Systematic Review Article

Accuracy of panoramic radiography in diagnosing maxillary sinus-root relationship: *A systematic review and meta-analysis*

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ABSTRACT

Objective: To investigate the accuracy of panoramic radiography (PR) in diagnosing maxillary sinus-root relationships (SRRs).

Materials and Methods: PubMed, EMBASE, CENTRAL, Web of Science, ScienceDirect, CBM, Baidu Scholar, and SIGLE were searched. The studies comparing the diagnostic accuracy of PR and computed tomography/cone-beam computed tomography (CT/CBCT) for SRR were included.

Results: Eleven studies were included. Meta-analyses showed that, for type I SRR, PR had the highest specificity, positive likelihood ratio (+LR), diagnostic odds ratio (DOR), and area under the curve (AUC), with a high sensitivity and a low negative LR (–LR). For type IV, PR had a high DOR and AUC, with the highest sensitivity but a low +LR, the lowest –LR, and the lowest specificity. For type II, PR had the lowest AUC, with a low sensitivity, +LR, and DOR and a high –LR. For type III, PR had the lowest sensitivity, +LR, and DOR and the highest –LR. The distance from root tips to the maxillary sinus floor on PR was significantly longer (mean difference: –1.88 mm; 95% confidence interval: –2.19 to –1.57; $P < .0001$) than that on CT/CBCT.

Conclusions: Currently available evidence suggests PR could be reliable for detecting type I SRR. PR has a good ability to confirm true type IV SRR but a poor ability to rule out false type IV SRR. For type II and III SRR, PR shows poor accuracy and tends to overestimate the extent of protrusion of the roots into the maxillary sinus. When PRs display type II, III, or IV SRR and related treatment is needed, CBCT should be used for further examinations. (*Angle Orthod.* 2018;88:819–829.)

KEY WORDS: Cone-beam computed tomography; Diagnosis; Maxillary sinus; Meta-analysis; Panoramic radiography; Systematic review

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INTRODUCTION

The maxillary sinus (MS) is the largest paranasal sinus, located in the posterior maxilla, and it has a close relationship with adjacent structures. With pneumatization, the MS floor (MSF) extends into the posterior alveolar process, creating protrusions of root apices into the sinus.[1] According to recent studies with cone-beam computed tomography (CBCT), individuals greatly vary regarding MSF morphology and sinus-root relationship (SRR). The incidence of roots protruding into the MS was 0% to 3.07%, 2.86% to 14.77%, 11.98% to 40.53%, and 9.6% to 44.70% for the first premolar, second premolar, first molar, and second molar, respectively.[1–7]

Complications regarding the SRR have been extensively reported in exodontia, endodontics, and implantology.[1] An increasing number of studies regarding the influence of the SRR on orthodontic treatment have been conducted in recent years, reporting common

Table 1. Search Strategies for All Databases (Updated on November 29, 2017)[a]

Step	PubMed, CENTRAL, EMBASE, CBM	Web of Science, ScienceDirect, Baidu Scholar, SIGLE
1	"Maxillary Sinus"[Mesh]) OR maxillary sinus	Maxillary Sinus
2	Cone-Beam Computed Tomography[MeSH] OR Cone-Beam Computed Tomography OR Cone-beam CT OR CBCT	Cone-beam computed tomography OR Cone-beam CT OR CBCT
3	"Radiography, Panoramic"[Mesh] OR Panoramic* OR Pantomograph* OR Orthopantomograph*	Panoramic* OR Pantomograph*
4	1 AND 2 AND 3	1 AND 2 AND 3

[a] CENTRAL indicates Cochrane Central Register of Controlled Trials; CBM, Chinese Biomedical Literature Database; SIGLE, System for Information on Grey Literature in Europe; MeSH, Medical Subject Headings.

complications such as tooth tipping, root resorption, prolonged treatment, and mini-screw risks.[8–11] An accurate diagnosis of SRR is important for predicting the feasibility, quality, and duration of comprehensive treatment and helps in formulating appropriate techniques and remedies before providing orthodontic treatment.

Panoramic radiography (PR) is currently the most frequently prescribed radiography for orthodontists to obtain comprehensive information about the dentition and the relationship between the teeth and adjacent structures. PR has the advantages of being low cost, providing a low dose of radiation, and being able to show a full view of multiple structures bilaterally. However, it is two-dimensional and presents certain drawbacks such as superimposition, magnification, ghost images, blurring, and curved structure spreading. In contrast, CBCT is a three-dimensional, multiplanar, and thin-sliced radiography and overcomes the disadvantages of PR.[1,12] The accuracy of linear measurements on CT/CBCT is comparable with that of macroscopic measurements.[13,14] However, the cost and radiation dose of CT/CBCT are higher than those of PR.[1,12]

In the past decade, several studies comparing the diagnostic accuracy of PR and CT/CBCT for SRR have been conducted,[12,15–24] but there has not been a systematic review. In the present study, CT/CBCT was used as the reference test, and a systematic review was carried out to investigate the diagnostic accuracy of PR for detecting SRR.

MATERIALS AND METHODS

This systematic review and meta-analysis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) checklist.[25] The literature search, data extraction, and quality assessment were performed independently by two authors. Any disagreements were resolved by discussion or by a third author.

Inclusion Criteria of Included Studies

Studies meeting the following criteria were considered eligible: (1) The study focused on permanent maxillary premolars and molars (except third molars) with fully formed apices and without periapical lesions. (2) The MSF was complete, not affected by disease or sinus augmentation. (3) The study compared the diagnostic accuracy of PR and CT/CBCT. (4) The study diagnosed SRR using the condensed classification proposed by Sharan and Madjar,[12] namely, type I: the root tip is not in contact with the MSF; type II: the root tip and the MSF are at the same horizontal level, and the root tip is in contact with the MSF; type III: the root tip is above the bottom of MSF and is projecting laterally on or enveloped by the MSF, but the root tip is not protruding into the sinus; and type IV: the root tip is protruding into the sinus cavity. (5) The primary outcome was true-positive (index, reference both positive), false-positive (reference negative, index positive), false-negative (reference positive, index negative), and true-negative (index, reference both negative), and the secondary outcome was the distance measured from the root tip to the inferior wall of MS ("+" indicating the root into and "–" out of the MS). (6) The study was a clinical study.

Search Methods

An electronic search was undertaken in databases PubMed, EMBASE, CENTRAL, Web of Science, ScienceDirect, CBM, Baidu Scholar, and the System for Information on Grey Literature in Europe (SIGLE). MeSH terms were combined with free-text words optimized for each database. The electronic search was updated on November 29, 2017, and had no language restrictions (Table 1). In addition, a manual search of reference lists of relevant studies was carried out for supplemental information.

Data Extraction and Analysis

Information about the characteristics and outcomes of the included studies was extracted. Specifically, the study characteristics were author, publication year, country, age, gender, sample size, tooth type, SRR classification, extractable SRR type, synthesis unit, and the index and reference test. The outcomes were the items defined in the inclusion criteria above.

Quality Assessment

The Quality Assessment of Studies of Diagnostic Accuracy-2 (QUADAS-2) was adopted for the quality assessment.[26] The assessment comprised the following four domains, all of which were evaluated for a risk of bias and the first three of which were assessed for applicability concerns: patient selection, index test, reference standard, and flow and timing.

Statistical Analysis

STATA 12.0 and RevMan 5.3 were used for meta-analyses. The outcomes, including sensitivity and specificity, were statistically pooled using a bivariate model and were adopted as effect measurements. The positive likelihood ratio (+LR), negative LR (–LR), and diagnostic odds ratio (DOR) were obtained according to the summary estimates of sensitivity and specificity. The summary reviewer-operator characteristic curve and the area under the curve (AUC) were used to reflect diagnostic efficiency. For continuous data, the meta-analysis was calculated by specifying mean difference (MD). The heterogeneity of the included studies was assessed with the I^2 statistic. A random-effect model was used for the meta-analysis if the heterogeneity was high ($I^2 > 50\%$). Otherwise (ie, $I^2 \leq 50\%$), a fixed-effect model was employed. Subgroup analyses and meta-regression were used to determine the potential sources of heterogeneity. Sensitivity analyses were performed to evaluate the robustness of the pooled results. The publication bias was assessed using funnel plots and the Deeks test.[27]

RESULTS

Description of Included Studies

A total of 879 records were initially retrieved from the literature search. Finally, 11 studies[12,15–24] were included in the systematic review and meta-analysis (Figure 1). Among the enrolled studies, 10 reported the diagnostic efficacy for type I, with a sample size of 1826 teeth and 4225 roots[12,15–22,24]; 10 investigated type II, with 1826 teeth and 4225 roots[12,15–22,24]; 8 investigated type III, with 1438 teeth and 3837 roots[12,15,17,18,20–22,24]; and 10 reported information on type IV, with 1658 teeth and 4225 roots.[12,15,17–24] Among all studies, 9 used CBCT,[15–19,21–24] while 2[12,20] used CT as the reference test. In addition, five studies reported the distance from the root tips to the MSF (Tables 2 and 3).[12,15,17,20,24]

Quality of Included Studies

Among the 11 included studies, one was assessed to have a low risk of bias[17]; five, a medium risk of bias[15,18,20,22,23]; and five, a high risk of bias.[12,16,19,21,24] In terms of applicability, all studies were assessed to have low applicability concerns (Table 4).

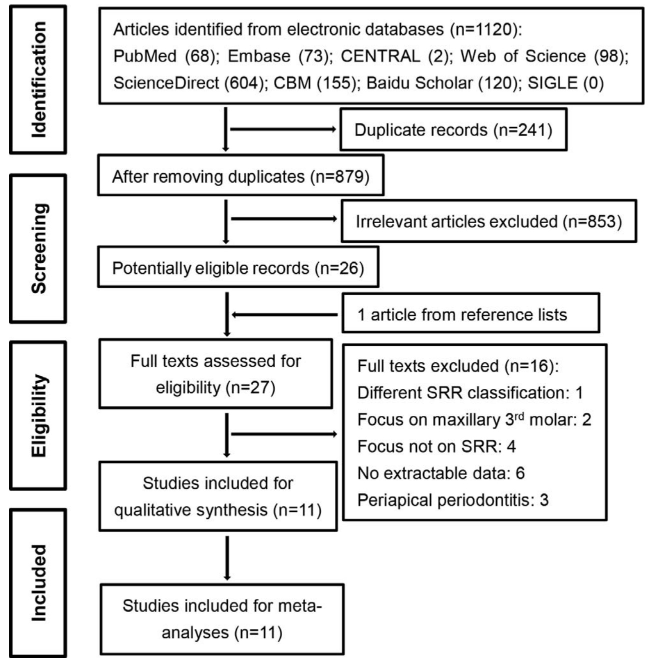

Figure 1. Flow diagram of the study inclusion process.

SYNTHESIZED RESULTS OF DIAGNOSTIC ACCURACY

Qualitative Results of Diagnostic Accuracy

Synthesized results of diagnostic accuracy. The pooled statistics (sensitivity, specificity, +LR, –LR, AUC, and DOR) are summarized in Table 5 and Figures 2 and 3.

Classification change between index and reference test. The pooled results indicated that, for the SRR diagnosed by CT/CBCT, PR showed an agreement of 73.41% for type I and 79.18% for type IV. However, 36.19% of type II and 69.35% of type III were given a higher SRR value on PR (Figure 4A). Comparatively, for the SRR diagnosed by PR, 88.80% of type I and 65.68% of type II were verified by CT/CBCT, but 49.33% of type III and 75.99% of type IV SRR were given a lower SRR value on CT/CBCT (Figure 4B).

Distance From Root Tips to the MSF

The meta-analysis showed that the pooled MD [95% confidence interval (CI)] was –1.88 mm [–2.19, –1.57 mm], $P = 0.00$. The distance from the root tips to the MSF on CT/CBCT was significantly shorter than that on PR (Figure 5).

Table 2. Summary of Characteristics of Included Studies[a]

Study ID	Country	Age, Year	Gender, M/F	Tooth Type	SRR Classification	Index Test (Parameters)	Reference Test (Parameters)
Sharan and Madjar (2006)[12]	Israel	40	55/25	Pre-/molar	Sharan	PR (Gendex Orthoralix-S)	CT (Phillips Brilliance 40: 120 kVp, 60 mA, slice spacing 2 mm, slice thickness 1.3 mm)
Lin (2009)[15]	Taiwan	50.4	42/38	Pre-/molar	Sharan	PR (Cranex Tome CEPH)	CBCT (i-CAT: 120 kVp, 8 mA, slice spacing 0.4 mm, slice thickness 0.4 mm)
Bokkasam et al. (2015)[16]	India	—	—	Pre-/molar	Condensed Sharan	PR	CBCT (Kodak 9000C)
Roque-Torres et al. (2015)[17]	Brazil	22	78/31	Pre-/molar	Sharan	PR (DOP 100: 57–60 kVp, 2 mA, 17.6 s)	CBCT (Classic i-CAT: 120 kVp, 8 mA, 40 s, voxel size 0.3 mm, FOV 23 × 17 cm)
Dehghani Tafti et al. (2015)[18]	Iran	—	—	Pre-/molar	Sharan	PR	CBCT (Planmeca: 84 kVp, 12 mA, 14 s, FOV 8 × 8 cm)
Jung and Cho (2009)[19]	Korea	42.3	49/48	Molar	Condensed Sharan	PR (Planmeca 2002 CC Proline)	CBCT (DCT_{PRO}: 90 kVp, 4 mA, 24 s, FOV 20 × 14 cm)
Ali et al. (2012)[20]	Iraq	29	16/11	Pre-/molar	Sharan	PR (Planmeca Dimax: 66 kVp, 10 mA, 18 s)	CT (Somatom: 130 kVp, 105 mA)
Fakhar et al. (2014)[21]	Iran	—	—	Pre-/molar	Sharan	PR (Planmeca Proline: 64–68 kVp, 8-10 mA, 18 s)	CBCT (Planmeca 3D max: 82–84 kVp, 12–14 mA, 12 s)
Lopes et al. (2016)[22]	Brazil	—	—	Pre-/molar	Condensed Sharan	PR (DOP100)	CBCT (Picasso Trio)
Mi et al. (2016)[23]	China	19.7	42/68	Pre-/molar	Condensed Sharan	PR	CBCT (Morita Micro CT: 87 kVp, 5.5 mA, 17.5 s, slice spacing 0.125 mm, slice thickness 0.125 mm)
Kalkur et al. (2017)[24]	India	18-45	49/36	Pre-/molar	Sharan	PR (Kodak 9000C: 70–74 kVp, 14.3–15.1 mA, 15.1 s)	CBCT (Kodak 9000C: 70–80 kVp, 10–10.8 mA, 24 s)

[a] M/F indicates male/female; SRR, maxillary sinus-root relationship; PR, panoramic radiography; CT, computed tomography; CBCT, cone-beam computed tomography; FOV, field of view.

Subgroup Analysis and Meta-regression

First, the threshold effects were assessed. The Spearman correlation coefficients were –0.321 ($P =$ .365), –0.042 ($P =$ .907), –0.190 ($P =$ .651), and –0.018 ($P =$ .96) for type I, II, III, and IV, respectively. Therefore, no substantial threshold effects existed for any SRR types. Moreover, sources of heterogeneity among the enrolled studies were determined using meta-regression and subgroup analyses. The sample size ($<$50 subjects; $>$50 subjects), synthesis unit (root; tooth), SRR classification (Sharan's; condensed Sharan's), tooth type (premolar and molar; molar), reference test (CT; CBCT), publication year (in/before 2012; after 2012), and country (mid-east Asia; east Asia; south Asia; south America) were investigated with single covariate meta-regression. The results suggested only the tooth type significantly affected the diagnostic efficacy for type I SRR ($P =$ .0081). A sensitivity analysis was performed by omitting the studies focusing on molars alone,[19] and no significant changes were observed for the overall estimates (Table 6).

Sensitivity Analysis

Studies with a high risk of bias[12,16,19,21,24] were omitted, and no significant changes were observed for the overall results (Table 6). In addition, the random-effect model was changed to a fixed-effect model for the pooling of continuous data, and no significant changes were observed for the overall MD estimates. Therefore, this study showed a good robustness (Table 6).

Publication Bias

Although the funnel plots for publication bias showed slight asymmetry, no statistical significance of the publication bias was observed for all types of SRR ($P =$

Table 3. Results of Individual Studies[a]

Study ID	Sample Size			Extractable SRR Type	Diagnostic Outcomes				Unit	Distance Measure, Mean (SD), mm	
	People	Teeth	Roots		TP	FP	FN	TN		PR	CT/CBCT
Sharan and Madjar (2006)[12]	80	—	422	I	85	2	20	315	Root	3.11 (2.54)	1.48 (1.50)
				II	50	9	69	294			
				III	26	35	72	289			
				IV	93	122	7	200			
Lin (2009)[15]	80	324	723	I	337	14	85	287	Root	3.30 (2.45)	2.10 (1.71)
				II	85	70	61	507			
				III	5	16	58	644			
				IV	79	117	13	514			
Bokkasam et al. (2015)[16]	30		388	I	59	19	36	274	Root	—	—
				II	205	34	71	78			
				IV	15	56	2	315			
Roque-Torres et al. (2015)[17]	109	872	1875	I	307	41	196	1331	Root	0.44 (3.06)	−1.56 (3.70)
				II	356	235	299	985			
				III	21	96	616	1142			
				IV	59	760	21	1035			
Dehghani Tafti et al. (2015)[18]	55	440	817	I	273	69	79	396	Root	—	—
				II	148	65	147	457			
				III	85	34	19	679			
				IV	54	89	12	662			
Jung and Cho (2009)[19]	97	388	—	I	150	0	14	224	Teeth	—	—
				II	39	13	9	327			
Ali et al. (2012)[20]	27	146	—	I	38	6	16	86	Teeth	4.65 (1.17)	2.55 (1.20)
				II	34	12	36	64			
				III	3	21	14	108			
				IV	8	24	2	112			
Fakhar et al. (2014)[21]	117	452	—	I	154	10	18	270	Teeth	—	—
				II	76	29	54	293			
				III	12	51	100	289			
				IV	19	101	19	313			
Lopes et al. (2016)[22]	46	330	—	I	85	11	24	210	Teeth	—	—
				II	38	30	51	211			
				III	2	6	4	318			
				IV	111	47	15	157			
Mi et al. (2016)[23]	110	220	1119	IV	293	148	7	671	Teeth	—	—
Kalkur et al. (2017)[24]	85	510	—	I	50	9	83	368	Teeth	6.30 (2.39)	4.06 (2.27)
				II	73	59	116	262			
				III	9	28	128	345			
				IV	45	237	6	222			

[a] SRR indicates maxillary sinus-root relationship; TP, true-positive; FP, false-positive; FN, false-negative; TN, true-negative; PR, panoramic radiography; CT, computed tomography; CBCT, cone-beam computed tomography; SD, standard deviation; "+",root into the MS; "–", the root out of the MS.

Table 4. Quality Assessment of the Included Studies According to the Quality Assessment of Studies of Diagnostic Accuracy-2[a]

Study	Risk of Bias					Applicability Concerns			
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Total	Patient Selection	Index Test	Reference Standard	Total
Sharan and Madjar (2006)[12]	High	Unclear	Unclear	Low	High	Low	Low	Low	Low
Lin (2009)[15]	Unclear	Unclear	Unclear	Low	Medium	Low	Low	Low	Low
Jung and Cho (2009)[19]	High	Unclear	Unclear	Low	High	Low	Low	Low	Low
Ali et al. (2012)[20]	Unclear	Unclear	Unclear	Low	Medium	Low	Low	Low	Low
Fakhar et al. (2014)[21]	High	Unclear	Unclear	Low	High	Unclear	Low	Low	Low
Bokkasam et al. (2015)[16]	High	Unclear	Unclear	Low	High	Unclear	Low	Low	Low
Roque-Torres et al. (2015)[17]	Low	Low	Low	Low	Low	Low	Low	Low	Low
DehghaniTafti et al. (2015)[18]	Unclear	Unclear	Unclear	Low	Medium	Unclear	Low	Low	Low
Lopes et al. (2016)[22]	High	Low	Low	Low	Medium	Unclear	Low	Low	Low
Mi et al. (2016)[23]	Unclear	Unclear	Unclear	Low	Medium	Low	Low	Low	Low
Kalkur et al. (2017)[24]	High	Unclear	Unclear	Low	High	Low	Low	Low	Low

[a] High indicates high risk; medium, medium risk; low, low risk.

Table 5. Summary of Diagnostic Efficacy of PR for Different SRR Types

Item	Type I	Type II	Type III	Type IV
Sen [95% CI]	0.75 [0.65–0.83]	0.55 [0.47–0.63]	0.17 [0.07–0.37]	0.86 [0.77–0.92]
Spe [95% CI]	0.97 [0.94–0.98]	0.88 [0.83–0.92]	0.93 [0.89–0.96]	0.76 [0.67–0.82]
+LR [95% CI]	22.9 [11.5–45.7]	4.7 [3.1–7.2]	2.5 [0.8–7.4]	3.5 [2.6–4.9]
–LR [95% CI]	0.26 [0.17–0.37]	0.51 [0.42–0.62]	0.89 [0.74–1.08]	0.18 [0.10–0.31]
AUC [95% CI]	0.95 [0.93–0.97]	0.78 [0.75–0.82]	0.83 [0.79–0.86]	0.87 [0.84–0.90]
DOR [95% CI]	90 [35–229]	9 [5–16]	3 [1–10]	20 [9–42]

[a] CI indicates confidence interval; Sen, sensitivity; Spe, specificity; +LR, positive likelihood ratio; –LR, negative likelihood ratio; AUC, area under the curve; DOR, diagnostic odds ratio.

.438, .136, .218, and .072 for type I, type II, type III, and type IV, respectively; Figure 6).

DISCUSSION

Complications related to the MS have long been a concern in dental clinics.[1,10] Although CBCT was recommended to evaluate implant sites and MSF in implantology,[28] only 49.6% of academic centers and 59.1% of private practices in America have adopted CBCT for implants preoperatively.[29] Currently, clear guidance on assessing SRR in orthodontics is not available.[30] The present study is the first systematic review and meta-analysis investigating the diagnostic efficacy of PR for determining the SRR. Overall, 11 studies were included and synthesized with good robustness.

The diagnostic accuracy of PR was assessed by comprehensively combining sensitivity, specificity, +LR, –LR, DOR, and AUC.[31] First, it was found that, for type I SRR, PR had the highest specificity, +LR, DOR, and AUC, with a high sensitivity and a low –LR, indicating that PR had the highest diagnostic efficiency for type I SRR. Second, for type IV SRR, PR had a high DOR and AUC, with the highest sensitivity but a low +LR, the lowest –LR, and the lowest specificity, indicating a good ability to confirm true type IV SRR but a poor ability to rule out false type IV SRR. Third, PR had the lowest AUC, with a low sensitivity, +LR, and DOR and a high –LR for type II SRR, showing that the diagnostic efficiency for type II is poor. Last, PR had the lowest sensitivity, +LR, and DOR and the highest –LR for type III, indicating the lowest diagnostic efficiency for type III SRR. In addition, it was found that, for the cases diagnosed by CT/CBCT, PR tended to give a higher value of SRR for 36.19% of type II and 69.35% of type III cases. For the cases diagnosed by PR, 49.33% of type III and 75.99% of type IV cases were verified to have a lower SRR value by CT/CBCT. Furthermore, the distance from root tips to the MSF on CT/CBCT was significantly shorter (–1.88 mm) than that on PR.

The differences in diagnostic accuracy are caused by the two-dimensional characteristics of PR, which lacks cross-sectional and coronal-sectional informa-

Table 6. Results of Sensitivity Analysis and Subgroup Analysis[a]

Item	Sen [95% CI]	Spe [95% CI]	+LR [95% CI]	–LR [95% CI]	AUC [95% CI]	DOR [95% CI]
Type I						
Original estimate	0.75 [0.65–0.83]	0.97 [0.94–0.98]	22.9 [11.5–45.7]	0.26 [0.17–0.37]	0.95 [0.93–0.97]	90 [35–229]
Omitting molar alone	0.73 [0.62–0.81]	0.96 [0.93–0.97]	17.4 [10.6–28.6]	0.29 [0.20–0.40]	0.95 [0.92–0.96]	61 [31–118]
Omitting high-risk bias	0.74 [0.67–0.80]	0.94 [0.90–0.97]	12.5 [7.6–20.5]	0.28 [0.22–0.35]	0.90 [0.87–0.93]	45 [28–74]
Type II						
Original estimate	0.55 [0.47–0.63]	0.88 [0.83–0.92]	4.7 [3.1–7.2]	0.51 [0.42–0.62]	0.78 [0.75–0.82]	9 [5–16]
Omitting molar alone	0.52 [0.45–0.59]	0.87 [0.81–0.91]	4.0 [2.9–5.5]	0.55 [0.48–0.63]	0.75 [0.71–0.78]	7 [5–11]
Omitting high-risk bias	0.52 [0.48–0.55]	0.86 [0.83–0.88]	3.7 [3.0–4.4]	0.56 [0.52–0.60]	0.63 [0.59–0.67]	7 [5–8]
Type III						
Original estimate	0.17 [0.07–0.37]	0.93 [0.89–0.96]	2.5 [0.8–7.4]	0.89 [0.74–1.08]	0.83 [0.79–0.86]	3 [1–10]
Omitting molar alone	0.17 [0.07–0.37]	0.93 [0.89–0.96]	2.5 [0.8–7.4]	0.89 [0.74–1.08]	0.83 [0.79–0.86]	3 [1–10]
Omitting high-risk bias	0.20 [0.05–0.55]	0.95 [0.90–0.98]	4.0 [0.9–18.8]	0.84 [0.61–1.17]	0.89 [0.86–0.91]	5 [1–31]
Type IV						
Original estimate	0.86 [0.77–0.92]	0.76 [0.67–0.82]	3.5 [2.6–4.9]	0.18 [0.10–0.31]	0.87 [0.84–0.90]	20 [9–42]
Omitting molar alone	0.86 [0.77–0.92]	0.76 [0.67–0.82]	3.5 [2.6–4.9]	0.18 [0.10–0.31]	0.87 [0.84–0.90]	20 [9–42]
Omitting high-risk bias	0.88 [0.78–0.94]	0.79 [0.71–0.85]	4.2 [2.9–6.2]	0.15 [0.08–0.30]	0.90 [0.87–0.92]	28 [11–72]

[a] Mean difference of distance from root tip to floor of maxillary sinus (mm): original estimate: –1.88 [–2.19, –1.57], $P < .0001$; omitting molar alone: –1.88 [–2.19, –1.57], $P < .0001$; omitting high-risk bias: –1.78 [–2.32, –1.23], $P < .0001$; changing random to fixed model: –1.96 [–2.11, –1.81], $P < 0.0001$. CI indicates confidence interval; Sen, sensitivity; Spe, specificity; +LR, positive likelihood ratio; –LR, negative likelihood ratio; AUC, area under the curve; DOR, diagnostic odds ratio.

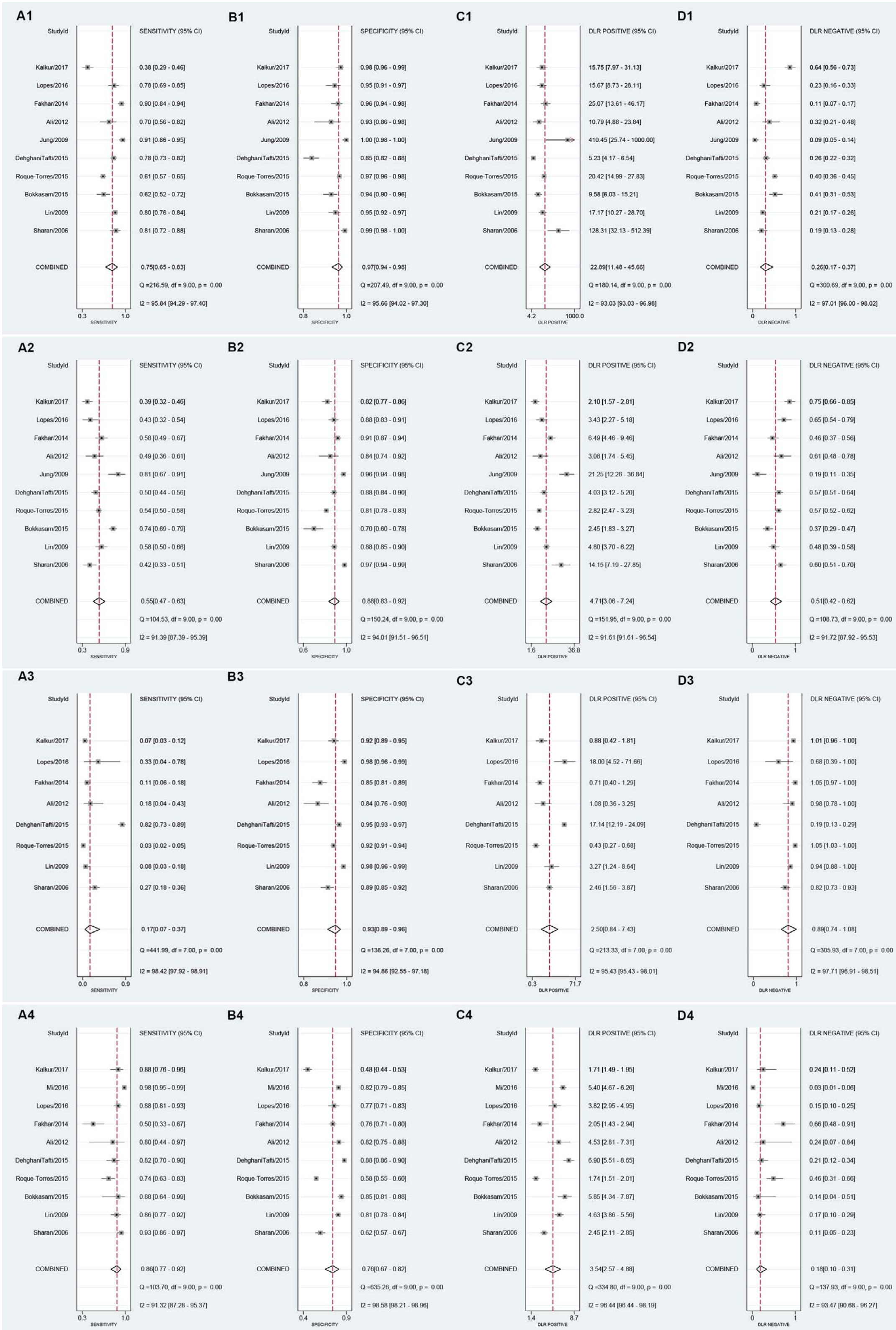

Figure 2. Pooled indices for the diagnostic efficacy of panoramic radiography (PR) for type I SRR: (A1) sensitivity, (B1) specificity, (C1) positive likelihood ratio, (D1) negative likelihood ratio; for type II SRR: (A2) sensitivity, (B2) specificity, (C2) positive likelihood ratio, (D2) negative likelihood ratio; for type III SRR: (A3) sensitivity, (B3) specificity, (C3) positive likelihood ratio, (D3) negative likelihood ratio; and for type IV SRR: (A4) sensitivity, (B4) specificity, (C4) positive likelihood ratio, (D4) negative likelihood ratio.

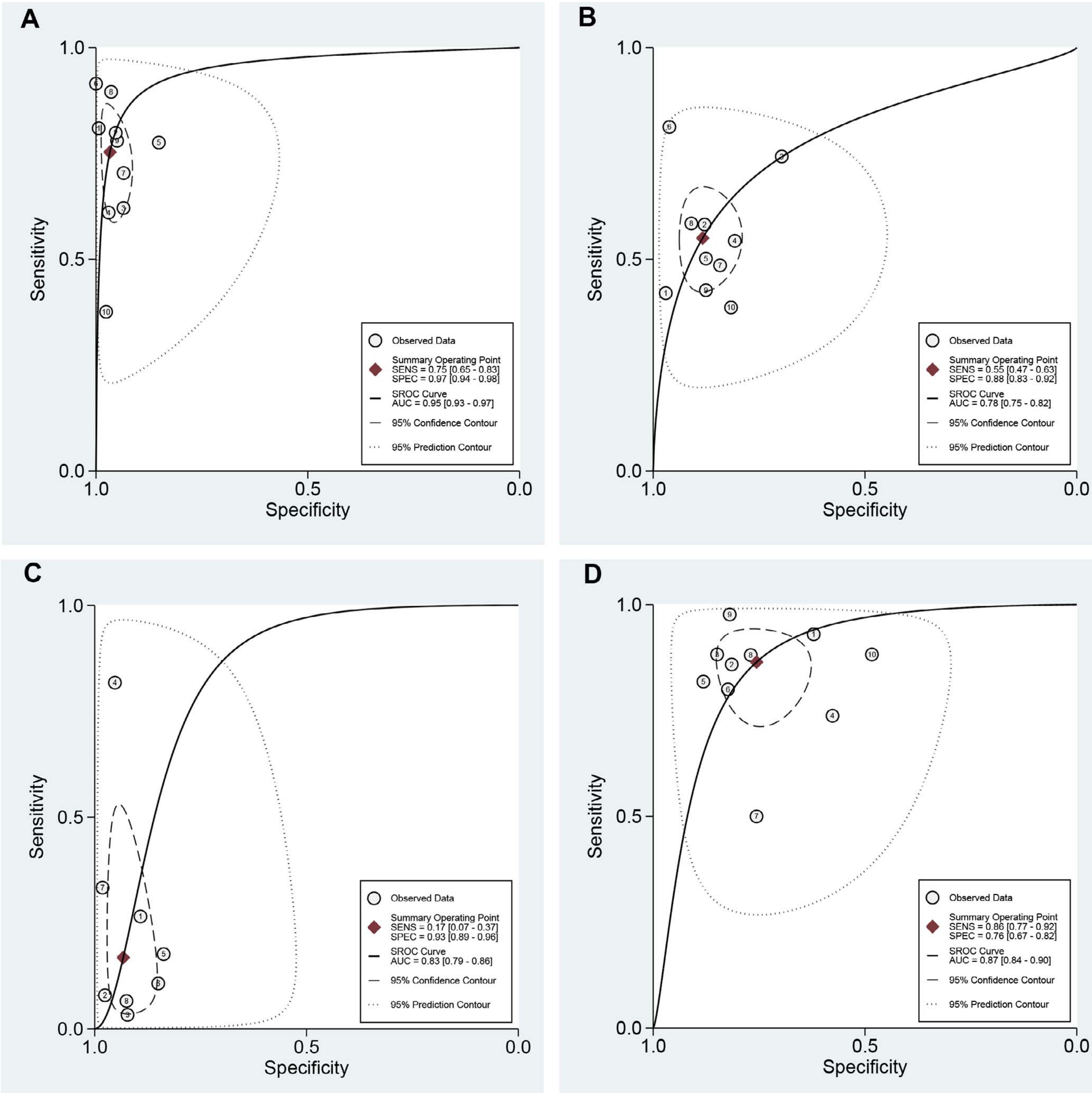

Figure 3. Summary receiver-operating characteristic (SROC) curves of panoramic radiography (PR) for (A) type I SRR, (B) type II SRR, (C) type III SRR, and (D) type IV SRR.

tion. CBCT showed 86.52%–97.03% and 71.56%–81.06% of the inferior MSF horizontally located between the buccal and palatal roots of the first and second molars, respectively, with the rest mainly located buccal to the buccal roots.[4,5,32,33] However, on PR, this characteristic could not be observed. Because of superimposition, the buccolingual distance between the root tip and MSF (type I SRR) could be judged as type II, III, or IV SRRs. Similarly, a type III SRR is easily judged as type IV SRR on PR. Moreover, the overestimation of the degree of protrusion may also be attributed to the vertical enlargement of PR.[12,22,34]

The diagnosis of SRR has great implications for orthodontic control. First, when developing a treatment plan, SRR should be considered as an important factor since orthodontic tooth movement through the MS (OTMTMS) may be accompanied by uncertainty and complications of tooth tipping, root resorption, and

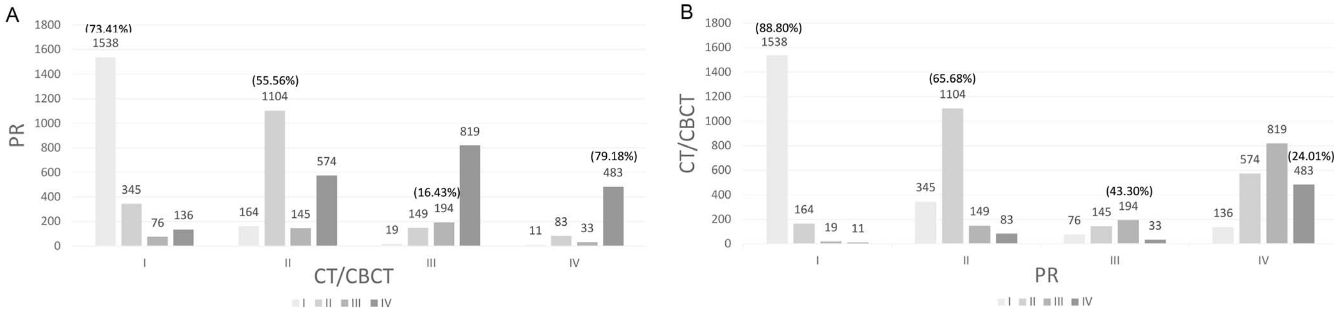

Figure 4. Classification changes in the sinus-root relationship between panoramic radiography and CBCT.

prolonged treatment.[9–11] Second, a tooth with a high value of SRR (type IV) may not be chosen as a priority to be extracted because of the high surgical risk.[1] Third, if OTMTMS is to be performed, for type I and II SRR, mesiodistal OTMTMS may be safe. For type III SRR, a force system to relieve the sinus-root contact before mesiodistal movement may be suggested, whereas for type IV SRR, OTMTMS should be performed cautiously and observed carefully. Fourth, a clear quantitative assessment of SRR is important for determining the insertion position and angle of mini-implants.

The present review suggests PR is a precise technique for the diagnosis of type I SRR, but for type II, III, and IV SRR, the diagnostic accuracy is insufficient or poor, and CT/CBCT may be recommended in these situations. However, dental practitioners must adhere to the ALARA principles that every effort should be made to reduce the patient's effective radiation dose to "as low as reasonably achievable."[34] CT/CBCT should always be chosen as an adjunct to conventional radiography and should never be prescribed routinely or periodically, especially for children.[34] Thus, it is suggested that the SRR be first evaluated with conventional dental radiography (PR or intraoral radiographs).[28–30,34] When a type II, III, or IV SRR is displayed and OTMTMS, extraction of a tooth, or mini-screw insertion is indicated, CBCT should be used for further examination.

Although this study was conducted carefully following the PRISMA standards, there were some limitations that must be addressed. First, although high concerns regarding applicability were not found for the included studies, five of the 11 included studies showed relatively high risk of bias. Second, heterogeneity existed among the included studies. Although the statistical analyses indicated the stability of the results, some confounding factors could not be assessed quantitatively, such as the diagnostic ability and subjective factors of examiners. Third, the radiographic facilities and parameters were not all the same among studies. Fourth, there is currently no cost-effective evaluation of this topic, and thus, a comprehensive evaluation of the benefits including cost and radiation is not available. These limitations should be taken into consideration to better interpret the results of this study.

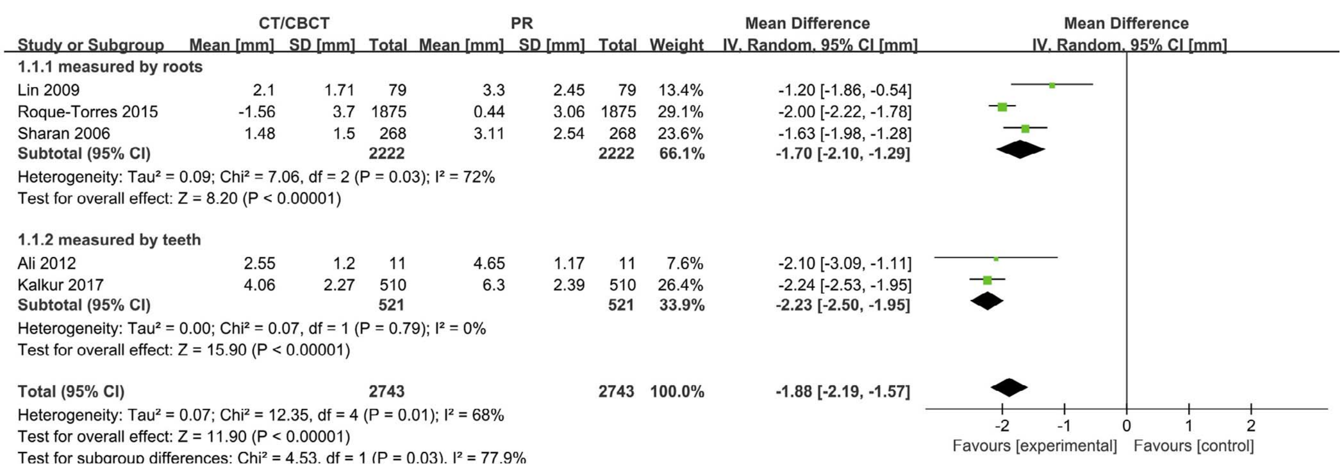

Figure 5. Forest plot showing the mean difference (MD) of the distance from root tip to maxillary sinus floor between panoramic radiography and CBCT.

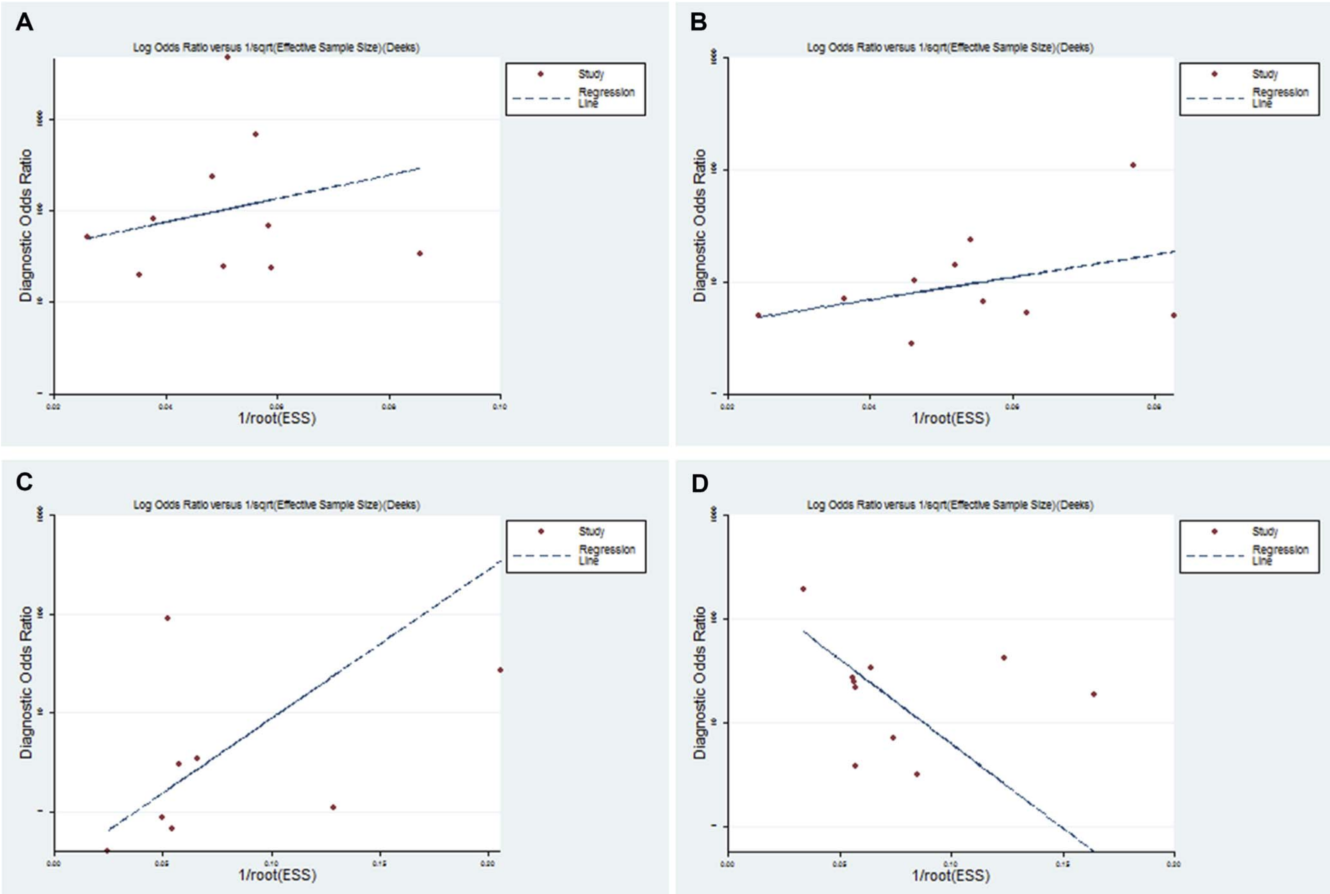

Figure 6. Funnel plots of potential publication bias for (A) type I SRR, (B) type II SRR, (C) type III SRR, and (D) type IV SRR.

CONCLUSIONS

- Currently available evidence suggests that PR could be reliable for detecting type I SRR in clinical practice.
- In addition, PR has a good ability to confirm true type IV SRR but a poor ability to rule out false type IV SRR.
- However, for type II and III SRR, PR shows poor accuracy and tends to overestimate the extent of protrusion of the roots into the MS.
- When PRs show type II, III, or IV SRR and orthodontic tooth movement through the maxillary sinus, extraction of teeth, or mini-screw insertion is indicated, CBCT should be used for further examination.

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