rod at the right angle and the other with the horizontal angulation-adjustable instrument (20° and 40°) from the right-angle position to mesial or distal directions (Figure 1). A double

blinded crossover study was performed. Two film holders were assigned for a random test with a 2-week interval to reduce the participants' bias. A two-dimensional imaging plate was attached with an assembled holder and inserted to the mandibular left first molar position. An acrylic resin block was prepared for the same and stable position of the intraoral film and holder. First, second, and third intraoral periapical radiography were performed horizontally at right-angle, together with 20° mesial- and 20° distal projections ($n = 41$ for each position), respectively. During each radiography, the XCP and the angulation-adjustable instruments were used, with their aiming rod and ring guiding the X-ray head alignment to the right-angle position. For the mesial- and distal-tube-shift radiographs, the newly designed holder was equipped with an adjustable aiming rod.

A digital imaging system (GXS-700; Gendex Dental System, Brea, CA, USA) was used with a photostimulable phosphor plate (size #2) as an image receptor with 70 kVp, 15 mA, and 0.26 s. After the exposure, the plate was applied to a scanner (CS 7600; Carestream Dental, Atlanta, GA, USA) by using a software (Kodak Dental Imaging; Carestream Dental). The radiographic cone-cutting errors due to the entire intraoral film unexposed to the X-ray beam and those involving the mandibular left molar were counted by an examiner. The X-ray cone alignment time (s) was measured for each radiography. In case of the cone-cutting errors, the radiograph was retaken until no error image was seen. The radiographic cone-cutting errors, the cone alignment total time, the number of the students taking periapical radiographs, and the frequency of radiography until obtaining no cone-cutting error were recorded.

When using each film holder at the respective horizontal positions, all frequencies of the cone-cutting errors were statistically analyzed with a Chi-square test. The time spent on the X-ray cone alignment between holders and among each holder's three angulations were statistically analyzed by using an independent t test and a one-way ANOVA, respectively. Multiple comparisons were confirmed with a Tukey test. The level of statistical significance was set at $p < 0.05$.

3. Results

Intraoral periapical radiographs using different holders are shown in Figures 2a–2h. With the X-ray beam at the right angle, no significant difference ($p = 0.314$) in the radiographic cone-cutting error frequencies was observed between holders (Table 1). When compared with the adjustable holder that showed no error frequency, the XCP resulted in significantly greater frequencies at both 20° mesial- and 20° distal shifts. The highest cone-cutting error frequency (73.2%) was found in the XCP holder with the distal shift, followed by the mesial shift (43.9%) (Table 1).

When using the XCP holder, radiographs with the cone-cutting errors involving mandibular left first molar were observed at the mesial (12.2%) and distal (19.5%) angulations, but not at the right angle. None was seen when the angulation-adjustable holder was used. Intergroup

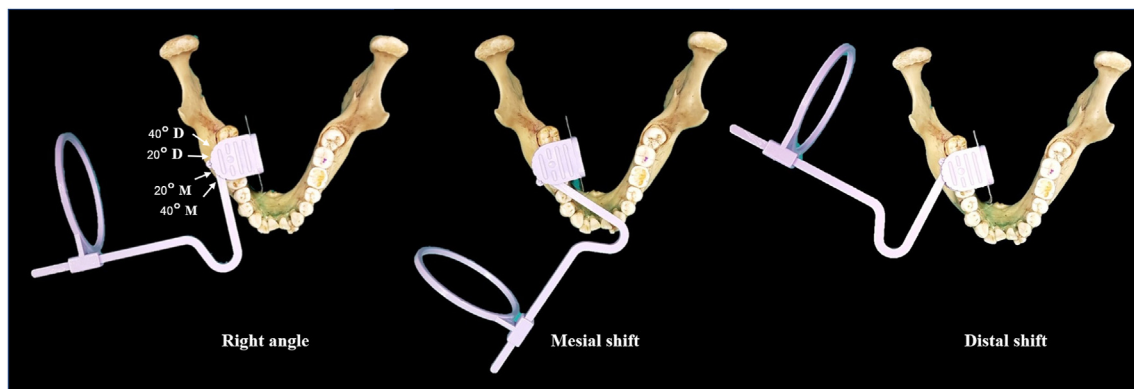


Figure 1. The newly angulation-adjustable holder with 20° and 40° from the right-angle position to mesial (M) or distal (D) directions.

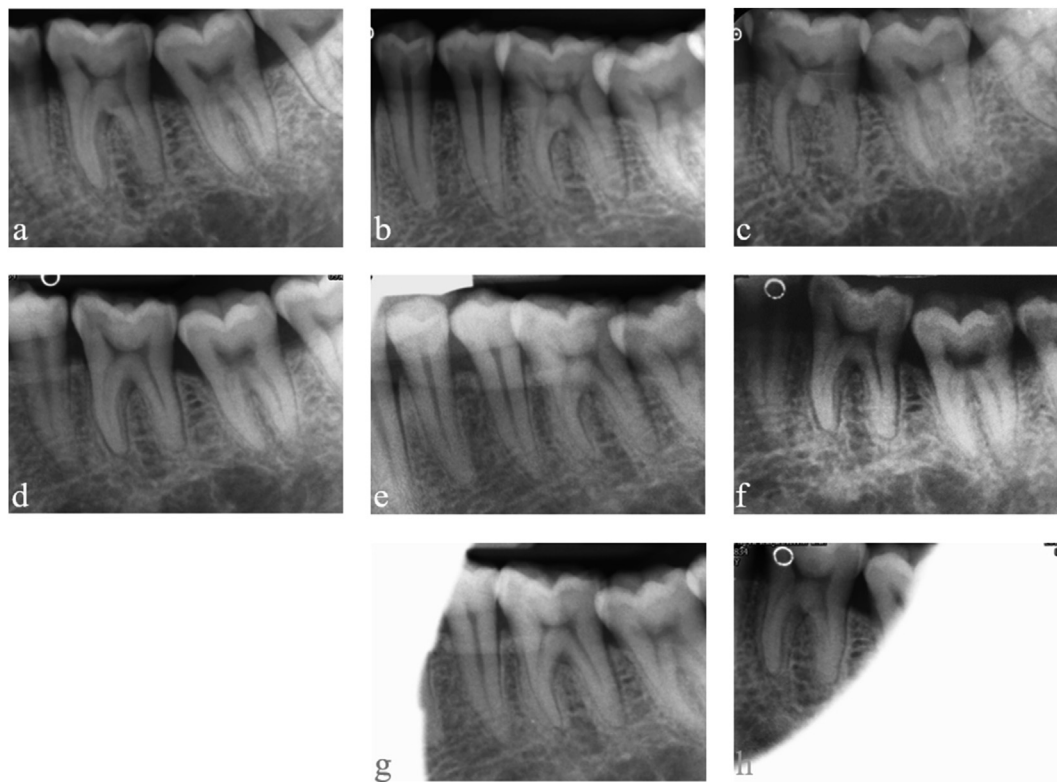


Figure 2. Intraoral periapical radiographs using an angulation-adjustable holder (a, b, and c) and an extension cone paralleling holder (d, e, and f) with right-angle, as well as 20° mesial- and 20° distal projections, respectively, and the radiographs with cone-cutting errors using an extension cone paralleling holder with 20° mesial- (g) and 20° distal (h) shifts.

Table 1. Frequencies and percentages of the periapical radiographs with and without cone-cutting errors at three horizontal angulations with the aids of an extension cone paralleling (XCP) holder or an angulation-adjustable holder.

Horizontal angulation	XCP holder		Angulation-adjustable holder		p-value*
	Without error	With errors	Without error	With errors	
Right angle	40 (97.6%)	1 (2.4%)	41 (100%)	0 (0%)	0.314
20° mesial	23 (56.1%)	18 (43.9%)	41 (100%)	0 (0%)	0.000
20° distal	11 (26.8%)	30 (73.2%)	41 (100%)	0 (0%)	0.000

* Chi-square test, at $p < 0.05$.

analyses using a chi-square test have shown some significant differences in the frequencies of the cone-cutting errors at the mesial ($p = 0.021$) and distal ($p = 0.003$) angulations (Table 2).

Table 2. Frequencies and percentages of the periapical radiographs with cone-cutting error involving mandibular left first molar at three horizontal angulations with the aids of an extension cone paralleling (XCP) holder or an angulation-adjustable holder.

Horizontal angulation	XCP holder		Angulation-adjustable holder		p-value*
	Without error	With errors	Without error	With errors	
Right angle	41 (100%)	0 (0%)	41 (100%)	0 (0%)	-
20° mesial	36 (87.8%)	5 (12.2%)	41 (100%)	0 (0%)	0.021
20° distal	33 (80.5%)	8 (19.5%)	41 (100%)	0 (0%)	0.003

* Chi-square test, at $p < 0.05$.

The X-ray cone alignment time at three horizontal angulations between holder types are shown in Table 3. An independent *t* test showed some significant differences between them at both shifts, but not at the right angle. Unlike those in the angulation-adjustable holder group shown with non-significant differences in the alignment time analyzed with a one-way ANOVA and Tukey test, the XCP instrument was detected with some significant differences in the alignment time between right angle and 20° mesial shift ($p = 0.008$), right angle and 20° distal shift ($p = 0.000$), and 20° mesial- and 20° distal shifts ($p = 0.000$). The longest time to align cone was detected with the XCP instrument at 20° distal shift (122.59 s), followed by 20° mesial shift (64.22 s).

Number and percentages of the students who took periapical radiography at three horizontal angulations, when using the XCP and the angulation-adjustable holders, until obtaining no cone-cutting error are shown in Table 4. For the angulation-adjustable holder, no radiograph-retaking was revealed. Using the XCP instrument, total number of the students who retook the radiographs at 20° mesial- and 20° distal shifts

Table 3. The X-ray cone alignment time (s, mean ± standard deviation) at three horizontal angulations with the aids of an extension cone paralleling (XCP) holder or an angulation-adjustable holder.

Horizontal angulation	X-ray cone alignment time		p-value
	XCP holder	Angulation-adjustable holder	
Right angle	24.59 ± 07.72 ^{a*}	27.61 ± 09.09 ^a	0.109
20° mesial	64.22 ± 46.01 ^{b***}	29.59 ± 12.61 ^a	0.000
20° distal	122.59 ± 90.36 ^{b,***}	32.76 ± 22.62 ^a	0.000
p-value	0.000	0.336	

Note: Different superscripted letters and asterisks indicate significant intrarow and intracolumn differences by an independent *t* test and a one-way ANOVA, respectively, at $p < 0.05$.

Table 4. Number and percentages of the dental students taking the periapical radiographs at three horizontal angulations with the aids of an extension cone paralleling (XCP) holder or an angulation-adjustable holder until obtaining no cone-cutting error.

Frequency of radiography	XCP holder			Angulation-adjustable holder		
	Right angle	20° mesial	20° distal	Right angle	20° mesial	20° distal
Once	40 (97.6%)	23 (56.1%)	11 (26.8%)	41 (100%)	41 (100%)	41 (100%)
Twice	1 (2.4%)	14 (34.2%)	6 (14.6%)	0 (0%)	0 (0%)	0 (0%)
Thrice	0 (0%)	3 (7.3%)	11 (26.8%)	0 (0%)	0 (0%)	0 (0%)
Four times	0 (0%)	1 (2.4%)	5 (12.2%)	0 (0%)	0 (0%)	0 (0%)
Five times	0 (0%)	0 (0%)	5 (12.2%)	0 (0%)	0 (0%)	0 (0%)
Six times	0 (0%)	0 (0%)	1 (2.4%)	0 (0%)	0 (0%)	0 (0%)
Seven times	0 (0%)	0 (0%)	2 (4.9%)	0 (0%)	0 (0%)	0 (0%)
Total	41 (100%)	41 (100%)	41 (100%)	41 (100%)	41 (100%)	41 (100%)
Retaking	1 (2.4%)	18 (43.9%)	30 (73.2%)	0 (0%)	0 (0%)	0 (0%)

were as high as 43.9% and 73.2%, respectively. The highest image-retaking frequency was seven times with the XCP instrument at the distal shift.

4. Discussion

In the present study, the mandibular molar regions were selected due to some more reports in the cone-cutting errors on them [24, 25]. At the right angle, the radiographs with the errors in the angulation-adjustable and the XCP groups were as low as 0% and 2.4%, respectively, and without significant difference. These were consistent with the results in a report showing a more drastic reduction in the errors from the co-usage of the XCP instrument and the paralleling technique, when compared with those from the co-usage of the Snap-A-Ray instrument and the bisecting angle [24]. Because our non-significant difference in the times for an X-ray cone alignment at the right-angle projection between holders, the usage of the film holder with the attached right-angle aiming rod and ring was indicated to assist the students to align the X-ray cone simply and properly.

The horizontal tube-shift radiography with the XCP instrument significantly increased the images with some cone-cutting errors (43.9% and 73.2% in mesial and distal shifts, respectively). However, the errors were substantially decreased to zero when the angulation-adjustable holder was used. The time spent by the dental students with less experiences to shift the X-ray cone angulations, particularly the distal shift, with the XCP instrument was significantly longer than that with the angulation-adjustable one. This reflected some difficulties among the students to change the X-ray beam angulations of the XCP holder with a fixed aiming rod at the right angle. In addition, a good visibility to the intraoral objects was important for the X-ray cone alignment. An addition of the buccal traction was reported to enhance the visions of a radiographic area, thus enabling the clinicians to adjust the X-ray beam path correctly and resulting in the error reductions [28]. Hence, the more errors in and the longer time spent during the distal shifts than those during the mesial shifts were explicable by the invisibility of the intraoral objects, when using the XCP instrument. Nonetheless, the zero cone-cutting error and a similar amount of time spent on all three angulations could be obtained by using the angulation-adjustable holder. These suggested that the aiming rod with the adjustable angulations enhanced the students' correct alignment of the X-ray cone, despite the unclear visibilities to the intraoral objects.

When using the XCP holder, radiographs with the cone-cutting errors involving mandibular left molar were considerably decreased at both the mesial (12.2%) and distal (19.5%) angulations. However, these frequencies were significantly higher than the zero error of the angulation-adjustable holder. It is a *de facto* practice of dental practitioners to not retake a radiograph after obtaining a cone-cutting image that does not involve the teeth under a treatment. A *de jure* quality of radiographs not

only aids the diagnostic and working procedures, but also serves as the dental patients' important documentation.

The undergraduate students' performances in the endodontic radiography were poor [26] and some clinical training programs influenced their proficiency [24, 25, 29]. Prior to their commencement in this study, each of 41 students took a minimum of 30 periapical radiographs of the patients with the standard and horizontal tube-shift angulation techniques. However, 30 (73.2%) and 18 (43.9%) of them required the radiograph-retaking procedures with the XCP instrument, until obtaining no cone-cutting error for the distal and mesial shifts, respectively. In addition, the highest frequency (seven times) of image retakes was detected with the distal shift angulation. The results illustrated their poor abilities in the X-ray cone alignment when no guiding instrument was attached to the holder. The retaking image procedure increases not only an unnecessary radiation exposure, but also wastes the dental resources. Hence, an improvement in their performances with a convenient and helpful instrument is needed in the next educational phases.

The laboratory experiment was conducted to prevent the volunteers from an inappropriate radiation exposure and to control some anatomical factors. Our determined crossover experiment was radiography of the patients' same area at three angulations by using two different devices and the cone-cutting radiograph would be retaken until no error occurred. However, such clinical investigations are not allowed by the human ethics and further investigations into other technical errors are needed. Some improper film positioning, some incorrect vertical angulations and horizontal overlapping, the ease of use, and the patients' satisfactions should be studied.

The "as low as reasonably achievable" principle in the radiation dose is required in all human radiography. To an extent, a dental instrument newly developed may play an important role in the treatment quality. Our results suggested that the newly designed holder supported the students during their horizontal tube-shift radiography, in accordance with the zero cone-cutting error and the time significantly saved. Dentists with several years of experiences may not need the instrument to avoid cone-cutting errors or to save time in the tube-shift periapical radiography. However, its aid is helpful for the treatment in some patients that requires a more consistent evaluation of some changes in the pathologic lesions, as well as the root length or width in a regenerative endodontics of the multirrooted teeth [30] for outcome assessments. Because of the all plastic body without metal component, this newly designed holder weighed only 11.5 g, was half as heavy as the standard type, and prevented the image superimpositions. Moreover, its U-shaped aiming rod did not interfere with the mouth corner during the distal shift projection. This innovative device effectively reduced such errors and the treatment time which were beneficial to both the patients and the dental personnel. Further research and development are required to make this film holder applicable to all teeth and those with a rubber dam clamp.

5. Conclusions

Under this study's conditions, periapical radiography by the dental students using the horizontal tube-shift technique with the angulation-adjustable holder caused no cone-cutting error and a significant reduction of the times for an X-ray cone alignment, when compared to those using the XCP instrument.

Declarations

Author contribution statement

Peraya Puapichardumrong: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Nongnapat Eakpunyakul; Suphakarn Tanpumprathet; Pimrekha Khueankaew; Priawwan Saelim: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Thosapol Piyapattamin: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare the following conflict of interests: Peraya Puapichardumrong has a petty patent number 14057 (angulation-adjustable film holder).

Additional information

No additional information is available for this paper.

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