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An intrarater/interrater reliability and agreement study comparing techniques for evaluating root canal curvature using periapical radiographs

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ABSTRACT

Background

Based on patient periapical (PA) radiographs, this study sought to assess the degree of agreement between four methods for measuring root canal curvature in first and second molars.

Method

This study investigated intra and interrater reliability and agreement, involving 150 root canals from the first and second molars of 103 patients. Radiographs were obtained from two dental imaging centers through convenience sampling, and each radiograph was assigned two unique identifiers to ensure blinding in measurements. An oral and maxillofacial radiologist and three dental students, who received training from the oral and maxillofacial radiologist, independently measured the curvature angles of all the canals using four different measurement techniques. In the initial round, each observer completed 600 measurements. After a ten-day period, the students repeated their measurements independently to evaluate consistency. The collected data were analyzed using SPSS version 26 and MedCalc version 23.2.7.

Results
With varying standard deviations, the average curvature angles determined by the Schneider, Hankins & ElDeeb, Weine, and Luiten techniques were roughly 21.70° (± 12.62°), 21.81° (± 13.77°), 27.51° (± 18.07°), and 30.63° (± 18.95°), respectively. The Luiten approach showed the best overall interrater agreement at 0.969, Schneider at 0.921, Hankins & ElDeeb at 0.935, and Weine at 0.949. Schneider (0.939) and Hankins & ElDeeb (0.938) were less consistent than Weine (0.967) and Luiten (0.966) in terms of intrarater reliability. Schneider and Weine (0.909) and Weine and Luiten (0.963) had the highest interrater agreement, whereas Schneider and Hankins & ElDeeb (0.575) had the lowest, according to pairwise comparisons. Additionally, Schneider and Luiten (0.876) and Weine and Hankins & ElDeeb (0.721) showed good agreement.

Conclusions

All four measuring approaches exhibited exceptional concordance, suggesting their dependability in assessing root canal curvature. Nonetheless, the Luiten approach may be the most reliable option for clinical application given the maximum interrater agreement found with it, particularly in circumstances demanding accurate and repeatable measurements. To improve treatment planning accuracy and results, clinicians are recommended to think about implementing the Luiten method or choosing a methodology that best fits their unique clinical situation.

Keywords
Root canal curvature, Periapical radiographs, Agreement coefficient, Schneider, Weine, Luiten

INTRODUCTION

The success of endodontic treatment is greatly influenced by the root canal's morphology. The likelihood of lodgement increases from 12.5% to 52.3% when the root canal's curvature is increased from less than 5 degrees to more than 20 degrees [1]. A canal angle more than 45 degrees is a crucial component in the British Endodontic Society's classification of endodontic cases as Level 3 complexity for treatment[2]. Because it reduces procedural errors and post-treatment problems, a precise assessment of root canal curvature is essential for efficient treatment planning and instrumentation. Canal curvature on radiographs can be measured using a number of techniques, each with unique advantages and disadvantages [3–5]. A thorough analysis of canal designs, including measures of length, curvature, and the location of calcified segments, was made possible by micro-CT and AI-assisted techniques [6–14]. Nonetheless, PA radiography continues to be one of the most widely available, useful, and frequently used methods for evaluating root canal architecture [15]

Because PA radiographs are easily accessible and offer detailed pictures of the root structures, they are commonly utilised in clinical practice to evaluate root canal architecture [16]. Numerous approaches, including the Schneider, Weine, Hankins & ElDeeb, and Luiten methods, have been developed to assess canal curvature from these radiographs [4]. Although these methods are widely used, there is little research comparing how consistently they agree with one another, particularly with regard to intra and interrater reliability, which are crucial for determining their usefulness in clinical practice. By clarifying the reliability of commonly used radiographic assessment methods, the findings also contribute to the existing literature. In the end, this understanding improves the accuracy of root canal curvature assessments, supporting improved clinical outcomes in endodontic practice.

To the best of our knowledge, prior research on this subject has mostly used in-vitro techniques, despite the fact that laboratory studies have looked at the consistency of root canal measurement techniques in the literature (e.g., Faraj,[17] ; Faraj,[18] ; Gay,[19] ; Hartmann et al.[20]). Because of this, the degree of agreement between various approaches in clinical situations is still unknown and has not been conclusively addressed.

It is vital to conduct pertinent study to improve the current body of knowledge by producing data that are pertinent to actual clinical settings as comprehending these agreements is critical for guaranteeing diagnostic consistency, treatment accuracy, and patient safety. This is especially significant since the findings provide dental professionals with solid and useful evidence for the first time, enabling them to implement accurate methods for evaluating root canal angles during regular clinical practice. The purpose of this study is to compare the accuracy of four radiographic measurement methods for determining root canal curvature in first and second molars: Schneider [21], Hankins & ElDeeb[22], Weine[23], and Luiten[24] .

METHODS

This study is documented using the GRRAS (Guidelines for Reporting Reliability and Agreement Studies) criteria. It acts as a mechanism to guarantee that research evaluating measurement agreement and reliability are fully and openly disclosed. In order to enable proper evaluation and interpretation of the results, the GRRAS highlights the significance of providing comprehensive information on the procedures, participants, and statistical analyses used[25]. The Guilan University of Medical Sciences Research Ethics Committees approved the study protocol (IR.GUMS.REC.1404.022), and it was carried out in compliance with the Declaration of Helsinki's ethical guidelines.

Study Design, settling and sampling

From January to June of 2025, Guilan University of Medical Sciences did this study on intrarater/interrater reliability and agreement. Two maxillofacial radiography centres that provide both general and specialised services to the general population provided the PA radiographs required for this study. Using the sample size determination formula for the Intraclass Correlation Coefficient created by Zou[26] , the minimum sample size for this study was determined to be 150 root canals from first and second molars for each procedure based on the study objectives and parameters.

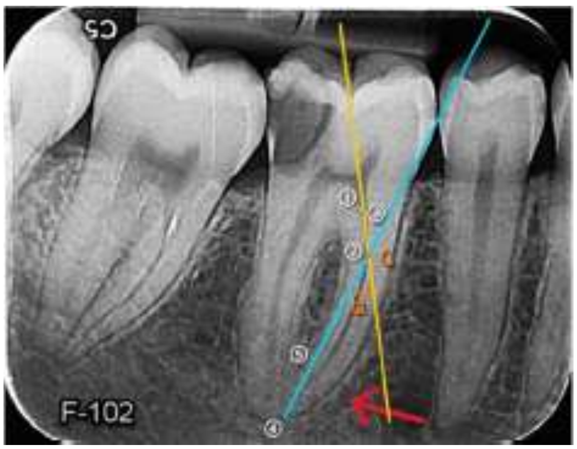

Fig. 1 Illustration of Schneider method measurement

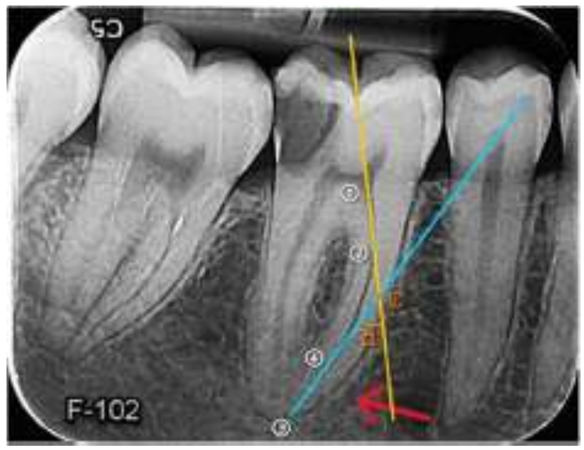

Fig. 2 Illustration of Weine method measurement

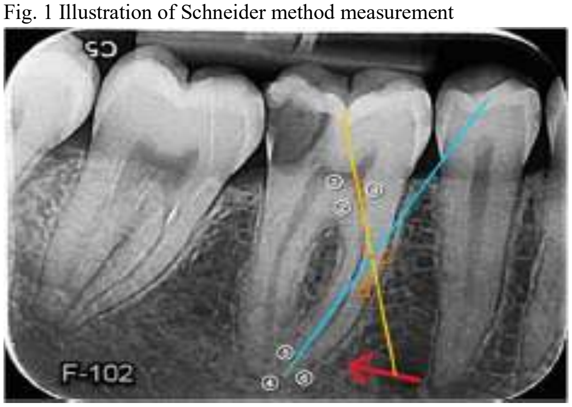

Fig. 3 Illustration of Luiten method measurement

Expected reliability (Intraclass Correlation Coefficient - ICC) (ρ):0.77.
Number of raters/repetitions per subject (k): 4.
Precision (± expected): 0.05.
Confidence level 100(1 - α): 95%
Using a convenience sampling method, 103 PA radio graphs were selected in reverse chronological order, starting with the most recent. These radiographs must have met all of the following criteria:

- PA radiographs of first and second molars (maxillary or mandibular) with clear and fully visible roots.

• Radiographs taken using the parallel technique.
• Radiographs with no image distortion or elongation/ foreshortening.
• The roots of the teeth were separated.
• Root formation was complete.
• There was no post inside the root canal.
• No root canal treatment.
• No root resorption or calcification.

Canal curvature and measurements

The Planmeca X-ray unit (Helsinki, Finland) used the parallel approach to take the pictures used in this investigation. The methods described by Schneider[21] , Weine[23] , Luiten et al.[24] , and Hankins & ElDeeb[22] were followed when measuring curvature.

Figures 1, 2, 3 and 4 illustrate each method applied to the same initial PA radiograph.

Each root canal was given two identifiers—one for the first measurement round and another for the second—to guarantee blinding during the two measurement sessions. Using all four techniques (Schneider, Weine, Luiten, and Hankins & ElDeeb), four observers—a maxillofacial radiologist and three sixth-year dentistry students—separately measured the curvature angle of

Fig. 4 Illustration of Hankins & ElDeeb method measurement

each root canal. According to the dental education curriculum, every student participating in this study had successfully completed a minimum of 11 credits in endodontics, which included two theoretical coursework and five clinical training credits, as well as five credits in oral and maxillofacial radiology, which included two theoretical and three practical courses.

Additionally, the co-investigator, an oral and maxillofacial radiologist, trained these observers, providing a thorough description of each technique along with pertinent pictures and videos for reference. Each observer evaluated the curvature values on ten randomly chosen PA radiographs to verify that they understood the procedures. The measurements have a 0.7 degree of agreement. Following calibration, four evaluators—OB1, OB2, OB3, all dental students, and OB4, a maxillofacial radiology expert (FO)—performed the initial round of measurements independently. With roughly ten days between repetitions of the identical procedure, the students conducted a second round of measurements independently for the full sample. They were instructed to take into account two approaches in order to lessen observer fatigue and guarantee data accuracy and consistency. First, to reduce physical and mental fatigue, take measurements within the allotted times with scheduled breaks. Even during these planned measuring periods, it was highly advised that they take breaks whenever they were tired. Second, switch up your responsibilities frequently to avoid concentrating on one thing for too long. The ICC using a two-way mixed effects model was used to evaluate the consistency of measurements both within and between examiners.

STATISTICAL ANALYSIS

The data were analyzed using Statistical Package for Social Science (SPSS) version 26 and MedCalc 23.2.7. The degree of canal curvature and observer variability were summarized using descriptive statistics. The two-way mixed effects, consistency, multiple raters/measurements ICC [27, 28] with a 95% confidence interval was used to evaluate the intrarater and interrater agreement for each measurement technique. The following is how ICC values were interpreted: (a) ICC < 0.5 indicates poor agreement; (b) ICC between 0.5 and 0.75 indicates moderate agreement; (c) ICC between 0.75 and 0.9 indicates good agreement, and (d) Outstanding agreement: ICC >0.9. The Freidman test, an appropriate distribution-free test, was employed to compare curvature angles recorded by the four methods because the study data does not follow a normal distribution. When the premise of normalcy is not met, related samples can be analyzed using the Friedman test, a non-parametric technique. In these circumstances, the Friedman test yields more accurate and trustworthy statistical results[30]. Bland-Altman, the preferred approach for method comparison, conducted pairwise comparisons comparing root canal curvature techniques[31]. Statistical significance was defined as a p-value of less than 0.05.

RESULTS

Table 1 displays the descriptive statistics of the curvature angles for the methods, including their distribution, mean in degrees, standard deviations (SD), and maximum, minimum, and range values. Weine and Luiten measured larger average curvature angles (~27.55° and 30.63°, respectively) than Schneider and Hankins & ElDeeb (~21.70° and 21.81°). Weine and Luiten's standard deviations (SDs) were significantly higher, suggesting that their measurements were more variable. Particularly with Luiten, the maximum angles reached 111°, indicating some extremely high curvature measurements.

The Freidman test was used to compare the four approaches since the Kolmogorov-Smirnov test results showed that the assumption of normality for ANOVA was not met. The results showed that there were notable differences between the canal curvature angles calculated using the four approaches used in this investigation. (F = 153.53). All comparison pairings, with the exception of Schneider-Hankins & ElDeeb, indicated a significant difference in the measurements, according to the pairwise comparison of methodologies (Fig. 5). The curvature angle distribution details and interrater and intrarater reliability for the various techniques and observers are shown in Table 2.

	Schneider	Weine	Luiten	Hankins and ElDeeb
Mean	21.70	27.55	30.63	21.81
Standard Deviation	12.62	18.07	18.95	13.77
Median	20.70	25.03	30.49	19.31
Max	62.59	101.65	111.01	95.46
Min	1	1	0	0
Range	61.59	100.65	111.01	95.46

Table 1 Curvature angle measurements according to the different methods

Measurements made by the same observer were quite consistent, as evidenced by the good intrarater reliability across approaches (ICC>0.85). Additionally, all approaches have strong interrater reliability (ICC>0.90), indicating that various observers generally agree on their measurements and boosting the methods' reproducibility. The comparison data, which includes the mean difference, the ICC, p-values, the maximum and minimum differences, the percentage of cases with discrepancies between measurements of less than 10 degrees, and the effect size calculations, are shown in Table 3.

Table 3 shows that the comparisons between Schneider and Hankins & ElDeeb (−63.07°) and Schneider and Luiten (−59.07°) showed the most variations in curvature angles. Every pair displayed a minimum difference of almost zero. Weine against Luiten had the greatest percentage of angles showing a difference of less than 10° (83.83%). At −1.43, this pair likewise has the second-lowest mean differences. On the other hand, there were only 26% of fewer than 10° deviations in the comparison between Luiten and Hankins & ElDeeb. Based on previous research[20] and clinical significance, a 10-degree difference was chosen as the limit in Table 3.A useful baseline for differentiating between little variations and significant alterations that can have clinical ramifications is a 10-degree threshold. The paired study reveals that there are differences in the methodologies' agreement. Weine and Luiten had the greatest ICC (0.909), which indicates strong agreement. Luiten and Hankins & ElDeeb comparisons revealed greater mean variances and intermediate agreement, with some techniques deviating by more than 50°.

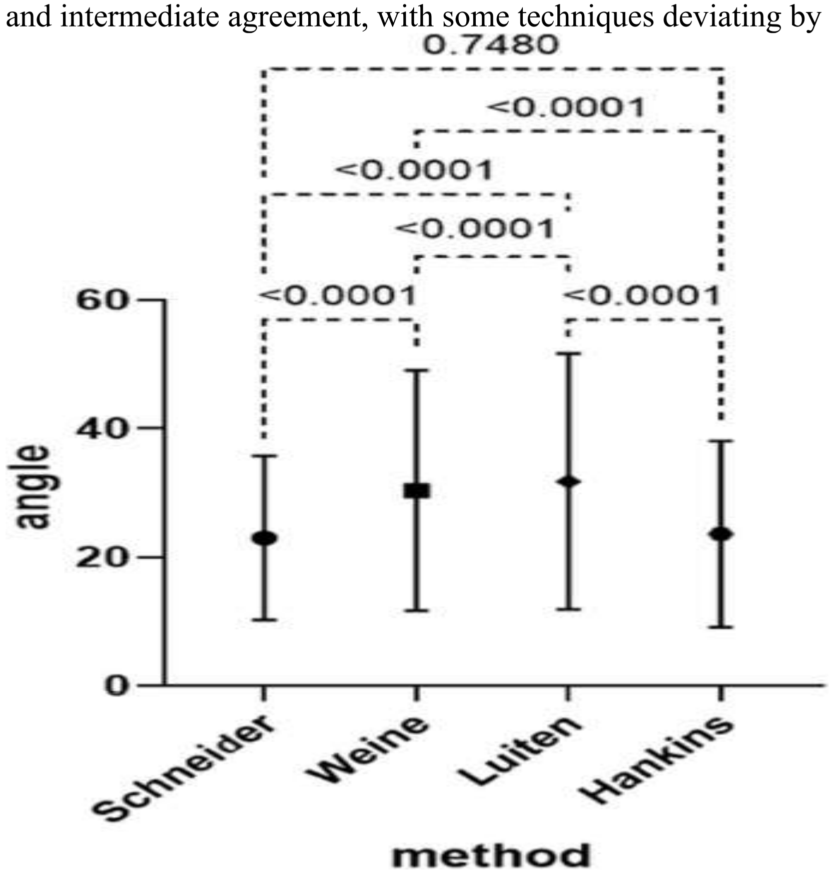

Fig. 5 Comparison of root canal curvature methods. Descriptive statistics (means, represented as dots, ±SDs represented as bars) for Schneider, Weine, Luiten and Hankins & ElDeeb methods. Dot-bars indicate the differences between methods at α = 0.05

When compared to Schneider's approach, the Bland-Altman plots (Fig. 6) further show that method differences tend to rise with more acute angles, which may indicate measurement bias or method-specific sensitivity for high-curvature canals. The Bland-Altman graphs for each approach are shown in Figure 6. These charts show the disparities between measurements on the y-axis and the mean angular values on the x-axis. Every plot contrasts two approaches. The Weine and Luiten techniques tend to exhibit an increasing disparity as the angles get more sharp when compared to Schneider's method. Weine-Luiten and Schneider-Hankins & ElDeeb method pairs exhibit linear fluctuations, keeping a constant difference at both smaller and greater angles.Compared to the Luiten and Weine techniques, the Hankins & ElDeeb method tends to exhibit decreasing differences as the angles become more acute.

Table 2 Curvature angle measurements, intrarater and interrater reliability according to the different observers and methods

METHOD	OB	MEASUREMENT	MEAN	SD	MIN	MAX	RANGE	Intrarater reliability ICC (CI 95%)	Interrater reliability ICC (CI 95%)
Schneider	OB1	1st	22.96	12.59	2.66	56.24	53.58	ICC=0.989	ICC=0.921
		2nd	22.79	12.06	2.91	53.32	50.41	CI(0.984–0.992)	CI(0.898–0.940)
	OB2	1st	23.24	13.10	2.12	59.25	57.13	ICC=0.959	
		2nd	23.76	13.34	1.74	57.78	56.04	CI(0.943–0.970)	
	OB3	1st	22.72	12.59	3.60	58.00	54.40	ICC=0.896	
		2nd	27.36	15.14	2.91	76.82	73.91	CI(0.857–0.925)	
	OB4	1st	17.88	11.49	1.00	62.59	62.59		
		2nd							
Weine	OB1	1st	30.49	18.41	1.77	86.71	84.94	ICC=0.994	ICC=0.949
		2nd	29.98	18.34	0.80	86.86	86.06	CI(0.992–0.995)	CI(0.934–0.961)
	OB2	1st	29.79	18.04	1.83	81.25	79.42	ICC=0.960	
		2nd	29.05	17.73	2.30	83.76	81.46	CI(0.945–0.971)	
	OB3	1st	30.77	19.70	2.54	101.65	99.11	ICC=0.948	
		2nd	29.73	18.18	2.72	100.20	97.48	CI(0.928–0.962)	
	OB4	1st	19.16	12.88	1.00	63.18	62.18		
		2nd							
Luiten	OB1	1st	32.25	20.05	1.18	96.15	94.97	ICC=0.994	ICC=0.969
		2nd	32.43	30.32	1.01	93.37	92.36	CI(0.992–0.996)	CI(0.960–0.976)
	OB2	1st	31.29	19.26	2.49	87.35	84.86	ICC=0.953	
		2nd	30.45	18.37	2.56	79.46	76.90	CI(0.935–0.966)	
	OB3	1st	31.80	20.43	2.77	111.01	108.24	ICC=0.947	
		2nd	30.58	18.94	1.55	111.72	110.17	CI(0.927–0.962)	
	OB4	1st	27.16	15.39	0	75.00	75.00		
		2nd							
Hankins & ElDeeb	OB1	1st	23.58	14.47	0	77.37	77.37	ICC=0.988	ICC=0.935
		2nd	22.18	14.86	0	82.89	82.89	CI(0.983–0.991)	CI(0.916–0.951)
	OB2	1st	23.43	13.53	1.18	70.31	69.13	ICC=0.943	
		2nd	22.23	12.91	1,21	62.93	61.72	CI(0.921–0.959)	
	OB3	1st	23.75	15.43	0	95.46	95.46	ICC=0.871	
		2nd	21.43	12.03	2.11	85.12	82.97	CI(0.822–0.907)	
	OB4	1st	16.47	09.68	1.02	60.90	59.88		
		2nd							

OB Observer, 1ST First round of measurement, 2nd Second round of measurement

Table 3 Pairwise comparison of the angle measurements based on the different methods

	Max. Dif.	Min. Dif.	Dif. <10°	Mean Dif.	ICC	P-value	Effectsize
Schneider vs. Weine	-55.07	0	72.33%	-7.37	0.909	< 0.001	0.375
Schneider vs. Luiten	-59.07	0	54.83%	-8.80	0.876	< 0.001	0.554

Schneider vs. Hankins-ElDeeb	-63.07	0.01	53.50%	-0.61	0.575	< 0.001	-0.008
Weine vs. Luiten	-31.59	0	83.83%	-1.43	0.963	< 0.001	0.165
Weine vs. Hankins-ElDeeb	-55.07	0	38.33%	6.76	0.721	< 0.001	-0.357
Luiten vs. Hankins-ElDeeb	-39.99	0.01	26.00%	8.19	0.676	< 0.001	-0.532

Bold Excellent agreement values for ICC (no significant differences between groups in p- values; large effect size) Abbreviation: ICC Intraclass correlation coefficient

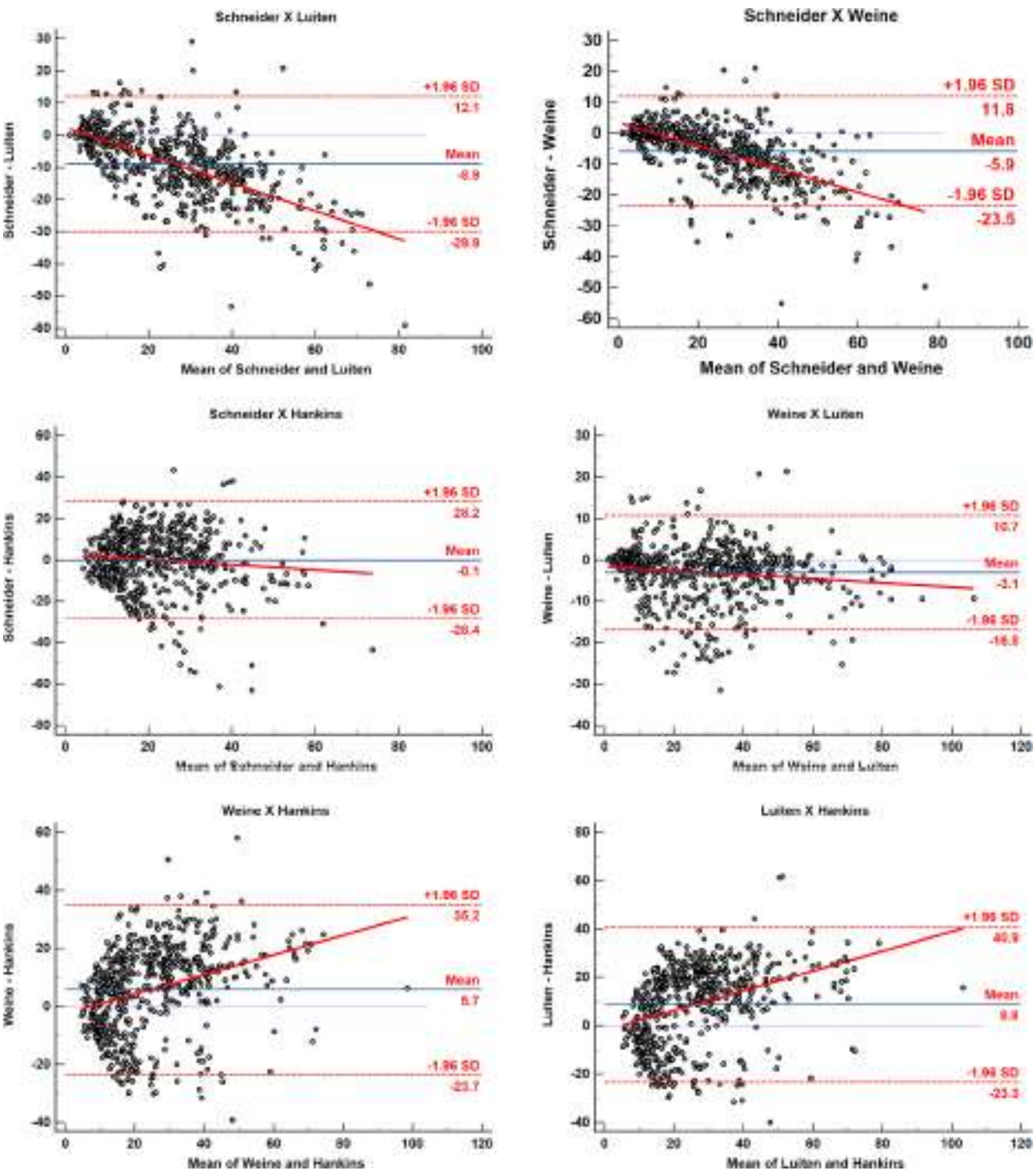

Fig. 6 Bland–Altman plots pair comparisons between root canal curvature methods

DISCUSSION

With a focus on their reproducibility, this work provides a thorough comparative evaluation of the root canal curvature assessment techniques put out by Schneider [21], Weine [23], Luiten et al. [24], and Hankins & ElDeeb [22]. For every approach, the results demonstrated exceptional consistency (correlation coefficients more than 0.90) among observers. This is in line with the findings published by Zhu et al.[32] and Hartmann et al.[20] . The Schneider method's simple approach, as recommended by Zhang[33] and Balani et al.[1] , probably contributed to its overall reliability even though it showed the lowest degree of agreement among the four methods examined. Crucially, when compared to the other assessed methods, the Schneider method also showed the highest favourable confidence interval.

Excellent agreement was also found when the Weine method's interrater consistency was evaluated. According to earlier research, the Weine method produces more reliable results than alternative approaches, especially when image quality is subpar. It is a practical choice for both clinical practice and research due to its simplicity, effectiveness, and high reliability [32]. When evaluating the Luiten method's agreement, it showed the highest degree of interrater agreement (ICC=0.969). Its well-defined reference points and division of the canal course into two measurable sections, which lower interpretation errors in gradually curved canals, may be the cause of this high reliability. Luiten's had the narrowest confidence interval (0.960–0.976) and the lowest standard deviation of all the approaches, suggesting good consistency between raters and repetitions. As a result, it seems to be the most reliable and repeatable approach in the current study, which makes it ideal for studies that need to reduce observer bias and improve consistency as well as for physicians' everyday practice.

The Hankins & El Deeb approach scored second in agreement after the Schneider method, while showing a high degree of agreement (ICC=0.935). This method's somewhat reduced repeatability may be explained by challenges in precisely defining the tooth's long axis, particularly for less skilled examiners. Additionally, this constraint may have an impact on the overall agreement results because this method only evaluates the apical region of the canal and ignores the curvature in the coronal segment.

All of the four approaches showed good to exceptional interrater agreement when compared. These results are consistent with those of Hartmann et al[20] , who found good agreement between six root curvature assessment techniques in an in vitro environment. The Schneider, Weine, and Pruett approaches also showed good agreement, according to Faraj & Botsioukis[18] .

Weine and Luiten had the best agreement amongst technique pairings (0.963), followed by Schneider and Weine (0.909). Schneider and Hankins & ElDeeb had the least amount of agreement (0.575). Schneider and Luiten's (0.876) and Weine and Hankins & ElDeeb's (0.721) agreement was deemed satisfactory.

These results are in line with earlier research by Hartmann et al[20] and Nagmood et al.[34] , who also observed outstanding reproducibility among quantitative root curvature assessment techniques. Notably, the current investigation was carried out clinically utilising radiographic images, whereas the two earlier studies were laboratory-based and used extracted teeth. Our study's high-quality imaging was guaranteed by strict inclusion requirements, such as clear visualisation of the canal from orifice to apical foramen. This reduced error in identifying reference points and drawing lines, thereby improving reproducibility and agreement.

Schneider and Weine techniques were shown to have a significant correlation (r = 0.83) in the study by Gunday et al[19] . The agreement between these two approaches in the current investigation was 0.909, which is marginally higher and in line with their conclusions. Nevertheless, Gunday's analysis was restricted to 100 mandibular molars, which decreased the sample's analytical variability[19] . The current study, on the other hand, comprised 150 examples of both mandibular and maxillary molars, providing a wider variety of curvature patterns. This anatomical variability might be seen as a strength of the current study in confirming the accuracy of quantitative techniques for measuring root curvature.

Zhu et al.'s study[32] investigated the Schneider and Weine methods' repeatability on premlars. Despite the claimed positive agreement and repeatability, methodological constraints should be taken into account when interpreting the results. Because of their broader canals and simpler architecture than molars, premolars may have less accurate central positioning of endodontic files on radiographs. As a result, the positive outcomes of their investigation may not accurately represent the difficulties in assessing curvature in more intricate molar canals, which are the subject of the current study.
In addition to the aforementioned points, visual estimation of root canal curvature—which is still frequently used by many clinicians—has been shown to be an unreliable approach for curvature assessment, as shown in the study by Faraj & Boutsionis[18] . Despite the variation in agreement coefficients among quantitative methods, such as those proposed by Schneider, Weine, Luiten, and Hankins & ElDeeb, these techniques offer a far more objective and reliable alternative to visual approximation. In other words, the results of multiple studies not only highlight the relatively high reliability of quantitative methods, but also show that using measurable indices can reduce discrepancies resulting from subjective interpretation in curvature measurement.

According to our findings, the Luiten method yielded the highest inter-examiner and intra-examiner agreement among the methods tested, suggesting a high level of reproducibility. This could first be seen as a sign of better accuracy. A more thorough examination, however, shows that in situations with particular anatomical configurations, this approach has distinct clinical limits. For instance, the Luiten method tends to underestimate the true curvature and may report a nearly zero-degree angle in teeth where the canal extends from the orifice in a relatively straight path but deviates significantly in a mesial or distal direction from the tooth's longitudinal axis because it lacks a mechanism to detect angular shifts between its defined reference points (from the orifice to 2 mm apically and from the apical foramen to 1 mm coronally).In situations where the canal follows a continuous curved path, the approach fails to adequately depict the full extent of curvature since it only considers sudden angular shifts within short segments rather than assessing the canal's overall directional deviation. This restriction is important from a clinical standpoint. Such canals may be incorrectly categorised as "straight" if the Luiten method is the only one used. This increases the risk of procedural errors, such as furcal perforation, especially during initial root canal instrumentation, because the file and the actual canal trajectory are not properly aligned.

The Hankins & ElDeeb method, on the other hand, showed a lower agreement coefficient than Luiten but performed better in detecting overall canal deviation in such cases. This method estimates curvature based on the angle between the tooth's longitudinal axis and a line parallel to the apical third of the canal. This could be because, instead of concentrating only on sudden directional changes, the Hankins & ElDeeb technique assesses the angular difference between the tooth's global orientation and the canal's final trajectory. Because of this, this method catches a substantial angle even in the absence of a noticeable curvature (i.e., when the canal exhibits a uniform angular deviation), giving a more accurate representation of the canal's actual shape.

It is suggested that a more thorough classification of root curvature patterns be developed, based on a combination of curvature location, number of deflection points, and overall angulation relative to the tooth's long axis. Once standardised, such a classification could serve as a reference for choosing the most appropriate measurement technique for each anatomical type, thereby improving diagnostic accuracy and treatment prognosis. Taken together, these findings suggest that although the Luiten method offers advantages in terms of repeatability and ease of application in conventional radiographic imaging, it is insufficient in identifying clinically significant deviations, such as dilacerations or gradual curvatures.

CLINICAL RELEVANCE

The Hankins & ElDeeb approach seems to be the best for dilacerations since it can catch sudden changes in the direction of the canal. Both the Luiten and Weine approaches show greater applicability for curvatures in the coronal third because they take measurements inside the canal's coronal region. Because the Hankins & ElDeeb approach is sensitive to deviations in the apical region, it again works better when the curvature is concentrated in the apical third. However, for canals exhibiting various curvatures, none of the examined approaches is adequately capable of accurately capturing the full canal morphology. Clinicians should pay close attention to this issue since failing to do so might result in problems including misclassification-related perforation risk.

Despite all of these suggestions, it may be possible to increase accuracy and consistency in clinical practice by combining or comparing several measuring techniques early on, possibly even during the initial evaluation. Early integration of several approaches may allow practitioners to improve overall treatment planning, cross-validate outcomes, and choose the best approach based on preliminary findings.

Policy-level implications

It is important to incorporate standardized root canal curvature measurement techniques, like the Luiten method, into dentistry curriculum and postgraduate training programs due to the high reliability and agreement shown by the various measurement methods. By ensuring that future practitioners have access to recognized and trustworthy techniques for evaluating root canal curvature, this integration will ultimately improve treatment results and diagnostic accuracy. Additionally, in order to promote uniformity across clinical settings, continuing education courses for practicing endodontists should stress the significance of choosing measurement techniques with proven high agreement. Standardization and a decrease in endodontic care variability may be achieved by establishing standards that support certain, evidence-based assessment techniques.

Limitations

There are several restrictions on this study. The kind of radiography used in this study is one of its main drawbacks. The buccolingual curvature of root canals could not be seen since PA imaging is inherently two-dimensional. Another issue was the dependency of measured values on observer proficiency; although repeated measurements helped improve data dependability, observer tiredness due to the huge number of samples likely altered the conclusions. Another significant drawback is the inability to compare the outcomes with gold-standard imaging techniques like CBCT. The combination of convenience sampling and retrospective selection may induce selection bias. Furthermore, considering the multiple inclusion criteria in the study, the generalizability of the results may have been limited.

Given that all the evaluated procedures in this study require vision of the apical part of the root canal, extra attention should be used when applying them to maxillary molars. This restriction led to an uneven distribution of samples between mandibular and maxillary molars in the current investigation (123 mandibular molars vs. 27 maxillary molars). The results should be interpreted cautiously because the data distribution in this investigation did not follow a normal distribution and the assumption of equal variances was validated at the 0.01 significance level.

RECOMMENDATION

In order to better understand how varying levels of experience or training affect measurement reliability and agreement, we recommend performing subgroup analyses by observer type in subsequent studies.

For future investigations, it is advisable to select photos where the root canals are clearly visible, with sufficient contrast. To lessen observer fatigue, measurements should be made in increments of twenty. Furthermore, it is best to examine photos in a controlled, low-light setting with a minimum resolution of 1024 x 768 pixels.

Conclusion

Excellent inter- and intrarater agreement was shown by the four techniques assessed in this study for determining root canal curvature in first and second molars. Excellent agreement was found in pairwise comparisons between Weine and Luiten, Schneider and Weine, Schneider and Luiten, and Weine and Hankins & ElDeeb. On the other hand, Schneider versus Hankins & ElDeeb and Luiten versus Hankins & ElDeeb showed the most differences.

Overall, it can be said that quantitative techniques for determining root canal curvature angles are much better than visual assessment based on the literature review and the current study's findings. However, a comprehensive clinical approach is necessary because of the variations among the quantitative approaches themselves and their intrinsic limits in accurately assessing root canal curvature. This should entail combining information from various measurement methods[35] with direct clinical observations and three-dimensional imaging evaluations.

Furthermore, it is advised that relevant guidelines and training programs be designed and implemented to promote and educate general dentists and dental students on the use of quantitative measurement methods.

References

1. Balani P, Niazi F, Rashid H. A brief review of the methods used to determine the curvature of root canals. J Res Dent. 2015;3(3):57–63.
2. Tomson P. A guide to good endodontic practice. London: British Endodontic Society; 2022. p.47–56.
3. Habib AA, Taha MI, Farah EM. Methodologies used in quality assessment of root Canal Preparation techniques: review of the literature. J Taibah Univ MedSci. 2015;10(2):123–31.
4. Hartmann RC, Fensterseifer M, Peters OA, de Figueiredo JAP, Gomes MS, Rossi-Fedele G. Methods for measurement of root Canal curvature: a systematic and critical review. Int Endod J. 2019;52(2):169–80.
5. Hema B, Saxena R, Agrawal K. Methods to determine root Canal curvatures and its managements. J Res Adv Dent. 2020;10(2):126–32.
6. Ghiasi M, Zaboli A, Mahdian M, Mallya SM. Artificial Intelligence for Root Canal Segmentation on Radiographic Images: a scoping review. 2025.

7. Zheng MWL. Assessment of consistency detection in mandibular first premolars root Canal morphology using U-net model: evaluation with dice coefficient and intersection over Union–A pilot study. University of Malaya (Malaysia); 2024.
8. Duman ŞB, Çelik Özen D, Bayrakdar IŞ, Baydar O, Alhaija ESA, Helvacioğlu Yiğit D, Çelik Ö, Jagtap R, Pileggi R, Orhan K. Second mesiobuccal Canal segmentation with YOLOv5 architecture using cone beam computed tomography images. Odontology. 2024;112(2):552–61.
9. Park J-W, Lee J-K, Ha B-H, Choi J-H, Perinpanayagam H. Three-dimensional analysis of maxillary first molar mesiobuccal root Canal configuration and curvature using micro–computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endodontology. 2009;108(3):437–42.
10. Baratto Filho F, Zaitter S, Haragushiku GA, de Campos EA, Abuabara A, Correr GM. Analysis of the internal anatomy of maxillary first molars by using different methods. J Endod. 2009;35(3):337–42.
11. Latke V, Narawade V. Enhancing endodontic precision: a novel AI-powered hybrid ensemble approach for refining treatment strategies. Int J Intell Syst Appl Eng. 2023;11(11s):73–84.
12. Al-Rammahi HM, Chai WL, Nabhan MS, Ahmed HMA. Root and Canal anatomy of mandibular first molars using micro-computed tomography: a systematic review. BMC Oral Health. 2023;23(1):339.
13. Martins JNR, Versiani MA. Worldwide assessment of the root and root Canal characteristics of maxillary Premolars - A Multi-center Cone-beam computed tomography Cross-sectional study with Meta-analysis. J Endod. 2024;50(1):31–54.
14. Xu M, Ren H, Liu C, Zhao X, Li X. Systematic review and meta-analysis of root morphology and Canal configuration of permanent premolars using cone beam computed tomography. BMC Oral Health. 2024;24(1):656.
15. Patil B, Ali A, Ivin S, Kamatagi L. Methods used to determine the curvature of root canals: A review. Int J Pure Med Res. 2020;5(4):1–5.
16. Setzer FC, Lee S-M. Radiology in endodontics. Dent Clin. 2021;65(3):475–86.
17. Faraj BM. Estimation accuracy of root canal curvatures from different dental diagnostic imaging techniques: an in vitro experimental study. Biomed ResInt. 2021;2021:6699635.
18. Faraj S, Boutsioukis C. Observer variation in the assessment of root Canal curvature. Int Endod J. 2017;50(2):167–76.
19. Günday M, Sazak H, Garip Y. A comparative study of three different root Canal curvature measurement techniques and measuring the Canal access angle in curved Canals. J Endod. 2005;31(11):796–8.
20. Hartmann RC, Ferraz ES, Weissheimer T, Poli de Figueiredo JA, Rossi-Fedele G, Gomes MS. Comparative analysis of methods for measuring root Canal curvature based on periapical radiography: A laboratory study. Int Endod J. 2024;57(12):1848–57.
21. Schneider SW. A comparison of Canal preparations in straight and curved root Canals. Oral Surg Oral Med Oral Pathol. 1971;32(2):271–5.

22. Hankins PJ, ElDeeb ME. An evaluation of the Canal master, balanced-force, and step-back techniques. J Endod. 1996;22(3):123–30.
23. Weine FS, Smulson MH. Endodontic therapy. Saint Louis. MO: MOSBY; 1982.
24. Luiten DJ, Morgan LA, Baumgartner JC, Marshall JG. A comparison of four instrumentation techniques on apical Canal transportation. J Endod. 1995;21(1):26–32.
25. Kottner J, Audigé L, Brorson S, Donner A, Gajewski BJ, Hróbjartsson A, Roberts C, Shoukri M, Streiner DL. Guidelines for reporting reliability and agreement studies (GRRAS) were proposed. J Clin Epidemiol. 2011;64(1):96–106.
26. Zou GY. Sample size formulas for estimating intraclass correlation coefficients with precision and assurance. Stat Med. 2012;31(29):3972–81.
27.Taherzadeh Chenani K, Farzan M. Guideline for selecting types of reliability and suitable Intra-class correlation coefficients in clinical research. J Biostatistics Epidemiol. 2021;7(3):305-09.
28. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016;15(2):155–63.
29. Portney LG, Watkins MP. Foundations of clinical research: applications to practice. Upper Saddle River, NJ: Pearson/Prentice Hall; 2009.
30. Hoffman JIE. Chap. 26 - Analysis of Variance. II. More Complex Forms. In: *Basic Biostatistics for Medical and Biomedical Practitioners (Second Edition)*. edn. Edited by Hoffman JIE: Academic Press; 2019: 419–441.
31. Mansournia MA, Waters R, Nazemipour M, Bland M, Altman DG. Bland-Altman methods for comparing methods of measurement and response to criticisms. Glob Epidemiol. 2021;3:100045.
32. Zhu Y-q, Gu Y-x, Du R, Li C. Reliability of two methods on measuring root canal curvature. Int Chin J Dent. 2003;3:118–21.
33. Zhang R, Hu T. Root Canal curvature. Int Endod J. 2010;43(7):616–8. Discussion 618–621.
34. Nagmode PS, Chavan KM, Rathi RS, Tambe VH, Lokhande N, Kapse BS. Radiographic evaluation of root Canal curvature in mesiobuccal Canals of mandibular molars by different methods and its correlation with Canal access angle in curved Canals: an in vitro study. J Conserv Dent. 2019;22(5):425–9.
35. Sadeghi S, Poryousef V. A novel approach in assessment of root Canal curvature. Iran Endod J. 2009;4(4):131–4.