

Accuracy of radiographic and protrusive occlusal record methods in determining condylar guidance angles: a systematic review and meta-analysis [version 1; peer review: 1 approved]

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SYSTEMATIC REVIEW

Accuracy of radiographic and protrusive occlusal record methods in determining condylar guidance angles: a systematic review and meta-analysis [version 1; peer review: 1 approved]

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Abstract

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Background: The objective of this systematic review was to compare the accuracy of radiographic and protrusive occlusal record (POR) methods in determining horizontal condylar guidance (HCG) angles in dentate and edentulous patients.

Methods: Studies assessing condylar guiding angles in dentulous/partially edentulous and totally edentulous patients free of temporomandibular disorders using both radiographic and protrusive occlusal record methods were included. A comprehensive search with PubMed/MEDLINE, Cochrane Central Register of Controlled Trials, Web of Science, Google Scholar and Open Grey databases was done. Two reviewers extracted the data after eligibility assessment. Study quality was examined using the NIH quality assessment tool and graded based on tooth selection, number of root canals assessed, study environment, number of observers, test reliability report, validation approach, validation criteria, and validity reliability. A meta-analysis of pooled data, subgroups and sensitivity analysis was performed using RevMan ($P < 0.05$).

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Results: The qualitative synthesis contained 33 papers, 32 of which were included in the meta-analysis. The standardised mean difference between the radiographic and protrusive occlusal record methods for right and left HCG angle in dentate patients was 0.68 [0.37, 0.98] and 0.63 [0.32, 0.95], respectively, and for right and left HCG angle in edentulous patients was 0.80 [0.36, 1.24] and 0.66 [0.18, 1.15], indicating a statistically significant difference ($p < 0.05$).

Conclusions: Clinical variability among the selected studies could not be completely avoided and the sample sizes were limited, resulting in

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a lack of statistical power. To rule out potential causes of heterogeneity, subgroup and sensitivity analyses were done separately for dentate and edentulous individuals for the right and left HCG angle. The present systematic review and meta-analysis concluded that for the dentate and edentulous patients, the right and left HCG angle values determined by radiographic method showed statistically significant difference as compared to the protrusive occlusal records.

PROSPERO registration: CRD42020206599 (28/09/2020)

Keywords

Horizontal condylar guidance, Cone beam computed tomography, Lateral cephalogram, Panoramic radiograph, Protrusive occlusal record



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Introduction

The registration of precise condylar path and mandibular movement on an articulator is critical to the achievement of an adequate oral rehabilitation of the patient. The inclination of the condylar trail, which is one of the five aspects of balanced occlusion, is therefore a crucial factor in prosthetic treatment success.^{1,2} This is the only aspect that is not under the control of a prosthodontist and should be reproduced precisely. Condylar guidance (CG) is described by the Glossary of Prosthodontic Terms⁹ as mandibular guidance created by the condyle and articular disc crossing the shape of the articular eminence (AE).³ Horizontal condylar guidance (HCG) and lateral condylar guidance (LCG) are the two types of CG. The horizontal condylar route is the path of movement of the condyle-disk assembly in the joint cavity during a protrusive mandibular movement, whereas the lateral condylar path is the path of movement of the condyle-disk assembly in the joint cavity during a lateral mandibular movement.⁴ Ignorantly recorded condylar guidance will result in occlusal interferences during functional actions, increasing chair side time for prosthesis adjustment, which can be unpleasant for both the patient and the prosthodontist.^{5,6}

Numerous strategies, such as interocclusal records, pantographic tracings, electronic jaw tracking devices, radiographic methods, and so on, can be used to determine horizontal condylar inclination, but programming a semi-adjustable articulator with a protrusive interocclusal record after training the patient to trace a gothic arch is still the most commonly used method in clinical practice.¹ The accuracy of Gothic arch recording is influenced by factors such as the patient's neuromuscular control, the stability of the record base, and the recording media. Additionally, when the patient moves the jaw laterally during protrusion, the registration of the condylar route alters.⁷ Even semi-adjustable articulator setup with interocclusal records has a limited degree of repeatability and is susceptible to instrument, operator, and interocclusal record material factors.¹

Radiographs can indeed show the shape of the articular eminence and the glenoid fossa of the temporal bone.⁸ Magnetic resonance imaging (MRI), cone-beam computed tomography (CBCT), computed tomography (CT), panoramic radiograph (OPG), and lateral cephalogram (LC) are currently accessible to visualise temporomandibular joint components.⁹ The primary advantages of these approaches are that measurements are based on stable bone landmarks and that mistakes caused by operator inexperience and insufficient neuromuscular control of the patient may be prevented.^{10,11}

Panoramic radiography produces a two-dimensional (2D) image of the temporomandibular joint (TMJ) with a flat reflection of the curved surface of the maxilla and a composite image of the tissues in the X-ray's route but it is frequently inaccurate for measuring HCG due to multiple structures being superimposed,⁹ whereas 3D multiplanar sections acquired from a CBCT scan give a better anatomic perspective of the condyle and its route without the superimpositions shown in 2D radiography images.^{11,12} Magnetic resonance imaging (MRI) is a thorough examination that is considered in the literature to be the "gold standard" in diagnosing TMJ disorders; nevertheless, it is not often utilised in everyday dentistry practice due to financial constraints.⁹

The primary disadvantages to the widespread use of these radiography techniques are the high cost of equipment, discomfort, and radiation exposure to patients.¹³ In the study conducted by Tannamala et al.,¹⁴ a difference of 2-4 degrees in HCG angle between OPG and the protrusive occlusal record was found while in the study by Shreshta et al.,¹³ a difference of 9-10 degrees in HCG angle between CBCT images and the protrusive occlusal record was observed whereas in the study by Das et al.¹¹ no significant difference between in HCG angle between CBCT images and the protrusive occlusal record was observed. Additionally, there is no agreement on the findings of several methods for determining the HCG angle and whether approach, clinical or radiographic, offers the most accurate HCG angle readings. There is still no research that have given a complete, quantitative study on which diagnostic reasoning may be based. As a result, the purpose of this systematic review and meta-analysis was to examine and evaluate the accuracy of radiographic and protrusive occlusal record (POR) techniques in estimating horizontal condylar guidance (HCG) angles in dentate and edentulous patients.

Methods

Protocol and registration

Our systematic review and meta-analysis was registered in PROSPERO (CRD42020206599) on the 28th September 2020, and it was undertaken and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.^{15,55}

Focused research question

In the Patient, Intervention, Comparison, and Outcome (PICO) design, the following focused question was proposed: "Is there a difference in the accuracy of radiographic and protrusive occlusal record techniques in estimating condylar guiding angles in dentate and edentulous patients?"

Search strategy

To obtain papers in the English language, a complete electronic search was conducted the databases PubMed/ MEDLINE, Cochrane Central Register of Controlled Trials, and Web of Science from 1st January 2011 till 31st December 2020. The distinct electronic search of the journals listed in Table 1 was carried out. Google Scholar, Greylit, and OpenGrey were used to conduct searches in the clinical trials database, cross-referencing, and Grey literature.

For searching articles, Medical Subject Headings (MeSH) terms, keywords, and other free phrases were coupled using Boolean operators (OR, AND). Following the syntactic guidelines of each database, the same terms were utilised across all search platforms. Table 1 shows the search method as well as the population, interventions, comparisons, outcomes, and study design (PICOS) tool.

Inclusion criteria outline according to the PICOS strategy

Population (P): Condylar guiding angles were determined in dentulous/partially edentulous and totally edentulous patients who were free of temporomandibular disorders. Dentulous patients with almost complete set of teeth or with partial edentulousness and nearly ideal occlusion with Class I molar relationship and aged 18 years and above, as well as completely edentulous patients with well-formed ridges, good neuromuscular control, adequate inter-maxillary space, and orthognathic jaw relation.

Interventions (I): Studies assessing radiographic techniques like cone beam computed tomography (CBCT), orthopantomogram (OPG), lateral cephalograms, computerized tomography (CT) scan and temporomandibular joint (TMJ) tomogram for determining accurate measurements of condylar inclination.

Table 1. Search method, study design (PICOS; Patient, Intervention, Comparison, and Outcome) tool, and the journals included in the comparison.

Focused Question	Is there a difference in the accuracy of radiographic and protrusive occlusal record methods in determining condylar guidance angles in dentate and edentulous patients?
Population (#1)	(Dentate [Text Word]) OR Dentulous [Text Word]) OR Edentulous [Text Word])
Intervention (#2)	(Dental radiography [Text Word]) OR " Cone-Beam Computed Tomography"[MeSH Terms] OR Cone-Beam CT Scan [Text Word]) OR Volumetric Computed Tomography [Text Word] OR Volumetric CT [Text Word] OR Cone-Beam CT [Text Word] OR Panoramic [MeSH Terms] OR Pantomography [Text Word] OR OPG [Text Word] OR Orthopantomography [Text Word] OR Panoramic Radiography [Text Word] OR lateral cephalogram [Text Word] OR cephalogram [Text Word])
Comparisons (#3)	(Protrusive occlusal record [Text Word] OR Protrusive wax record [Text Word] OR Inter-occlusal wax record [Text Word] OR Protrusive inter-occlusal record [Text Word] OR Protrusive inter-occlusal registration [Text Word])
Outcomes (#4)	(Horizontal condylar value [Text Word] OR condylar guidance [Text Word] OR Horizontal condylar angle [Text Word] OR Sagittal condylar guidance [Text Word] OR Condylar guidance [Text Word] OR Condylar ramp [Text Word]) OR Horizontal condylar inclination [Text Word])
Study design (#5)	(Clinical study [Text Word] OR Clinical trial [MeSH] OR randomized controlled studies [Text Word] OR randomized control trials [MeSH] OR randomized control clinical trial MeSH OR non-randomized control trials [Text Word] OR Quasi experimental studies [Text Word] OR before and after study design [Text Word] OR cohort studies [Text Word] OR in vivo study [Text Word] OR Cross-sectional study [Text Word])
Search Combination	#1 AND #2 AND #3 AND #4 AND #5
Database search	
Language	No restriction (Articles in English language or other language where English translation is possible)
Electronic Databases	PubMed/MEDLINE, Cochrane Central Register of Controlled Trials, Web of Science, Open grey, Google scholar
Journals	Journal of Prosthetic Dentistry, Journal of the Indian Prosthodontic Society, European Journal of Prosthodontics and Restorative Dentistry, The journal of advanced prosthodontics, International Journal of Prosthodontics and Restorative Dentistry
Period of Publication	Studies published between 1-1-2011 to 31-12-2020

Comparison (C): Studies assessing clinical techniques like protrusive occlusal wax record, for determining accurate measurements of condylar inclination

Outcome (O): Condylar guidance angles using different methods irrespective of the methods of quantifying the outcomes.

Study design (S): Clinical trials, *in vivo* studies, randomised controlled trials, non-randomised control trials, quasi experimental investigation, before and after research design, and cohort studies comparing radiographic and clinical techniques.

Exclusion criteria

The following studies were excluded:

1. Non-clinical studies, *in-vitro* studies, and animal studies. Furthermore, studies that reported on a single intervention were discarded.
2. Studies on patients with TMJ problems, defective restorations, periodontal disease, excessive attrition, and impaired neuromuscular control.
3. Studies not fully available in the database.
4. Article reporting only abstracts were also excluded.
5. Case series, case reports, reviews, and *in vitro* research were also eliminated.

Screening process

Two review authors (A.M.L. and S.T.K.) conducted the search and screening in accordance with the previously defined procedure. After the initial retrieval, duplicates were removed and the titles and abstract of all the results were screened by 2 authors (A.M.L. and A.M.P). Full text publication articles were retrieved for those articles that met the eligibility criteria. The list of excluded articles at the initial retrieval was crosschecked by all the authors and disagreements were resolved by discussing amongst all. The entire papers were evaluated in the second phase, and papers that did not fulfil the inclusion requirements were unanimously discarded. Cohen's kappa (k) determined the degree of agreement between the two reviewers to be 0.90 for titles and abstracts and 0.92 for full-texts. After discussion, the third author (S.M.) settled the disagreements among the authors/reviewers. Some studies included both 'dentulous' and 'edentulous' patients. If the findings for the subset of teeth fulfilling the qualifying criteria were available in such studies, that subset of teeth was included in the current review. The study was discarded if it was not possible to split the study findings into two groups. The authors of the listed papers were contacted via email to clarify any concerns or missing data.

Data extraction

The following data were extracted from the included studies by two independent reviewing authors (D.A.W. and J.M.G.) using pilot tested customised data extraction forms: study identification number, place of study, sample size, age of patient, articulator model, make of machine, radiographic techniques, outcome measures, author's conclusions.

Assessments of the risk of bias and quality

To assess the risk of bias and methodological quality of the included articles, a simplified version of the NIH (National Institutes of Health) Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies¹⁶ was used, as they reported the results of cross-sectional studies. The assessment "Cannot Determine" (CD) was recorded for the element of the questionnaire for which no information was available in the text. Consistency of studies scoring five or more "Yes" out of eight was rated "Good," consistency of studies scoring three to five "Yes" was considered "Fair," and consistency of studies scoring fewer than three "Yes" was labelled "Poor".¹⁷

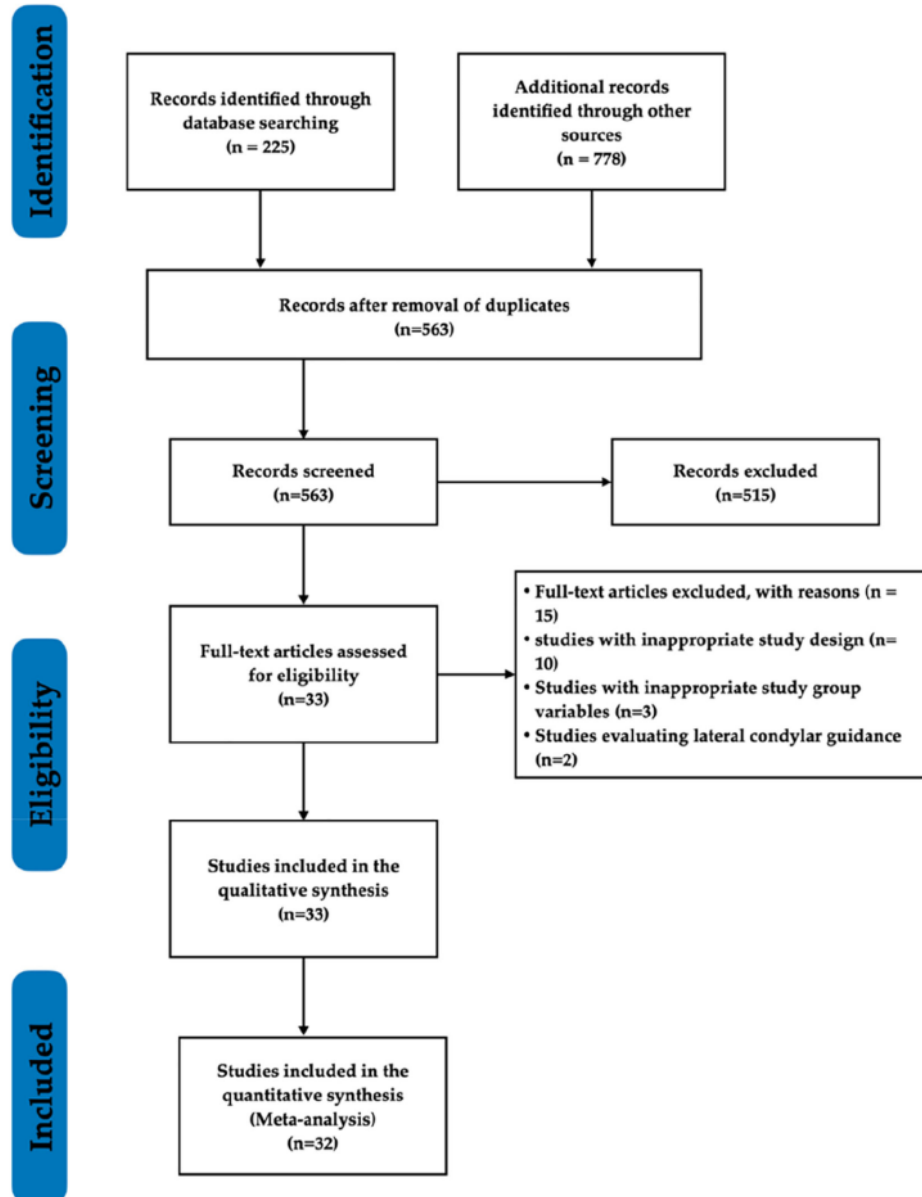
Quantitative synthesis

For statistical analysis, Review Manager (RevMan) 5.3 was utilised. The pooled results for dichotomous data were presented as relative risks (RRs) at 95 % confidence intervals (CIs), with $P < 0.05$ deemed significant. The I² test at $\alpha = 0.10$ was used to measure statistical heterogeneity. For $I^2 > 50\%$ and $P \leq 0.10$, subgroup analysis was performed. The random-effects model was used when I^2 was more than 50%. To determine the stability of the data, sensitivity analysis was performed. Funnel plots were used to detect publication bias in research with more than ten trials for each outcome evaluated.¹⁸

Results

Literature search

The preliminary electronic database search yielded 225 titles (PubMed/MEDLINE and Cochrane library) and 778 titles (Google Scholar); hand scanning the reference lists of the selected studies yielded no further articles. After removing duplicates, there were 563 titles left. Out of these 563 articles, 515 were removed at the initial screening after reading the titles and abstracts. Further to the reviewers' analysis and discussions, 48 papers were chosen for full-text evaluation. Following pre-screening, implementation of the inclusion and exclusion criteria, and maintaining of the PICOS questions, 33 studies remained (10 with inappropriate study design, 3 with inappropriate comparison group, and two studies evaluated lateral condylar guidance) and were included in the qualitative analysis, whereas 32 studies were included in the quantitative synthesis. A flowchart of the search results is represented in [Figure 1](#).



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 Figure 1. PRISMA flow diagram.

Study characteristics

The general characteristics of 33 studies^{1,7-9,11,13,14,19-44} are summarized in Table 2. All included studies were unicentric trials published between 2011 and 2020. Typically, 26 studies were conducted in India,^{1,7,11,13,14,19,20,23-27,29,30,32,34-44} two each in Iran^{8,28} and Saudi Arabia^{22,33} and one each in Nepal,²¹ Korea³¹ and Poland.⁹ In total, 20 studies included were conducted among dentate patients having a total sample size of 595 and age ranged from 18–43 years^{1,19,20,21,25,27,30,32,34,37-40,42,44} while 15 studies included were conducted among edentulous patients having a total sample size of 277 and age ranged from 35–75 years.^{7-9,11,13,14,19,20,22-24,26,28,29,31,33,35,36,41,43} The ethical approval was obtained in 25 studies^{1,9,11,13,14,19-26,30-36,38,40-43} while informed consent was obtained in only 20 studies.^{8,9,11,20-26,30,33,35-38,40-43} The funding information was mentioned in only two studies by Godavarthi et al⁷ and Naqash et al.³³ Out the 33 included studies, only 6 studies,^{11,25,28,35,37,38} have mentioned about the sample size estimation. The brands and the models of the articulator, OPG, CBCT, CT scan, LC and TMJ tomogram varied according to the studies. Radiographically the HCG angle was measured using OPG^{1,7-9,14,19-23,26-28,30-32,34-40,42} in 24 studies, seven studies recorded HCG angle with CBCT,^{8,11,25,31,33,35,43} five studies used LC^{1,23,24,29,41} and one study each recorded HCG angle with CT scan¹³ and TMJ tomogram.⁴⁴ For all of the included studies, the orientation jaw relation was registered utilising face-bow and was transferred on to the semi-adjustable articulator employing mounting jig or extra oral gothic arch tracers, and the protrusive interocclusal record was obtained by instructing the subject to protrude the mandible forward by 6mm. The condylar guidance angle was measured between the Frankfort's horizontal plane and the line formed along the posterior slope of articular eminence (AE), connecting the most concave (highest) point on the glenoid fossa and the most convex (lowest) point on the apical portion of AE in all the included studies. The right and left HCG angle was calculated separately for both the dentate and edentulous patients in all the included studies except for studies Amin et al,²⁰ Jerath S et al,²⁵ Katiyar et al²⁶ and Paul et al¹ cumulative value of right and left angle is mentioned.

35 Assessment of risk of bias

The included studies' quality evaluation revealed a wide range of results. Table 3 shows the assessment of the risk of bias for the included studies. Out of the 33 studies, only seven studies were rated as good quality studies,^{8,11,25,28,35,37,39} whereas the remaining 26 studies were rated as fair quality studies.^{1,7,9,13,14,19-24,26,27,29-34,36,38,40-44} This fair quality was basically due to no justification of sample size, no assessor blinding and no mention about participation rate and confounder blinding.

Synthesis of results

A final tally of 32 papers^{1,7,8,11,13,14,19-44} met the quantitative analysis inclusion criteria. Following that, four independent meta-analyses were done to assess the right and left HCG angle in dentate and edentulous patients.

HCG angle of right side for dentate patients

The pooled outcomes from 16 studies,^{8,11,13,14,22-24,26,28,29,31,33,35,36,41,43} with a total sample size of 738 each in the radiographic and POR group, the standardized mean difference (SMD) value for HCG angle using random effect model was 0.68 [0.37, 0.98] and showed a statistically significant difference ($P < 0.0001$) between the radiographic and POR group [$Tau^2 = 0.41$, $Chi^2 = 145.77$, $I^2 = 86\%$], (Figure 2). After subgroup analysis was performed using a random-effect model, it was discovered that for the CBCT method,^{8,11,31,33,35,43} there was a statistically significant difference favouring the radiographic method (SMD, 1.35; 95% CI: 0.41–2.30; $P < 0.00001$) with 93% heterogeneity. For OPG method,^{8,14,22,23,26,28,31,35,36} radiographic method showed a statistically significant difference as compared to POR method (SMD, 0.52; 95% CI: 0.22–0.83; $P = 0.0009$) with 74% heterogeneity. LC method^{23,24,29,41} showed no statistically significant difference between the radiographic and POR group (SMD, 0.04; 95% CI: -0.30–0.39; $P = 0.80$) with the heterogeneity of 38%. CT scan method¹³ showed a statistically significant difference between the radiographic and POR method (SMD, 1.41; 95% CI: 0.50–2.32; $P = 0.002$) (Figure 2).

HCG angle of left side for dentate patients

The pooled outcomes from 16 studies,^{8,11,13,14,22-24,26,28,29,31,33,35,36,41,43} with total sample size of 738 each in the radiographic and POR group, the standardized mean difference (SMD) value for HCG angle using random effect model was 0.63 [0.32, 0.95] and showed a statistically significant difference ($P = 0.008$) between the radiographic and POR group [$Tau^2 = 0.43$, $Chi^2 = 151.64$, $I^2 = 87\%$], (Figure 3). After subgroup analysis was performed using a random-effect model, it was discovered that for the CBCT method,^{8,11,31,33,35,43} there was a statistically significant difference favouring the radiographic method (SMD, 1.29; 95% CI: 0.44–2.13; $P = 0.03$) with 94% heterogeneity. For OPG method,^{8,14,22,23,26,28,31,35,36} radiographic method showed a statistically significant difference as compared to POR method (SMD, 0.51; 95% CI: 0.14–0.87; $P = 0.006$) with 82% heterogeneity. LC method^{23,24,29,41} showed no statistically significant difference between the radiographic and POR group (SMD, -0.05; 95% CI: -0.54–0.44; $P = 0.84$) with the heterogeneity of 67%. CT scan method¹³ showed a statistically significant difference.

Table 2. Characteristics of the included studies.

Study ID	Place of study	Sample size D/E	Age group	Articulator model	Make of machine	Radiographic techniques	Dentulous/Edentulous		Author's conclusions
							Right I/C/r	Left I/C/r	
Acharya S et al 2015 ¹²	India	20 D 20 E	18-30 years 45-75 years	HANAU articulator model Wide-Vue, U.S.A.	Orthoralix 9200; Gendex Dental Systems, Milan, Italy)	OPG	Dentulous 34.05/34.25/0.55 Edentulous 29.50/26.75/0.72	Dentulous 35.53 (6.248)/30.83 (5.384) Edentulous 29.10 (9.135)/24.20 (7.066)	Measurement of condylar inclination angles using panoramic radiographs gave higher values, as compared to the inter-occlusal record method. The use of OPG to set condylar guidance on the articulator should be taken into consideration for both dentulous and edentulous subjects
Amin B et al 2018 ²⁰	India	30 D 30 E	40-60 years	Hanau Wide-Vue	Orthophos XG	OPG			
Bhandari A et al 2018 ²¹	Nepal	25 E		HanauTM Wide-Vue Articulator, Whip Mix Corporation, USA	Orthoralix 9200 DDE Gendex, U.S.A.	OPG	24.0(6.24)/21.3 (5.31)/0.643	24.48(4.96)/21.08 (5.55)/0.622	The panoramic radiographic tracing can be used to calculate the mean horizontal condylar guidance in the completely edentulous patients
Das A et al 2020 ¹¹	India	40 D	20-40 years	Hanau Wide-Vue; Whip Mix Corp	Carestream Kodak 9300C; Kodak	CBCCT	35.43 (3.13)/32.78 (2.64)/0.95	35.18(2.62)/32.9 (2.49)/0.95	CBCCT can be used to obtain the sagittal horizontal guidance for programming semi adjustable and fully adjustable articulators
Dewan H et al 2019 ²²	Saudi Arabia	30 D	20-40 years	Whipmix 2240 series (Louisville, USA)	Model orthorelix DDE, Gendex, USA	OPG	42.57 (7.60)/36.37 (9.42)/0.658	42.71(7.84)/35.85 (6.87)/0.537	OPG could be used as an alternative to clinical methods to overcome the disadvantages associated with conventional techniques.
Galgali G et al 2016 ²³	India	120 D	20-40 years	HANAUTM Wide-Vue, Whip Mix Corporation, USA	OPG LC	OPG LC	34.83 (6.44)/34.03 (6.63)/34.16 (6.83)	35.7(6.5)/35.16 (5.85)/34.16(6.83)	The correlation between protrusive interocclusal records and the lateral cephalogram radiograph tracings which were more positively related than the panoramic radiograph.
Godavarthi AS et al 2015 ⁷	India	20 D 20 E	20-30 years 40-65 years	Hanau wide Vue-II	Dentsply Gendexorthoralix 9200	OPG	Dentulous 37.10 (5.902)/40.55 (6.669)/0.677 Edentulous 36.10 (5.543)/36.70 (4.846)/0.473	Dentulous 34.75 (4.506)/40.15 (4.246)/0.736 Edentulous 33.60 (4.261)/0.329	Panoramic radiograph can be used as an alternative to interocclusal technique only in edentulous patients.

Table 2. Continued

Study ID	Place of study	Sample size D/E	Age group	Articulator model	Make of machine	Radiographic techniques	Dentulous/edentulous			Author's conclusions
							Right I/C/r	Left I/C/r	Both I/C/r	
Goyal MK et al 2011 ²⁴	India	20 D	19-35 years	Hanau wide-Vue	Kodak 8000 C unit	LC	36.05 (7.54)/32.75 (6.17)	36.05(7.54)/34.75 (7.69)	Both I/C/r	No significant difference found in mean sagittal condylar values obtained from arcon articulator and cephalometric tracings indicates replication of sagittal condylar guidance value from image of articular eminence.
Jerath S et al 2019 ²⁵	India	15 E	45-70 years	Hanau wide Vue	Newtom Giano, Italy	CBCT	33.09 (4.65)/26.80 (2.14)	33.81(3.45)/27.00 (2.23)	33.45 (4.04)/26.90 (2.19)	Highest value of horizontal condylar guidance angulation was obtained by CBCT, lowest was obtained by interocclusal wax records.
Katiyar P et al 2018 ²⁶	India	20 D	20-30 years	Hanau articulator Wide-Vue, Teledyne/Water Pik, Fort Collins, CO	Satelac X Mind Pano ceph digital x-ray machine	OPG	34.80 (12.697)/34.05 (14.16)/0.132	36.95 (11.30)/37.35 (14.13)/0.18	35.88 (11.916)/35.70 (14.06)/0.163	Considering the inaccuracies of the interocclusal record technique, the alternative method of recording protrusive condylar guidance angle by panoramic radiograph is not difficult to perform and appears to have useful clinical application.
Khalikar S et al 2017 ²⁷	India	10 E	50-60 years	Hanau wide vue articulator		OPG	25.8(4.26)/29.5 (4.7)	26.0(4)/31.0(3.29)		OPG and protrusive records may be used as a reliable guide for measuring condylar guidance angulation.
Kharzinejad A et al 2018 ²⁸	Iran	42 D			Cranex D Finland-himsilky	OPG	35.88(3.27)/33.9 (3.19)/0.81	35.93(3.27)/33.78 (3.22)/0.83		There was significant difference in the difference between the condylar slope in panoramic radiography and the interocclusal records in the right and left sides.
Kumar KR et al 2017 ²⁹	India	20 D	20-35 years		Kodak 8000C	LC	35.22 (1.42)/35.85 (1.38)	34.51(1.56)/35.85 (1.38)		The mean difference in the sagittal condylar guidance values of an arcon articulator and lateral cephalogram is non-significant on right side and highly significant on left side.

Table 2. Continued

Study ID	Place of study	Sample size D/E	Age group	Articulator model	Make of machine	Radiographic techniques	Dentulous/edentulous			Author's conclusions
							Right I/C/r	Left I/C/r	Both I/C/r	
Kumari W et al 2016 ³⁰	India	10 E	50-65 years	Hanau wide Vue semi-adjustable articulator		OPG	37.108(26)/25.7 (3.4)	38.0(9.56)/25.40 (3.59)		A definite difference was found between the condylar guidance values obtained by the OPG and the most commonly used extraoral gothic arch tracing method in edentulous patients.
Kwon OK et al 2017 ³¹	Korea	20 D	20-40 years		Kodak CS 9000; Carestream Dental, Sydney, Australia; Kavo Dental, Biberach, Germany	OPG CBCT	38.9(9.0)/35.3 (8.1)/30.1 (6.7)/0.834/0.845	38.7(6.4)/36.1 (6.3)/30.2 (6.3)/0.918/0.791		Strong correlations were detected between the SCGAs obtained using radiographic images and the protrusive occlusal record.
Lofter JE et al 2017 ⁷	Poland	10 D	18 years+			OPG	65.92(8.01)	64.83(5.81)		In young, healthy patients without clinical symptoms of TMJ dysfunction the functional OPG images should not be compared with the range of the mandibular opening.
Mittal S et al 2020 ³²	India	15 E	45-65 years	Hanau articulator model Wide-Vue, U.S.A		OPG	33.27(5.43)/35.0 (4.98)/0.719	30.93(4.90)/30.07 (5.13)/0.622		Panoramic radiographs can be considered as a reliable aid to calculate horizontal condylar guidance for programming of semi adjustable articulator.
Naqash TA et al 2020 ³³	Saudi Arabia	23 D	18-30 years	Denar Mark II articulator (Whip Mix Corporation, USA)	KaVo 3D eXam; Kavo Dental, Germany	CBCT	38.12 (4.81)/31.82 (4.53)/0.874	38.96(4.19)/32.14 (4.32)/0.842		Strong correlations were found between SCGAs obtained using PR and CBCT techniques. CBCT values were 6-7° higher than those obtained using the protrusive occlusal records.
Patil R et al 2015 ³⁴	India	10 E		HanauTM Wide-Vue Articulator (Whip Mix Corporation)	Kodak 8000c, France	OPG	17.00 (3.432)/18.50 (4.11)/0.53	17.30 (4.739)/20.00 (4.08)/0.55		Gothic arch tracing gave quite similar readings as suggested by the radiographic landmarks and can be continued as a successful clinical method.
Paul R et al 2018 ¹	India	20 E	45-75 years	Hanau™ Wide-Vue Articulator (Whip Mix Corporation, USA)	X-Mind Pano D+, Satelec, Acteon group, Thailand, Bangkok	OPG LC	35.60(4.97)/38.95 (4.77)/28.35 (5.62)/0.94/0.89	34.80(5.17)/38.95 (4.77)/28.00 (6.8518)/0.93	35.20 (4.94)/38.95 (4.77)/28.17 (5.99)/0.94	HCG values from cephalometric tracing of diagnostic radiographs can be used as an adjunct to the clinical method but cannot be used independently for programming a semi-adjustable articulator.

Table 2. Continued

Study ID	Place of study	Sample size D/E	Age group	Articulator model	Make of machine	Radiographic techniques	Dentulous/Edentulous			Author's conclusions
							Right I/C/r	Left I/C/r	Both I/C/r	
Prakash SS et al 2019 ³⁵	India	25 D	18-30 years	HANAU Wide - Vue Articulator Whip Mix Corporation, USA	STRONA Germany Newtom, Italy	OPG CBCT	35.85 (4.21)/30.96 (4.70)/29.80 (4.44) 0.97/0.958	35.96(4.23)/31.13 (4.22)/29.80 (4.44)/0.970/0.979	Between radiographic techniques, OPG showed higher HCI values than CBCT.	
Prasad KD 2012 ³⁶	India	75 D	20-40 years	HANAU Wide-Vue Articulator, Whip Mix Corporation, USA		OPG	36.68 (4.69)/34.71 (5.27)/0.413	38.18(5.22)/35.00 (4.85)/0.291	Interocclusal record technique with inherent errors of up to 30°; the radiographic method may have clinical relevance.	
Salemi F et al 2017 ⁸	Iran	28 D	13-43 years		SCARA II, Planmeca, Helsinki, Finland New Tom 3G (Quantitative Radiology, Verona, Italy)	OPG CBCT	35.43(30)/33.49 (2.94)/32.60 (3.08)	35.67(3.36)/33.94 (3.40)/32.92(3.16)	CBCT and Panoramic can be used instead of interocclusal record for adjusting condylar guidance in articulator, if necessary.	
Shah K et al 2014 ³⁷	India	24 E		Hanau Wide Vue		OPG	38.54 (4.18)/30.42 (6.06)/-0.078	41.88(5.69)/32.38 (8.55)/-0.109	Condylar guidance values obtained from the radiographs were higher than those obtained at the stage of jaw relation recording stage.	
Shah BI et al 2013 ³⁸	India	20 E	40-60 years	Hanau Wide Vue		OPG	37.93(8.89)/35.45 (4.69)	38.95(5.22)/37.35 (5.17)	No significant difference found in mean sagittal condylar values obtained from Hanau Wide Vue Articulator and OPG tracings indicates replication of sagittal condylar guidance values from image of articular eminence.	
Shetty S et al 2018 ³⁹	India	12 E		Hanau Wide-Vue		OPG	29.483 (4.64)/26.33 (3.75)	28.77(5.2)/26.67 (3.172)	Correlation exists between the condylar guidance angles obtained by radiographic method and intraoral gothic arch tracing method.	
Shetty S et al 2013 ⁴⁰	India	15 E		Hanau Wide Vue		OPG	37.13 (5.40)/12.73 (11.08)	35.13(4.79)/13.47 (9.87)	The condylar guidance value/angle obtained from the radiographs was higher than those obtained during jaw relation and try-in.	

Table 2. Continued

Study ID	Place of study	Sample size D/E	Age group	Articulator model	Make of machine	Radiographic techniques	Dentulous/Edentulous			Author's conclusions
							Right I/C/r	Left I/C/r	Both I/C/r	
Shrestha P et al 2012 ⁴³	India	12 D	20-40 years	Protar 7, KaVo Dental GmbH, Bismarckring, Biberach	Somatom Sensation 40, Siemens Erlanger Germany	CT scan	43.83 (6.57)/33.33 (7.75)/0.423	42.42(6.06)/33.64 (7.94)/0.237		The right and left HCG values were almost similar. The CT scan showed higher HCG values than the clinical methods
Singh S et al 2017 ⁴¹	India	10 D	20-40 years			LC	34.10 (6.41)/31.30 (7.31)/0.79	34.10(6.41)/31.80 (6.44)/0.90		Radiographic method can be used to yield consistent HCG; however, the protrusive method should be employed.
Sirana P et al 2018 ⁴²	India	20 E	35-60 years	Hanau Wide-View semi-adjustable articulator		OPG	29.35 (4.58)/26.84 (3.69)	27.54(5.01)/25.15 (3.24)		There was correlation between sagittal condylar guidance obtained by both intraoral gothic arch method as well as radiographic method done on digital panoramic radiographs.
Tannamala PK et al 2012 ⁴⁴	India	10 D		Hanau articulator Model Wide-View 183	Planmeca Promax; Helsinki, Finland	OPG	36.50 (3.75)/32.80 (5.01)	35.50(4.35)/32.10 (5.9)		The protrusive condylar guidance angles obtained by panoramic radiograph may be used in programming semi-adjustable articulators.
Vadodaria J 2015 ⁴⁵	India	30 D	24-40 years	Hanau Wide Vi		CBCT	39.63 (1.96)/27.43 (2.61)/0.08	40.50(2.70)/28.75 (3.01)/0.10		CBCT presents with highest mean condylar guidance values when compared with all three clinical methods.
Venkateshwaran R et al 2014 ⁴⁴	India	21 E				TMJ tomogram	30.47 (7.89)/25.23 (9.41)/0.78	30.47(8.35)/25.71 (10.15)/0.74		The articular eminence traced on a TMJ tomogram image represents the horizontal condylar inclination with a mean difference of 5° in 21 subjects evaluated.

C - Comparative group, CBCT - Cone beam computed tomography, D - Dentulous, E - Edentulous, I - Intervention group, LC - Lateral cephalogram, OPG - Orthopantomogram, r - Correlation co-efficient.

Table 3. Methodological quality appraisal of included studies.

Study ID	Objective clearly stated?	Study population clearly defined?	Participation rate at least 50%?	Subjects comparable?	Justification of sample size?	Reliability of outcome measures?	Assessors blinding?	Adjustment for confounders?	Quality of Studies
Acharya S et al 2015 ¹⁹	Yes	Yes	No	Yes	No	Yes	No	No	Fair ³²
Amin B et al 2018 ²⁰	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Bhandari A et al 2018 ²¹	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Das A et al 2020 ¹¹	Yes	Yes	No	Yes	Yes	Yes	No	No	Good
Dewan H et al 2019 ²²	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Galagali G et al 2016 ²³	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Godavarthi AS et al 2015 ⁷	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Goyal MK et al 2011 ²⁴	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Jerath S et al 2019 ²⁵	Yes	Yes	No	Yes	Yes	Yes	No	No	Good
Katiyar P et al 2018 ²⁶	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Khalikar S et al 2017 ²⁷	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Khazinejad A et al 2018 ²⁸	Yes	Yes	No	Yes	Yes	Yes	No	No	Good
Kumar KR et al 2017 ²⁹	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Kumari VV et al 2016 ³⁰	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Kwon OK et al 2017 ³¹	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Loster JE et al 2017 ⁹	Yes	Yes	No	Yes	No	Yes	Yes	No	Fair
Mittal S et al 2020 ³²	Yes	Yes	No	Yes	No	Yes	No	No	Fair

Table 3. Continued

Study ID	Objective clearly stated?	Study population clearly defined?	Participation rate at least 50%?	Subjects comparable?	Justification of sample size?	Reliability of outcome measures?	Assessors blinding?	Adjustment for confounders?	Quality of Studies
Naqash TA et al 2020 ³³	Yes	Yes	No	Yes	No	Yes	No	No	Fair ³⁴
Patil R et al 2015 ³⁴	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Paul R et al 2018 ¹	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Prakash SS et al 2019 ³⁵	Yes	Yes	No	Yes	Yes	Yes	No	No	Good
Prasad KD 2012 ³⁶	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Salemi F et al 2017 ⁸	Yes	Yes	No	Yes	No	Yes	Yes	No	Good
Shah K et al 2014 ³⁷	Yes	Yes	No	Yes	Yes	Yes	No	No	Good
Shah RJ et al 2013 ³⁸	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Shetty S et al 2018 ³⁹	Yes	Yes	No	Yes	Yes	Yes	No	No	Good
Shetty S et al 2013 ⁴⁰	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Shreshtha P et al 2012 ¹³	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Singh S et al 2017 ⁴¹	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Sirana P et al 2018 ⁴²	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Tannamala PK et al 2012 ¹⁴	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Vadodaria J 2015 ⁴³	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Venkateshwaran R et al 2014 ⁴⁴	Yes ⁹	Yes	No	Yes	No	Yes	No	No	Fair

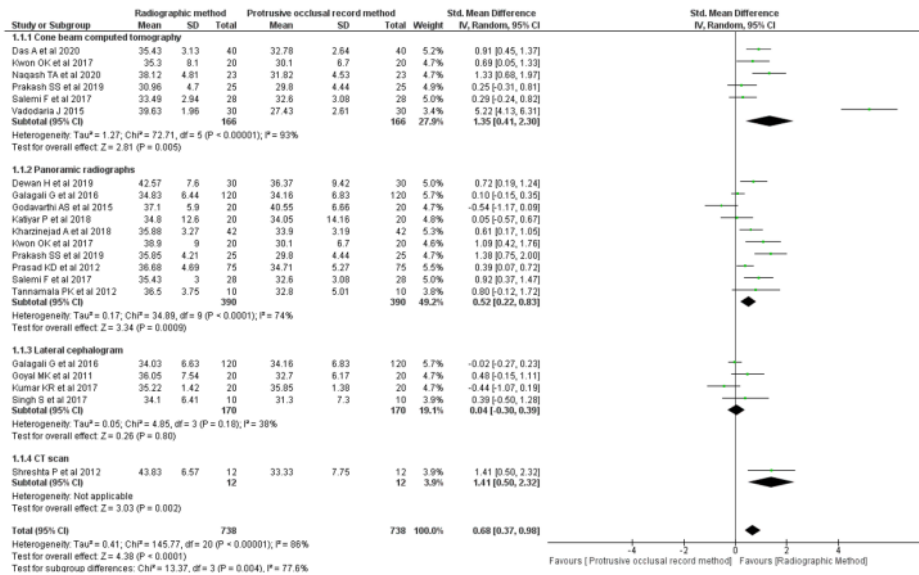


Figure 2. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for right side horizontal condylar guidance angle in dentulous patients. SD - standard deviation, IV - inverse variance, CI - confidence interval.

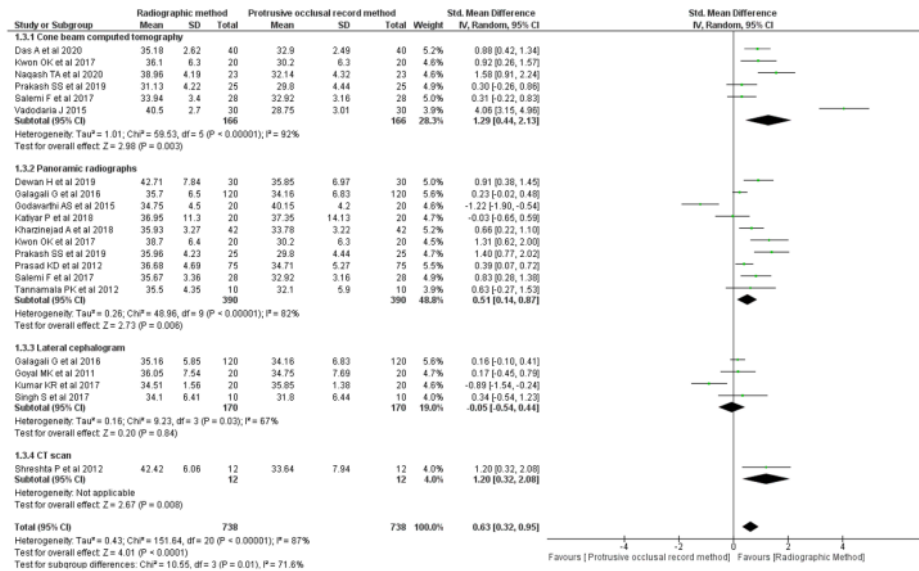


Figure 3. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for left side horizontal condylar guidance angle in dentulous patients. SD - standard deviation, IV - inverse variance, CI - confidence interval.

HCG angle of right side for edentulous patients

The pooled outcomes from 14 studies, 1,7,21,25,27,30,32,34,37-40,42,44 with total sample size of 257 and 237 in the radiographic and POR group, respectively, the standardised mean difference (SMD) value for HCG angle using random effect model was 0.82 [0.34, 1.29] and showed a statistically significant difference (P=0.0008) between the radiographic

and POR group [Tau²=0.68, Chi²=75.09, I²=83%] (Figure 4). After subgroup analysis was done using a random-effect model, it was shown that the CBCT method²⁵ had a statistically significant difference favouring the radiography technique (SMD, 1.69; 95% CI: 0.84–2.54; P<0.0001). For OPG method,^{1,7,21,27,30,32,34,37–40,42} radiographic method showed a statistically significant difference as compared to POR method (SMD, 0.65; 95% CI: 0.11–1.20; P=0.02) with 83% heterogeneity. LC method¹ showed a statistically significant difference between the radiographic and POR group (SMD, 1.99; 95% CI: 1.22–2.77; P<0.00001). TMJ tomogram method⁴⁴ did not show a statistically significant difference between the radiographic and POR method (SMD, 0.59; 95% CI: 0.34–1.29; P=0.06) (Figure 4).

HCG angle of left side for edentulous patients

The pooled outcomes from 14 studies,^{1,7,21,25,27,30,32,34,37–40,42,44} with total sample size of 257 and 237 in the radiographic and POR group, respectively, the standardized mean difference (SMD) value for HCG angle using random effect model was 0.66 [0.18, 1.15] and showed a statistically significant difference (P=0.007) between the radiographic and POR group [Tau²=0.67, Chi²=77.39, I²=83%] (Figure 5). After subgroup analysis was done using a random-effect

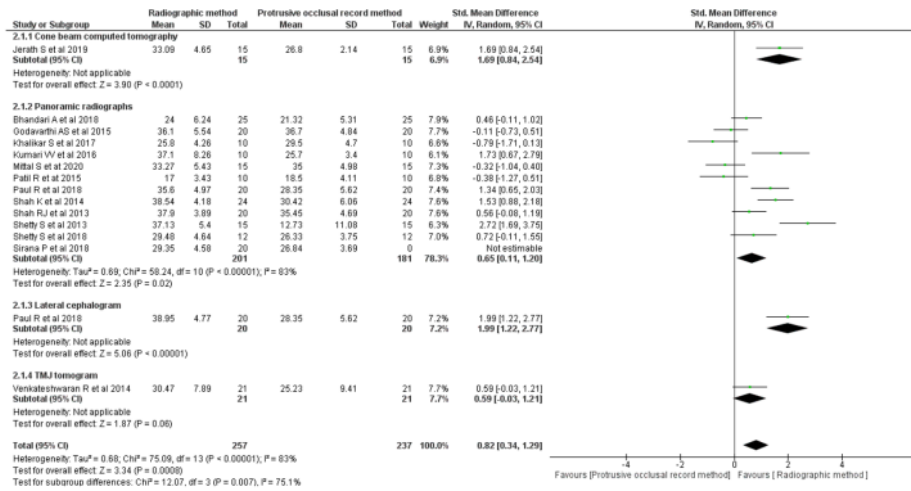


Figure 4. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for right side horizontal condylar guidance angle in edentulous patients. SD - standard deviation, IV - inverse variance, CI - confidence interval.

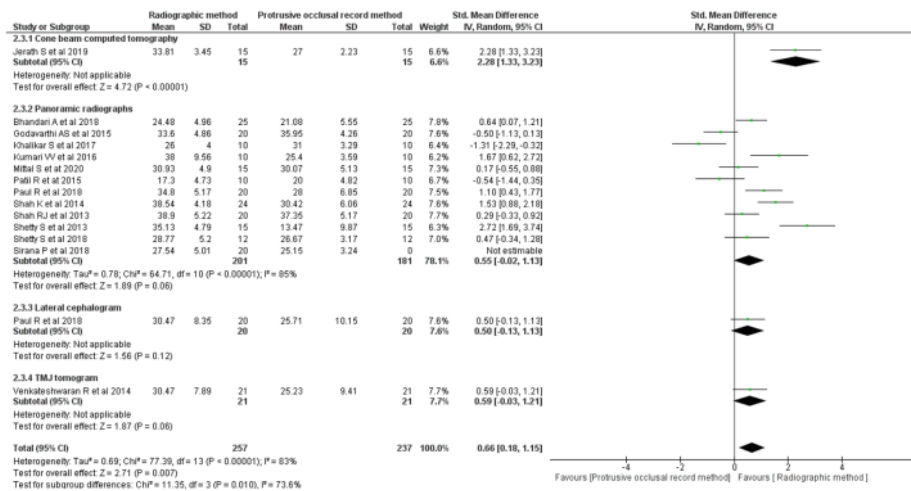


Figure 5. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive guidance records for left side horizontal condylar guidance angle in edentulous patients. SD - standard deviation, IV - inverse variance, CI - confidence interval.

Table 4. Sensitivity and subgroup analysis of the outcomes between radiographic techniques and protrusive occlusal record group for dentulous and edentulous patients.

Item	Dentulous patients' condylar guidance angle		Edentulous patients' condylar guidance angle	
	Right (SMD, 95% CI)	Left (SMD, 95% CI)	Right (SMD, 95% CI)	Left (SMD, 95% CI)
Original estimates by random effect model	0.68 [0.37, 0.98], P<0.0001	0.63 [0.32, 0.95], P<0.0001	0.80 [0.36, 1.24], P=0.0004	0.66 [0.18, 1.15], P=0.007
Inclusion of studies of low risk of bias only	0.80 [0.47, 1.12], P<0.00001	0.72 [0.42, 1.01], P<0.00001	1.34 [0.78, 1.89], P<0.00001	1.41 [0.46, 2.36], P=0.004
Inclusion of studies of moderate risk of bias only	0.68 [0.28, 1.08], P=0.0009	0.61 [0.19, 1.02], P=0.004	0.68 [0.12, 1.24], P=0.02	0.46 [-0.05, 0.97], P=0.08
Fixed or random effects				
Random effect	0.68 [0.37, 0.98], P<0.0001	0.63 [0.32, 0.95], P<0.0001	0.80 [0.36, 1.24], P=0.0004	0.66 [0.18, 1.15], P=0.007
Fixed effect	0.42 [0.31, 0.53], P<0.00001	0.46 [0.36, 0.57], P<0.00001	0.73 [0.54, 0.92], P<0.00001	0.60 [0.41, 0.80], P<0.00001
Exclusion of subgroups with single study	0.57 [0.27, 0.87], P=0.0002	0.61 [0.29, 0.93], P=0.0002	0.64 [0.15, 1.13], P=0.010	0.55 [-0.02, 1.13], P<0.00001
Inclusion of CBCT only	1.35 [0.41, 2.30], P=0.005	1.29 [0.44, 2.13], P=0.003	-	-
Inclusion of OPG only	0.52 [0.22, 0.83], P=0.0009	0.51 [0.14, 0.87], P=0.006	0.64 [0.15, 1.13], P=0.010	0.55 [-0.02, 1.13], P<0.00001
Inclusion of LC only	0.04 [-0.30, 0.39], P=0.80	-0.05 [-0.54, 0.44], P=0.84	-	-

CBCT - Cone beam computed tomography, CI - Confidence interval, LC - Lateral Cephalogram, OPG - Orthopantomogram, SDM - Standardised mean difference.

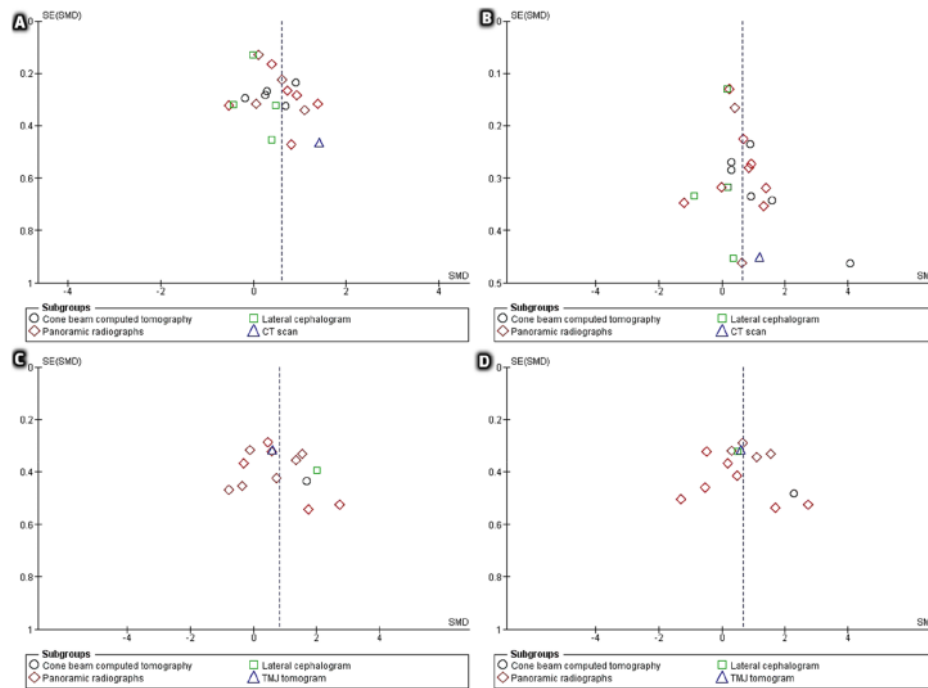


Figure 6. Funnel plot for horizontal condylar guidance angle, **A: Right side dentulous patients, B: Left side dentulous patients, C: Right side edentulous patients, D: Left side edentulous patient.** CT - Computed tomography, SE - Standard error, SMD- Standardized mean difference, TMJ - Temporo-mandibular joint.

model, it was discovered that for the CBCT technique,²⁵ there was a statistically significant difference favouring the radiography method (SMD, 2.28; 95% CI: 1.33–3.23; $P < 0.00001$). For OPG method,^{1,7,21,27,30,32,34,37–40,42} radiographic method showed a statistically significant difference as compared to POR method (SMD, 0.55; 95% CI: -0.02–1.13; $P = 0.06$) with 85% heterogeneity. LC method¹ did not show a statistically significant difference between the radiographic and POR group (SMD, 0.50; 95% CI: -0.13–1.13; $P = 0.12$). TMJ tomogram method⁴⁴ did not show a statistically significant difference between the radiographic and POR method (SMD, 0.59; 95% CI: -0.03–1.21; $P = 0.06$) (Figure 5).

Sensitivity analysis

Table 4 presents the results of sensitivity analysis of the right and left HCG angle for the dentate and edentulous patients. Studies of fair quality^{1,7,9,13,14,19–24,26,27,29–34,36,38,40–44} or good quality^{8,11,25,28,35,37,39} were excluded from sensitivity analysis. After excluding these studies, the HCG angle values for the right and left sides of dentate patients, as well as the right side of edentulous patients, did not show a significant difference when comparing the radiographic and POR groups, with the exception of the left HCG angle values in edentulous patients, which showed an adverse change. A reanalysis using the fixed-effect model revealed that the results were not unfavourable. Excluding subgroups from a single research did not result in a substantial improvement in the SMD of HCG levels. Also, the inclusion of single radiographic technique of only CBCT and only OPG showed that the outcomes were not adverse whereas when inclusion of only LC was considered no statistically significant difference was found between the radiographic and protrusive occlusal record group for the HCG value of right and left side for dentate patients (Table 4).

Publication bias

Figure 6 represents the funnel plot comparing horizontal condylar guidance angle between radiographic techniques and protrusive occlusal records for HCG angle values of right and left side for dentate and edentulous patients resemble a symmetrical (inverted) funnel indicating lack of publication bias.

Discussion

The route followed by the condyle with reference to the articular eminence when the mandible advances protrusively or laterally from centric relation is referred to as the condylar path.⁴⁵ It is an essential regulating element since it impacts mandibular motions and is unique to each patient.¹⁹

Prosthodontics considers an equivalent of condylar guiding on an articulator to be an essential requirement.⁴⁶ Articulators are utilised to imitate the patient's interocclusal positioning and certain mandibular motions. The sophistication and adaptability of the articulator determine the precision with which mandibular motions are reproduced. Using proper technique, the semi-adjustable articulator is capable of replicating specific points on the path of the condyle during a protrusive movement, when set with an interocclusal positional record.⁴⁷

Because condylar inclination values obtained with various planes of reference cannot be compared,⁴⁸ the plane of reference is an important element to consider. As a result, the radiological pictures give sagittal reconstructions of the skeletal components, and the contour of the articular eminence may be utilised to help in establishing the condylar guiding inclination of a semi-adjustable articulator.¹⁹

As a result, the goal of this study was to compare the condylar guidance values acquired by tracing radiography pictures to those produced by interocclusal protrusive recordings of dentulous and edentulous patients. The values of horizontal condylar inclination vary with age, gender, and ethnicity. This review included 33 studies published from 2011 to 2020 conducted in various countries which directly compared both the techniques. The age of the included dentate and edentulous patients ranged 18–43 years and 35–75 years, respectively. In completely edentulous patients, condylar paths are determined by the following factors: the bony fossae, tone of the muscles responsible for mandibular movements and their nerve controls, limitations imposed by the attached ligaments, shape and movements of the menisci while in dentate patients during protrusive movement, as the mandible moves forward there is an influence of the anterior guidance which affects the exact path of the condyle, hence separate analysis of dentate and edentulous patients was conducted.⁴⁹ Hence, the results of this systematic review can be applicable to a varied population range and also in conditions as close as possible to those observed in daily clinical practice.

The overall results of the present systematic review and meta-analysis indicated that the HCG angle values of the right and left side showed a statistically significant difference favouring the radiographic method as compared to POR for dentate as well as edentulous patients. The sub-group analysis showed that for CBCT and OPG images the SMD of HCG angle values for dentate and edentulous patients on right side and left side showed a statistically significant difference as compared to the POR method except for edentulous patients the left side HCG angle values did not show a statistically significant difference between the two groups, whereas for LC images the SMD of HCG angle values of right and left side did not show a statistically significant difference between the two groups, except in edentulous patients right side HCG angle values showed a significant difference between the two groups.

The methodologies applied in the studies differed considerably. In the clinical method, the protrusive jaw relation is used to set the condylar elements of the articulator so they will reproduce inclinations, which are exact or nearer to the patient's temporomandibular articulation. In the included studies interocclusal protrusive wax records, Lucia jig and gothic arch tracers have been used in setting the condylar guidance in semi-adjustable articulators. As the HCG changes with amount of protrusion, for studies where protrusive wax records were used the amount of protrusion was kept same for all the patients at 6 mm and the same protrusive records were used for programming the articulator so it is important to keep the distance of protrusion the same.^{20,50} Once the protrusive jaw relation is established, the majority of research employed a Hanua Wide-vue semi adjustable articulator, while a few studies used a whip mix semi adjustable articulator to measure horizontal condylar inclination. The reference plane is used to calculate horizontal condylar inclination. Hanua articulators generate more precise angles since they mount the cast in reference to the Frankfort horizontal plane, whereas whip mix employs the nasion-porion plane as a reference plane.^{35,51} POR technique for measuring SCGAs, regardless of the material used, is inconsistent, lacks precision and has lower levels of reproducibility because of significant differences between the instruments,^{31,33} deformation or compression of the records, cast tipping due to improper adaptation of casts, force applied by the operator on record,³² changes in values with the degree of protrusion, the amount of overjet and overbite.^{1,8,33} Also, semi-adjustable articulators are unable to reconstruct the condylar movements adequately because of their fixed inter-condylar distance and straight condylar pathway.³³ Christensen et al. demonstrated that radiographically measured condylar angles yielded higher values than intraoral recording techniques. The rigid mechanical principles controlling the motions of an adjustable articulator appear to be inapplicable to man's dynamic mandibular locomotor system.^{19,52}

Panoramic radiography, lateral cephalogram and CBCT are now widely used in diagnoses. Significantly higher condylar guidance angle values in panoramic radiograph as compared to protrusive interocclusal record are reported for this review. The review's results might be supported for any of the following basis. First, the panoramic radiography technique often yields a larger value than the actual, as demonstrated by Gilboa et al.⁴⁶ in their study, in which they discovered the sagittal condylar inclination to be seven degrees more on average than its true anatomic contour in dry skulls. Second, when the occlusal rims are kept in a protruded mandibular position, they exert significant pressure on the mucosa of the

denture basal seat, depressing the resilient oral mucosa and bringing the inter-ridge distance closer, resulting in a narrower triangular wedge shaped space between the posterior part of the occlusal rims, similar to the Christensen's space found in natural dentition and documented by protrusive interocclusal records, resulting in a lower value for HCG when positioned in semi-adjustable articulators.^{20,21} While the results obtained by lateral cephalogram were comparable to that of POR. However, the reference line used in all the included studies is the same, there were variations in the results of the included patients studies which may be because of variation in patients head positioning leading to parallax errors, the models of the panoramic machine, magnification differences, image distortions, overlapping of the mandibular notch, coronoid process, zygomatic arch around TMJ in an OPG and LC as well as the quantitative measurements can be affected by the different operator's perceptions.^{7,14,21,23,30,34}

The glenoid fossa and the AE can be easily identified since CBCT gives a three-dimensional information for both sides without superimpositions. For both dentate and edentulous individuals, the mean sagittal condylar values obtained from CBCT are slightly greater than those obtained from POR on both sides. Similar results were obtained by the individual studies included in the review, where in the study by Vadodaria⁴³ condylar guidance obtained by CBCT were about 10° more than clinical methods were testified by Jerath et al.,²⁵ Kwon et al.³¹ and Naqash et al.³³ where HCG angle values obtained from CBCT measurements being 5°–6° higher than those from protrusive occlusal records. The most significant advantage of CBCT is that it produces unique pictures that demonstrate characteristics in 3D that intraoral, panoramic, and cephalometric images do not. Cursor-driven measurement methods offer the physician an interactive real-time dimensional evaluation capability. Measurements taken on a computer screen are free of distortion and magnification. Furthermore, CBCT has other advantages such as superior image quality, employing a narrower field of view for a shorter check time, compatibility with various radiographic arrangements for image output, and ease of setup of minimum units in a general clinical context. These CBCT preferences may be utilised to determine the condylar position during dynamic registration in edentulous and dentulous patients and precisely locate the condyle.^{8,43,53} The main drawback of utilising CBCT is the expensive cost of the equipment.⁵⁴ For, CT scan and TMJ tomo gram radiographic technique only one study in each group was included, hence it is difficult to draw conclusions for these techniques.

Nonetheless, there are several limits to this evaluation. The clinical variability among the selected studies could not be completely avoided. The studies' sample sizes were limited, resulting in a lack of statistical power. None of the investigations correlated HCG angle measurements to actual MRI images, which are the gold standard in diagnosing TMJ problems.⁹ The eligible studies provided less evidence for inter and intra examiner reliability for radiographic scans and POR. Also, separate analysis was not performed for different methods of recording POR (protrusive wax records, jig's method and gothic arc tracing), number of missing teeth for partially edentulous patients as well as comparison between different radiographic methods and right and left HCG angles was also not performed. However, to rule out potential causes of heterogeneity, subgroup and sensitivity analyses were done separately for dentate and edentulous individuals for the right and left HCG angle. Likewise, it was difficult to rule out the clinical heterogeneity occurring because of type of radiographic machine, tube voltage, selection of landmarks, head positioning and software capabilities. Only, seven studies were rated as good quality studies, exhibiting a low risk of bias suggesting that in future, high-quality of *in-vivo* studies assessing the reliability and accuracy of radiographic scans and POR with consistent outcome parameter should be conducted.

Conclusions

The present systematic review and meta-analysis concluded that for the dentate and edentulous patients, the right and left HCG angle values determined by radiographic method showed statistically significant difference as compared to the protrusive occlusal records. Yet, in clinical general practice, the approach most used to assess horizontal condylar inclination is by recording protrusive interocclusal records; however, if not managed properly, this method may result in restoration with distinctive errors. The numerous radiography approaches available through CBCT, OPG, and LC provide unique opportunities to minimise mistakes that may occur as a result of material mishandling while eliminating time-consuming procedures. Therefore, a clinically applicable HCG angle to program semi-adjustable dental articulators can be obtained by adjusting the value measured using CBCT images and pantographic tracings.

Data availability

Underlying data

All data underlying the results are available as part of the article and no additional source data are required.

Reporting guidelines

Open Science Framework: PRISMA checklist for 'Accuracy of radiographic and protrusive occlusal record methods in determining condylar guidance angles: a systematic review and meta-analysis' <https://doi.org/10.17605/OSF.IO/WAQNJ>.⁵⁵

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Vineet Vinay 

Department of Public Health Dentistry, Sinhgad Dental College and Hospital, Pune, Maharashtra, India

The systematic review is conducted properly. The best features of this systematic review are the process of search strategy, data extraction, and quantitative synthesis of the results.

The language of the manuscript is up to the mark.

Kindly look for more systematic reviews in the same line and conduct Umbrella review in future.

The hard work of the researchers is clearly depicted in the conduct and writing of the manuscript.

As a statistician, I can say that the sensitivity and subgroup analysis is a correctly done and it fulfills the requirements of the research.

However I personally believe that any research cannot be perfectly done. In this manuscript, there are limitations regarding the number of studies included, however, I believe that it's not in the hand of the researchers.

Are the rationale for, and objectives of, the Systematic Review clearly stated?

Yes

Are sufficient details of the methods and analysis provided to allow replication by others?

Yes

Is the statistical analysis and its interpretation appropriate?

Yes

Are the conclusions drawn adequately supported by the results presented in the review?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Systematic Review and Meta-analysis, Research design, Statistics

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 15 Mar 2022

Dian Agustin Wahjuningrum, Faculty of Dental Medicine, Universitas Airlangga, Surabaya City, East Java, Indonesia

Thank you so much, respected reviewer, for the positive comments to our attempt to perform a systematic review and meta analysis.

We will surely look for more systematic reviews in the same context and conduct Umbrella review in future.

Appreciation from a person who expertise in statistic, we are highly obliged.

Thank you once again, respected reviewer.

Competing Interests: No competing interests were disclosed.

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