BUKTI KORESPONDENSI
Jurnal Internasional Bereputasi

Judul Artikel	:	Accuracy of radiographic and protrusive occlusal record methods in determining condylar guidance angles: a systematic review and meta-analysis.
Penulis	:	Alexander Maniangat Luke, Sam Thomas Kuriadom, Jeny Mary George**, Dian Agustin Wahjuningrum**
Jurnal	:	F1000Research 2022, 11:105
Penerbit	:	Taylor & Francis

1	Manuscript was submitted to Journal **"F1000Research"**	**Received: 6 November 2021**
	Thank you for submitting your manuscript: Accuracy of Radiographic and protrusive occlusal record methods in determining condylar guidance anglesA systematic review and Meta-analysis Luke AM et al.	
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3	Decision: **Accepted for Publication**	**14 Desember 2021**
4.	**Published on F1000Research 2022, 11:105**	**27 Januari 2022**
5.	**First peer review report published**	**09 Maret 2022**
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6.	**Reviewers suggested for your article 75347**	**08 Juni 2022**

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]

Alexander Maniangat Luke[1,2], Sam Thomas Kuriadom[1,2], Jeny Mary George[1], Dian Agustin Wahjuningrum[3]

Author details

This article is included in the IIARP Publications gateway.

Abstract

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 occlusal records.

PROSPERO registration: CRD42020206599 (28/09/2020)

Keywords

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

Corresponding authors: Alexander Maniangat Luke, Dian Agustin Wahjuningrum

Competing interests: No competing interests were disclosed.

Grant information: The author(s) declared that no grants were involved in supporting this work.

How to cite: Luke AM, Kuriadom ST, George JM and Wahjuningrum DA. 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]. *F1000Research* 2022, 11:105 (https://doi.org/10.12688/f1000research.75347.1)

First published: 27 Jan 2022, 11:105 (https://doi.org/10.12688/f1000research.75347.1)
Latest published: 27 Jan 2022, 11:105 (https://doi.org/10.12688/f1000research.75347.1)

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

Reviewer Report 16 Views

08 Mar 2022 | for Version 1

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

Cite this report

Responses (1)

APPROVED

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.

https://f1000research.com/articles/11-105/v1#referee-response-121335

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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?

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

Back to all reports

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

https://f1000research.com/articles/11-105/v1#referee-response-121335

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.

Focused Q...	Is there ...
Populatio...	(Dentate ...
Intervent...	(Dental r...
Compariso...	(Protrusi...

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

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,

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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.

RESPOND TO THIS REPORT

Responses (1)

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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RESPOND TO THIS REPORT

Responses (1)

AUTHOR RESPONSE 16 Mar 2022

Dian Agustin Wahjuningrum, Department of Conservative Dentistry, Faculty of Dental Medicine, Universitas Airlingga, Surabaya City, East Java, 60132, Indonesia

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

Competing Interests

No competing interests were disclosed.

Respond Report a concern

agustin wahjuningrum Dian <dian-agustin-w@fkg.unair.ac.id>

Article submission received

1 pesan

editorial@f1000research.com <editorial@f1000research.com> 6 November 2021 13.52
Kepada: dian-agustin-w@fkg.unair.ac.id

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Thank you for submitting your manuscript:

Accuracy of Radiographic and protrusive occlusal record methods in determining condylar guidance angles- A systematic review and Meta-analysis
Luke AM *et al.*

Funders: no grant funding was stated during submission.

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Please quote the article number 75347 in any correspondence.

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Luke AM, Kuriadom ST, George JM and Wahjuningrum DA

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The details provided are:

Dian Agustin Wahjuningrum
Universitas Airlangga
Prof Moestopo 47

60132
Indonesia

The APC for this article, once any discounts have been taken into account, is $1350.00

If you have any questions, please contact us as soon as possible.

Best regards

The F1000Research team

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Luke AM, Kuriadom ST, George JM and Wahjuningrum DA

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Best wishes,

Florence
The Editorial Team, F1000Research

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Regards

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First peer review report published

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Accuracy of radiographic and protrusive occlusal record methods in determining condylar guidance angles: a systematic review and meta-analysis
Luke AM, Kuriadom ST, George JM and Wahjuningrum DA

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Best regards,

Helena
The Editorial Team, F1000Research

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Reviewers suggested for your article 75347

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Dear Dian Agustin

Accuracy of radiographic and protrusive occlusal record methods in determining condylar guidance angles: a systematic review and meta-analysis
Luke AM, Kuriadom ST, George JM and Wahjuningrum DA

I hope you're well. As your article requires further reviewer suggestions, we have selected some potential reviewers which we would like you to check, so that we can invite them to review your article.

The suggested reviewers meet our suitability criteria, and according to our assessment appear to be appropriate for your paper. Please look at the Suggestions Awaiting Approval section of your Suggest Reviewers page to check whether they have an appropriate level of expertise, and don't (as far as you are aware) have any relevant conflicts of interest. Please either approve or reject the suggestions.

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Best regards,

Helena
The Editorial Team, F1000Research

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Pg. 1 ln 2
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Attached
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Pg. 2 ln 24-32
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Pg. 2 ln 31-34, ln 43-45
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Pg. 3 ln 3-28
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Pg. 2 ln 47-52
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Pg. 2 & 3 Table 1
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Pg. 3 ln 2-14
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Pg. 3 ln 17-21
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Pg. 3ln 14-15
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Pg. 4 ln 17-21
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Pg. 4 ln 23-29
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Pg. 4 ln 31-37
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Pg. 5 ln 1-13
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	n/a
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	nil
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Pg. 4 ln 31-37
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Pg. 4 ln 31-37
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Pg. 4 ln 31-37

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Pg. 5(Fig 1)
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Pg. 4 ln 47-49
Study characteristics	17	Cite each included study and present its characteristics.	Pg. 7-12 Table 2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Pg. 12 table 3
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimates and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Pg. 7-12 Table 2
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Pg. 12 ln 6-10
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Pg. 13 (ln 3) – pg. 17(ln 5) Figures 2,3,4,5,
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Pg. 17 ln 8 – 18 & table 4
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Pg. 19 Fig 9
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Pg. 12 table 3
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Pg. 20 (ln 11) to pg. 21(ln9)
	23b	Discuss any limitations of the evidence included in the review.	Pg. 21, ln 13-20
	23c	Discuss any limitations of the review processes used.	Pg. 21, ln 10-17
	23d	Discuss implications of the results for practice, policy, and future research.	Pg. 2, ln 27-33
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Pg. 2, ln38
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Pg. 2, ln 38 -40
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N/A
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Pg. 24, ln 44

Section and Topic	Item #	Checklist item	Location where item is reported
Competing interests	26	Declare any competing interests of review authors.	Pg. 21, ln 47
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Pg. 21, ln 41

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71
For more information, visit: http://www.prisma-statement.org/

PRISMA 2020 for Abstracts Checklist

Section and Topic	Item #	Checklist item	Reported (Yes/No)
TITLE			
Title	1	Identify the report as a systematic review.	Yes
BACKGROUND			
Objectives	2	Provide an explicit statement of the main objective(s) or question(s) the review addresses.	Yes
METHODS			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for the review.	Yes
Information sources	4	Specify the information sources (e.g. databases, registers) used to identify studies and the date when each was last searched.	Yes
Risk of bias	5	Specify the methods used to assess risk of bias in the included studies.	Yes
Synthesis of results	6	Specify the methods used to present and synthesise results.	Yes
RESULTS			
Included studies	7	Give the total number of included studies and participants and summarise relevant characteristics of studies.	Yes
Synthesis of results	8	Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and confidence/credible interval. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	Yes
DISCUSSION			
Limitations of evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency and imprecision).	Yes
Interpretation	10	Provide a general interpretation of the results and important implications.	Yes
OTHER			
Funding	11	Specify the primary source of funding for the review.	No
Registration	12	Provide the register name and registration number.	Yes

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

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Accuracy of ~~R~~radiographic and protrusive occlusal record methods in determining condylar guidance angles~~-~~: a~~A~~ systematic review and m~~M~~eta-analysis

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Abstract~~-~~

Background: The objective of this systematic review was to investigate and 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 ~~C~~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 ~~c~~Comprehensive search with PubMed/MEDLINE, Cochrane Central Register of Controlled Trials, Web of Science, Google Scholar and Open Grey databases was done and two reviewers extracted the data after assessing the studies for eligibility criteria. ~~**Results:**~~ The quality of the selected studies was examined using the NIH quality assessment tool and graded based on tooth selection, the number of root canals assessed, the study environment, the number of observers, the test reliability report, the validation approach, the validation criteria, and the validity reliability. A meta-analysis of pooled data, subgroups and sensitivity analysis was performed using RevMan ($P<0.05$).

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: The clinical variability among the selected studies could not be completely avoided as well as the studies' sample sizes were limited, resulting in a lack of statistical power. 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. 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. ~~For dentate and edentulous patients, the HCG angle values determined by radiographic method showed significantly accurate measurements as compared to POR method.~~

PROSPERO registration: CRD42020206599 (28/09/2020)

Keywords: Horizontal condylar guidance; Cone beam computed tomography; Lateral cephalogram; Panoramic radiograph; Protrusive occlusal record

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 Terms 9 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.

Materials and 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].

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?"

Protocol and registrationSearch strategy

To obtain papers in the English language, a complete electronic search was conducted on databases such as PubMed/ MEDLINE, Cochrane Central Register of Controlled Trials, and Web of Science from 1st January 2011 tillunti 31st December 2020. The distinct electronic search of the journals listed in Table 1 was carried out. Google Scholar, Greylist, 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.

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

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 1 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), ~~O~~orthopantomogram (OPG), lateral cephalograms, computerized tomography (CT) scan and temporomandibular joint (TMJ) tomogram for determining accurate measurements of condylar inclination.

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-randomi~~s~~ed 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 Studies [16] 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 $I2>50\%$ and $P\leq0.10$, 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.

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], Korea [31] and Poland [9]. In total, 20~~Twenty~~ 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~~fifteen~~ 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, 23,24,26,28,29,31,33,35,36,41,43]. 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 al [7] 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~~7~~ studies recorded HCG angle with CBCT [8,11,25,31,33,35,43], five~~5~~ studies used LC [1,23,24,29,41] and one study each recorded HCG angle with CT scan [13] 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 al [26] and Paul et al [1] cumulative value of right and left angle is mentioned.

1 **Table 2:** Characteristics of the included studies.

2

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	
Acharya S et al 2015 [19]	India	20 D 20 E	18-30 years 45-75 years	HANAU articulator modelWide-Vue, U.S.A.	Orthoralix 9200; Gendex Dental Systems, Milan, Italy)	OPG	Dentulous 35.8/33.75/0.57 Edentulous 30.35/26.5/0.57	Dentulous 34.05/34.25/0.55 Edentulous 29.50/26.75/0.72		Measurement of condylar inclination angles using panoramic radiographs gave higher values, as compared to the inter-occlusal record method.
Amin B et al 2018 [20]	India	30 D 30 E	40 - 60 years	Hanau Wide-Vue	Orthophos XG	OPG			Dentulous 35.53(6.248)/ 30.83(5.384) Edentulous 29.10(9.135)/ 24.20(7.066)	The use of OPG to set condylar guidance on the articulator should be taken into consideration for both dentulous and edentulous subjects
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	CBCT	35.43(3.13)/ 32.78(2.64)/ 0.95	35.18(2.62)/ 32.9(2.49)/ 0.95		CBCT 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.
Galagali G et al 2016 [23]	India	120 D	20–40 years	HANAUTM Wide-Vue,		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

				Whip Mix Corporation, USA						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 Gendexorth oralix 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(4.860)/ 35.95(4.261)/0.329		Panoramic radiograph can be used as an alternative to interocclusal technique only in edentulous patients.
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)		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-hinisilky	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.

Kumari VV et al 2016 [30]	India	10 E	50-65 years	Hanau wide Vue semi-adjustable articulator		OPG	37.10(8.26)/ 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.
Loster JE et al 2017 [9]	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 at 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 at 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,	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(6.851 8)/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

					Bangkok				
Prakash SS et al 2019 [35]	India	25 D	18 – 30 years	HANAU Wide – Vue Articulator, Whip Mix Corporation , USA	SIRONA Germany Newtom, Italy	OPG CBCT	35.85(4.21)/ 30.96(4.70)/ 29.80(4.44) 0.97/ 0.958	35.964.23)/ 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 RJ et al 2013 [38]	India	20 E	40-60 years	Hanau Wide Vue		OPG	37.9(3.89)/ 35.45(4.69)	38.9(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.
Shreshta P et al 2012 [13]	India	12 D	20-40 years	Protar 7, KaVo Dental GmbH, Bismarckring, Biberach	Somaton 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-Vue 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 [14]	India	10 D		Hanau articulator ModelWide-Vue 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 [43]	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 bean computed tomography, D- Dentulous, E- Edentulous, I- Intervention group, LC- Lateral cephalogram, OPG- Orthopantomogram, r- Correlation co-efficient

Assessment of rRisk 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 seven7 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.

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
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
Kharzinejad 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 at 2020 [32]	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Naqash TA et al 2020 [33]	Yes	Yes	No	Yes	No	Yes	No	No	Fair
Patil R et at 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
Shreshta 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	Yes	No	Yes	No	Yes	No	No	Fair

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 [8,11,13,14,22,23,24,26,28,29,31,33,35,36,41,43], 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 method [13] 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).

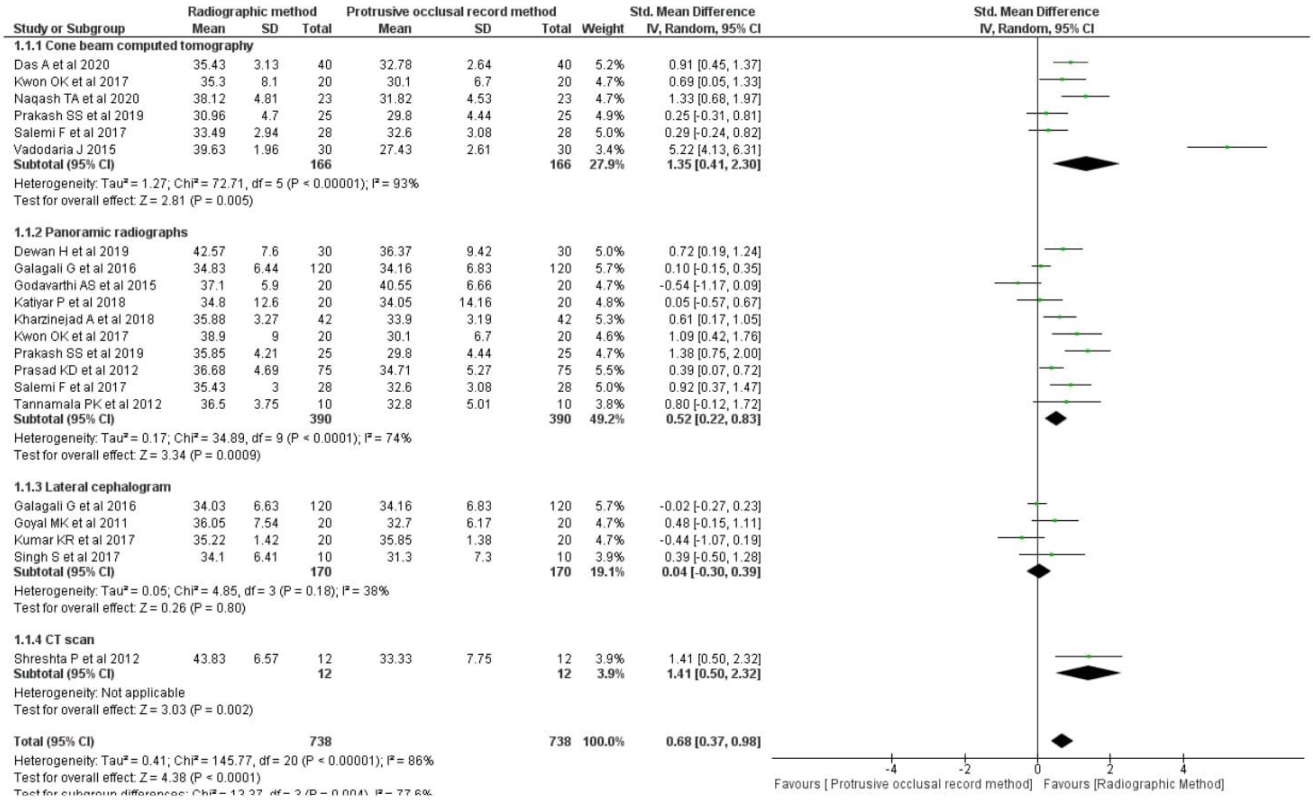

Figure 2. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for right side horizontal condylar guidance angle in dentulous patients. SD- standard deviation, IV- inverse variance~~XXX,~~ CI- confidence interval.

HCG angle of left side for dentate patients

The pooled outcomes from 16 studies [8,11,13,14,22,23,24,26,28,29,31,33,35,36,41,43], 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 method [13] showed a statistically significant difference.

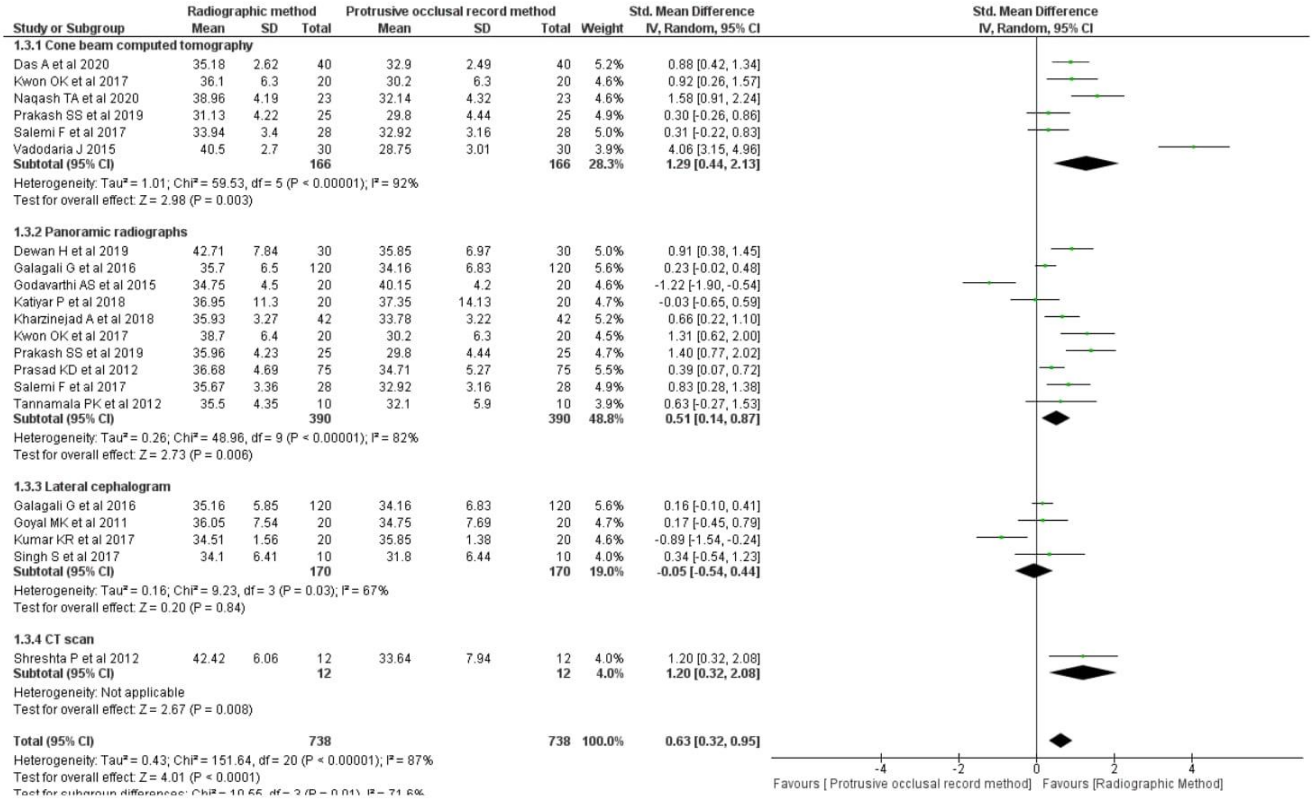

Figure 3. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for left side horizontal condylar guidance angle in dentulous patients. SD- standard deviation, IV- inverse variance ~~XXX,~~ CI- confidence interval.

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 standardi~~z~~sed 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 [Tau^2 =0.68, Chi^2 =75.09, I^2 = 83%], (Figure 4). After subgroup analysis was done using a random-effect model, it was shown that the CBCT method [25] 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 method [1] 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 method [44] 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).

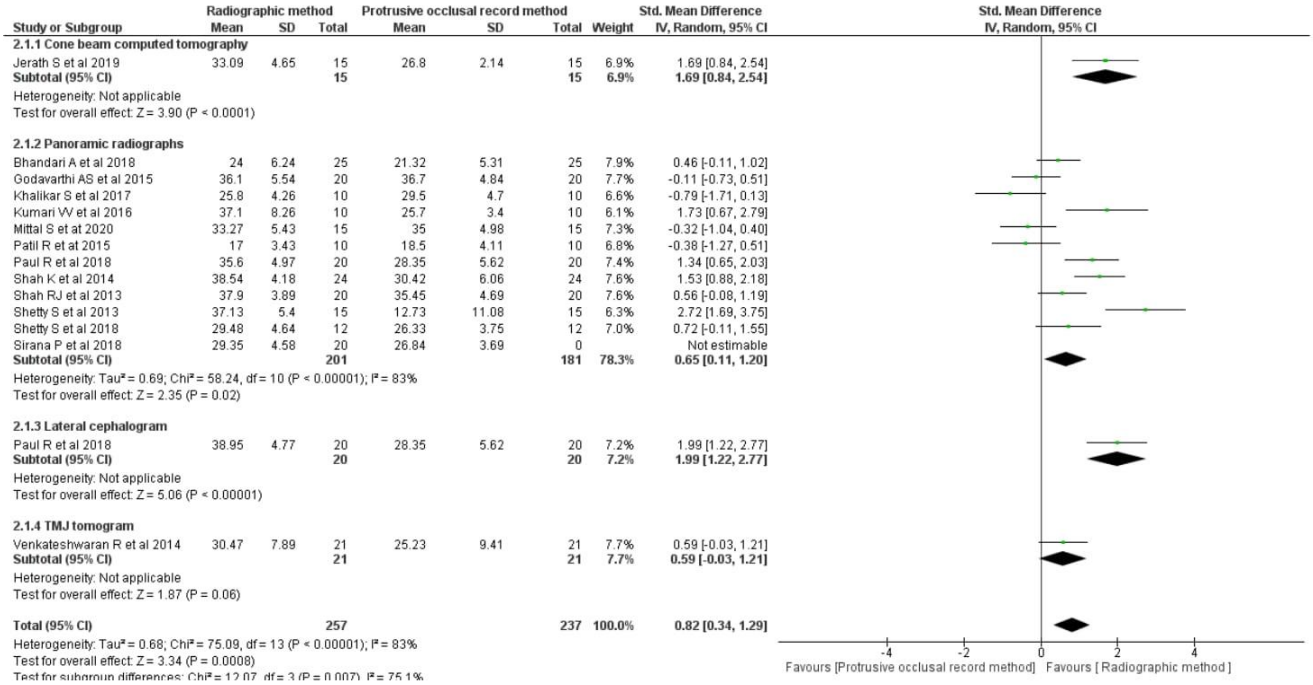

Figure 4. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for right side horizontal condylar guidance angle in edentulous patients. SD- standard deviation, IV- inverse variance~~XXX,~~ CI- confidence interval.

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 [Tau^2 =0.67, Chi^2 =77.39, I^2 = 83%], (Figure 5). After subgroup analysis was done using a random-effect 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 method [1] 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 method [44] 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).

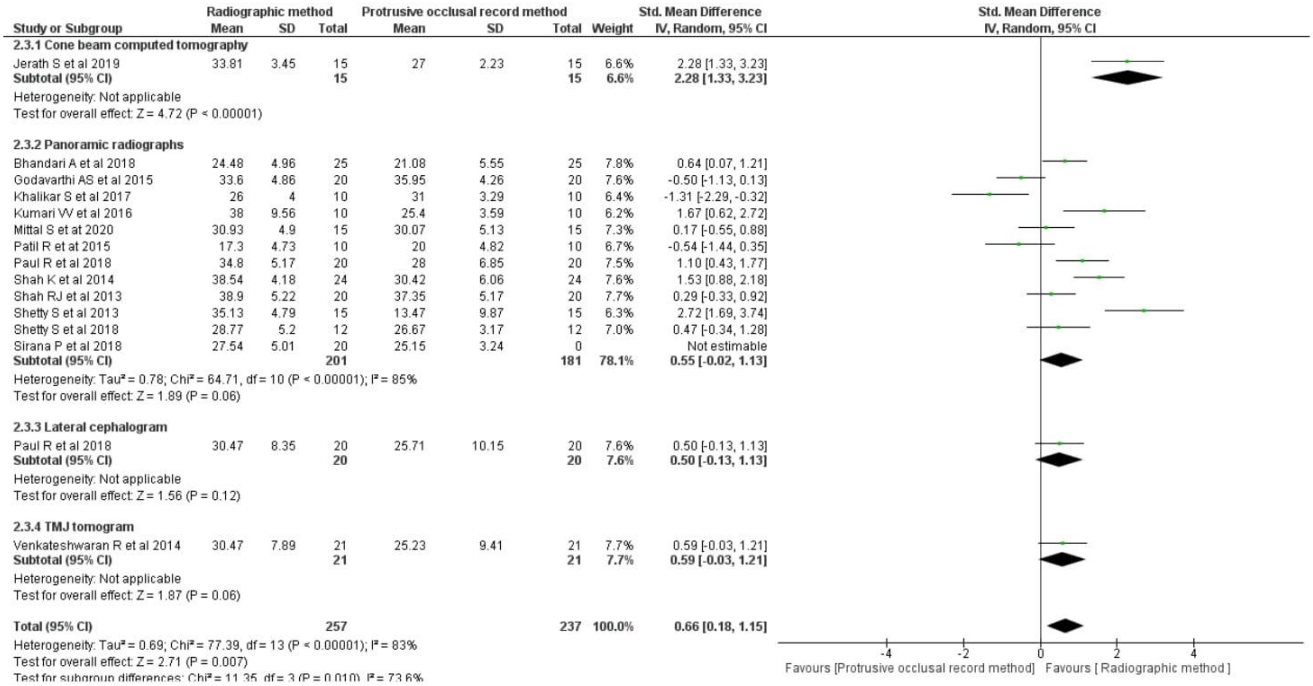

Figure 5. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for left side horizontal condylar guidance angle in edentulous patients. SD- standard deviation, IV- inverse variance~~XXX~~, CI- confidence interval.

Sensitivity analysis

~~The~~ 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).

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

Item	Dentulous pPatients' Ccondylar guidance angle		Edentulous pPatients' cCondylar 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- Standardizsed Mean Difference

Publication bias

Figure 6 represents the fFunnel 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.

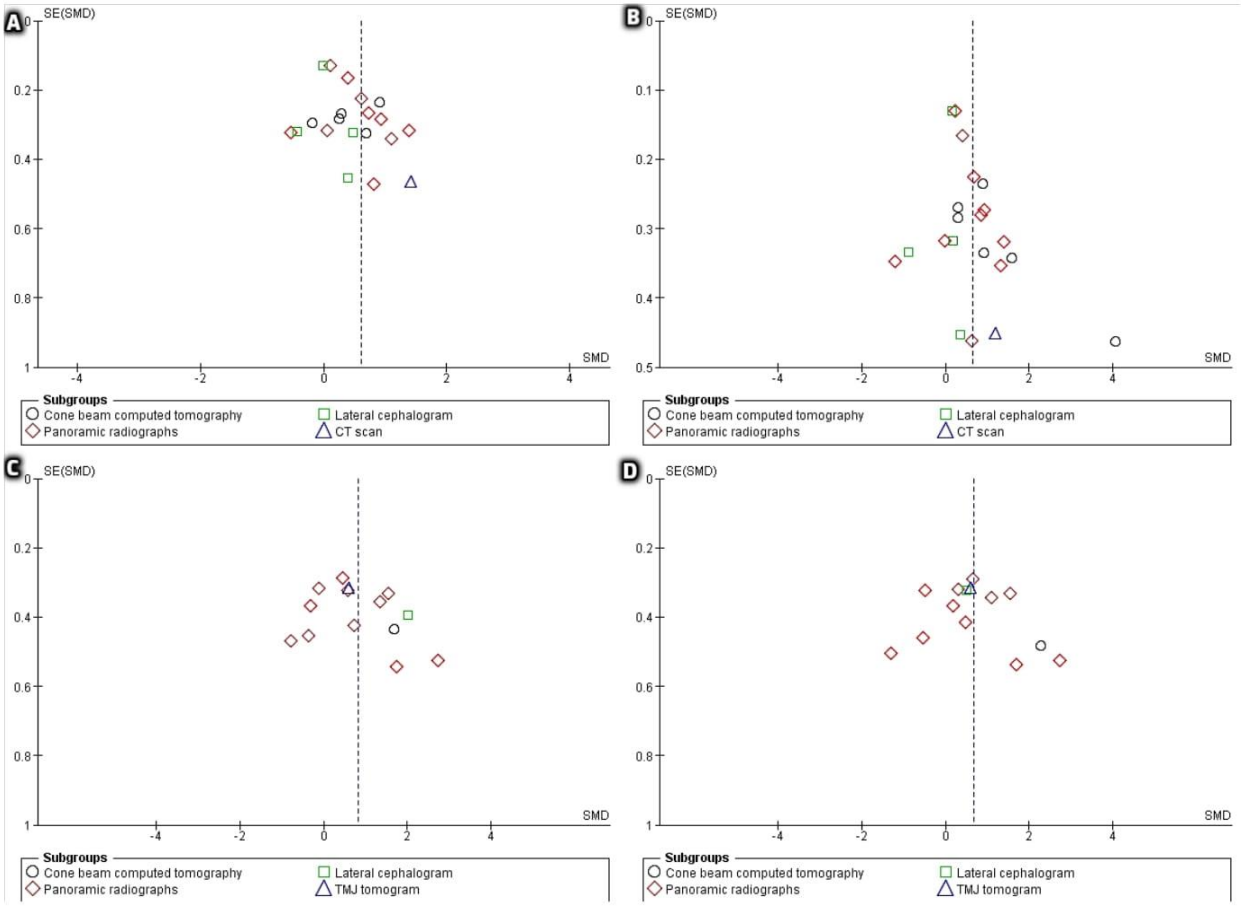

Figure 6. Funnel plot for horizontal condylar guidance angle, A: Right side dentulous patients, B: Left side dentulous patients, C: Right side edentulous patients, D: Left side edentulous patient. CT- Computed tomography, SE- Standard error, SMD- Standardized mean difference, TMJ- Temporo-mandibular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

Discussion

When the mandible advances protrusively or laterally from centric relation, Tthe route followed by the condyle with in 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 which is different to that of dentate patients because in them 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 Vadodaria [43] 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 cCephalometric images do not. Cursor-driven measurement methods offer the physician with 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 tomogram 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, seven7 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 opportunitiesy 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 (and Software) Aavailability

Underlying data

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

Reporting guidelines: The PRISMA checklist is available at https://doi.org/10.17605/OSF.IO/2YRMX

Ethics approval

Ethical approval for this type of analysis is exempted as the study authors collected and synthesized the data from previous published studies and clinical trial in which the informed consent and ethical clearnces had been obtained by the investigators. However the current systematic review and meta-analysis was registered in PROSPERO available at https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020206599.

Author Contributions

Conceptualization, A.M.L, S.T.K. and J.M.G.; methodology, A.M.L.; software, S.T.K.; validation, D.A.W..; formal analysis, A.M.L.; investigation, A.M.L.; resources, D.A.W.; data curation, A.M.L.; writing—original draft preparation, A.M.L.; writing—review and editing, D.A.W.; supervision, S.T.K..; project administration, A.M.L. All authors have read and agreed to the published version of the manuscript.

Grant information

The authors declared that no grants were involved in supporting this work.

Competing interests

No competing interests

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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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v1 **First published:** 27 Jan 2022, **11**:105
https://doi.org/10.12688/f1000research.75347.1
Latest published: 27 Jan 2022, **11**:105
https://doi.org/10.12688/f1000research.75347.1

Abstract

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 ($P<0.05$).

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

Open Peer Review

Approval Status ✓

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version 1 27 Jan 2022	✓ view

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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

This article is included in the IIARP Publications gateway.

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Competing interests: No competing interests were disclosed.

Grant information: The author(s) declared that no grants were involved in supporting this work.

How to cite this article: Luke AM, Kuriadom ST, George JM and Wahjuningrum DA. **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]** F1000Research 2022, **11**:105 https://doi.org/10.12688/f1000research.75347.1

First published: 27 Jan 2022, **11**:105 https://doi.org/10.12688/f1000research.75347.1

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 Terms 9 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 1 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 Studies[16] 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 $I2>50\%$ 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.

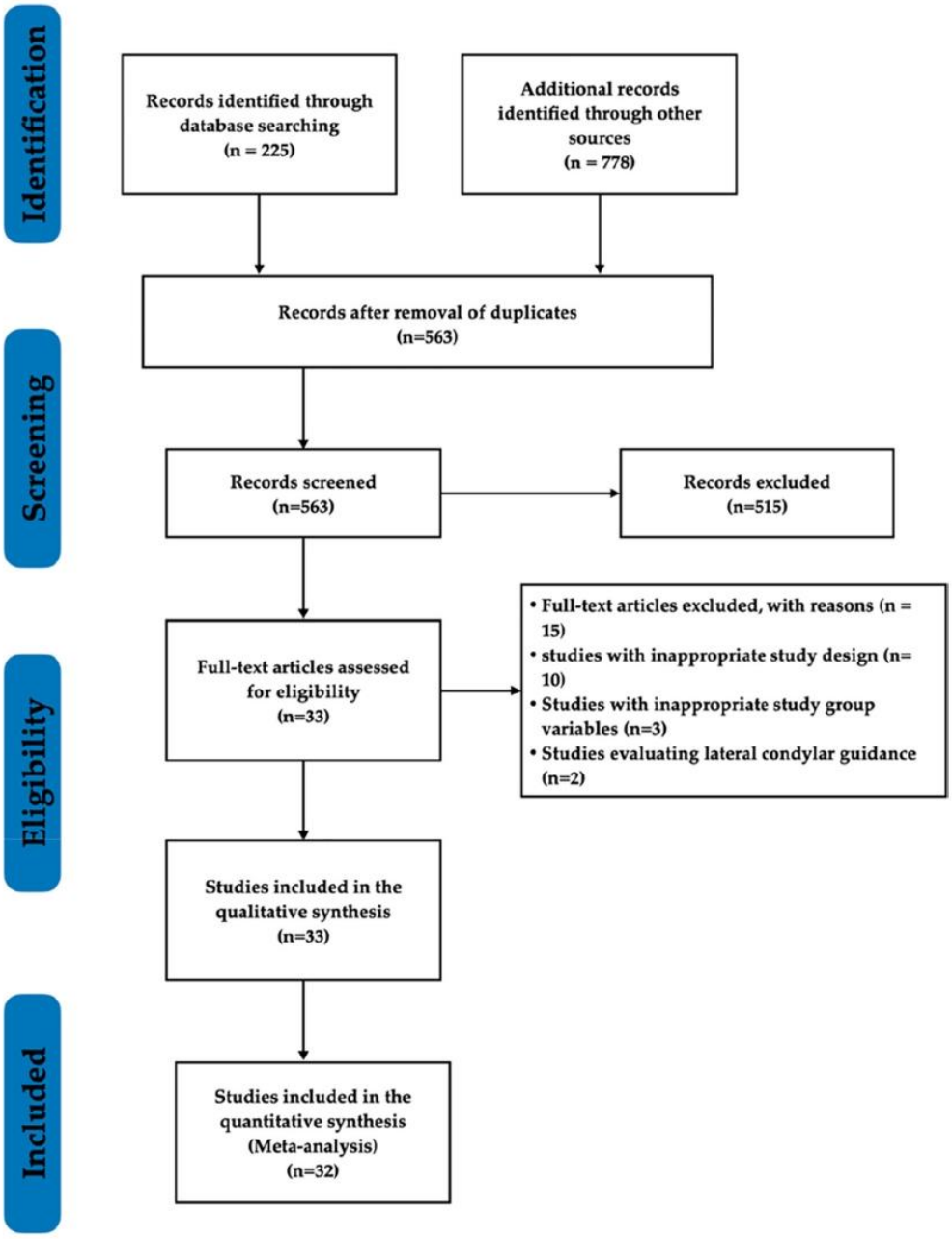

Figure 1. PRISMA flow diagram.

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] Korea[31] 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 al[7] 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 scan[13] 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 al[26] and Paul et al[1] cumulative value of right and left angle is mentioned.

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 method[13] 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 method[13] 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	Both I/C/r	
Acharya S et al 2015[19]	India	20 D 20 E	18-30 years 45-75 years	HANAU articulator modelWide-Vue, U.S.A.	Orthoralix 9200; Gendex Dental Systems, Milan, Italy)	OPG	Dentulous 35.8/33.75/0.57 Edentulous 30.35/26.5/0.57	Dentulous 34.05/34.25/0.55 Edentulous 29.50/26.75/0.72		Measurement of condylar inclination angles using panoramic radiographs gave higher values, as compared to the inter-occlusal record method.
Amin B et al 2018[20]	India	30 D 30 E	40-60 years	Hanau Wide-Vue	Orthophos XG	OPG			Dentulous 35.53 (6.248)/30.83 (5.384) Edentulous 29.10 (9.135)/24.20 (7.066)	The use of OPG to set condylar guidance on the articulator should be taken into consideration for both dentulous and edentulous subjects
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	CBCT	35.43 (3.13)/32.78 (2.64)/0.95	35.18(2.62)/32.9 (2.49)/0.95		CBCT 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.
Galagali G et al 2016[23]	India	120 D	20–40 years	HANAUTM Wide-Vue, Whip Mix Corporation, USA		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 (4.860)/35.95 (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)		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-hinisilky	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 VV et al 2016[30]	India	10 E	50-65 years	Hanau wide Vue semi-adjustable articulator		OPG	37.10(8.26)/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.
Loster JE et al 2017[9]	Poland	10 D	18years+			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 at 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 at 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	SIRONA Germany Newtom, Italy	OPG CBCT	35.85 (4.21)/30.96 (4.70)/29.80 (4.44) 0.97/0.958	35.964.23)/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 RJ et al 2013[38]	India	20 E	40-60 years	Hanau Wide Vue		OPG	37.9(3.89)/35.45 (4.69)	38.9(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	
Shreshta P et al 2012[13]	India	12 D	20-40 years	Protar 7, KaVo Dental GmbH, Bismarckring, Biberach	Somaton 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-Vue 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[14]	India	10 D		Hanau articulator ModelWide-Vue 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[43]	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 bean 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
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
Kharzinejad 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 W 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 at 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
Patil R et at 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
Shreshta 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	Yes	No	Yes	No	Yes	No	No	Fair

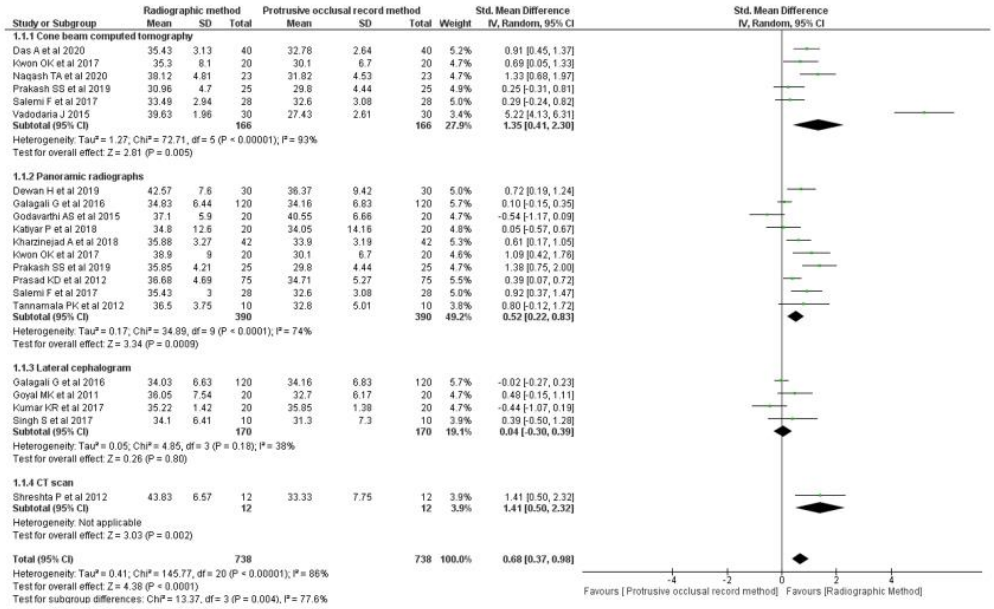

Figure 2. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for right side horizontal condylar guidance angle in dentulous patients. SD - standard deviation, IV - inverse variance, CI - confidence interval.

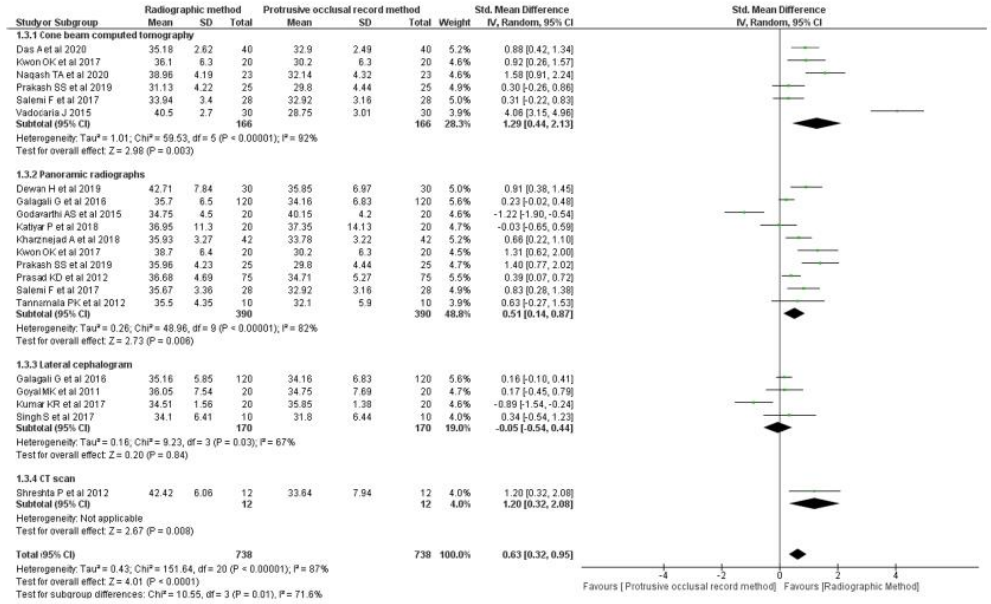

Figure 3. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for left side horizontal condylar guidance angle in dentulous patients. SD - standard deviation, IV - inverse variance, CI - confidence interval.

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 [Tau^2 =0.68, Chi^2 =75.09, I^2 = 83%] (Figure 4). After subgroup analysis was done using a random-effect model, it was shown that the CBCT method[25] 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 method[1] 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 method[44] 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 [Tau^2 =0.67, Chi^2 =77.39, I^2=83%] (Figure 5). After subgroup analysis was done using a random-effect

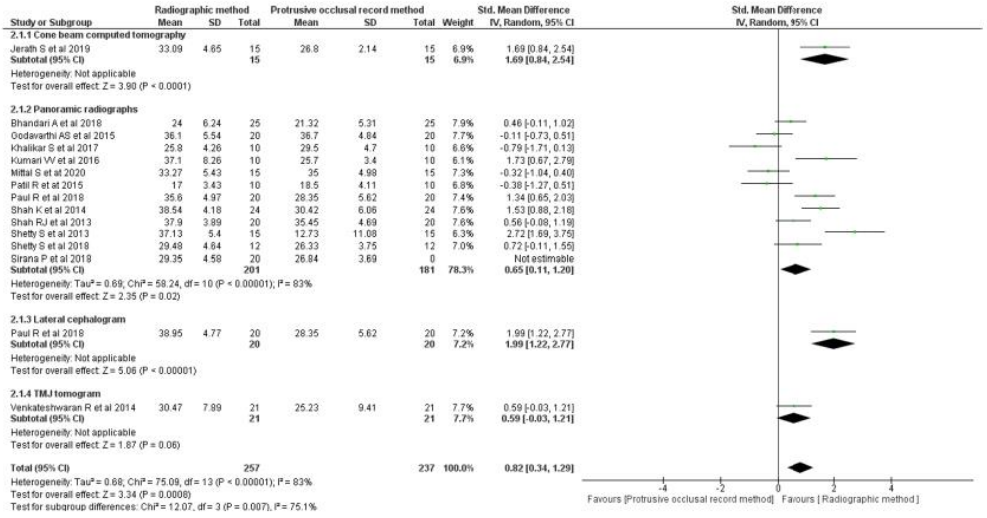

Figure 4. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for right side horizontal condylar guidance angle in edentulous patients. SD - standard deviation, IV - inverse variance, CI - confidence interval.

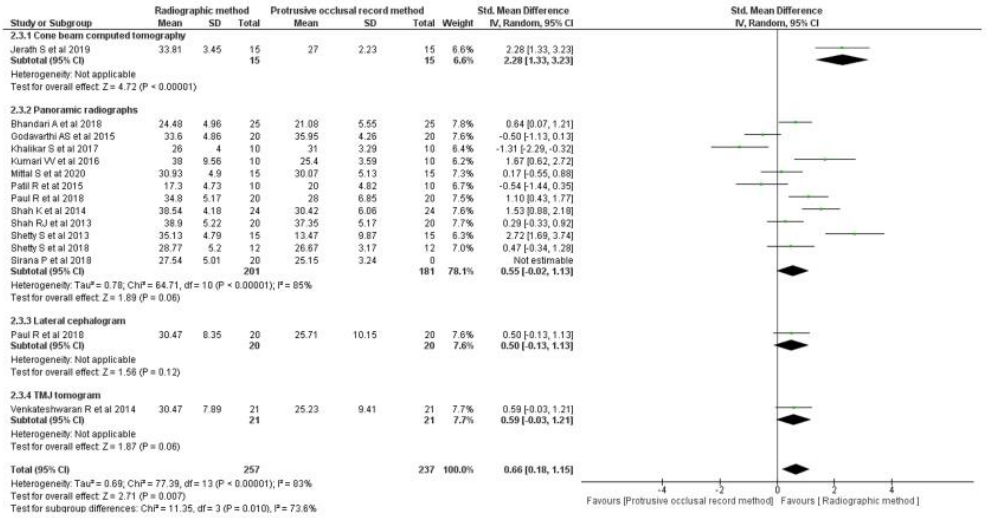

Figure 5. Forest plot of the pooled analysis and the subgroup analysis comparing radiographic techniques and protrusive occlusal records for left side horizontal condylar guidance angle in edentulous patients. SD - standard deviation, IV - inverse variance, CI - confidence interval.

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.

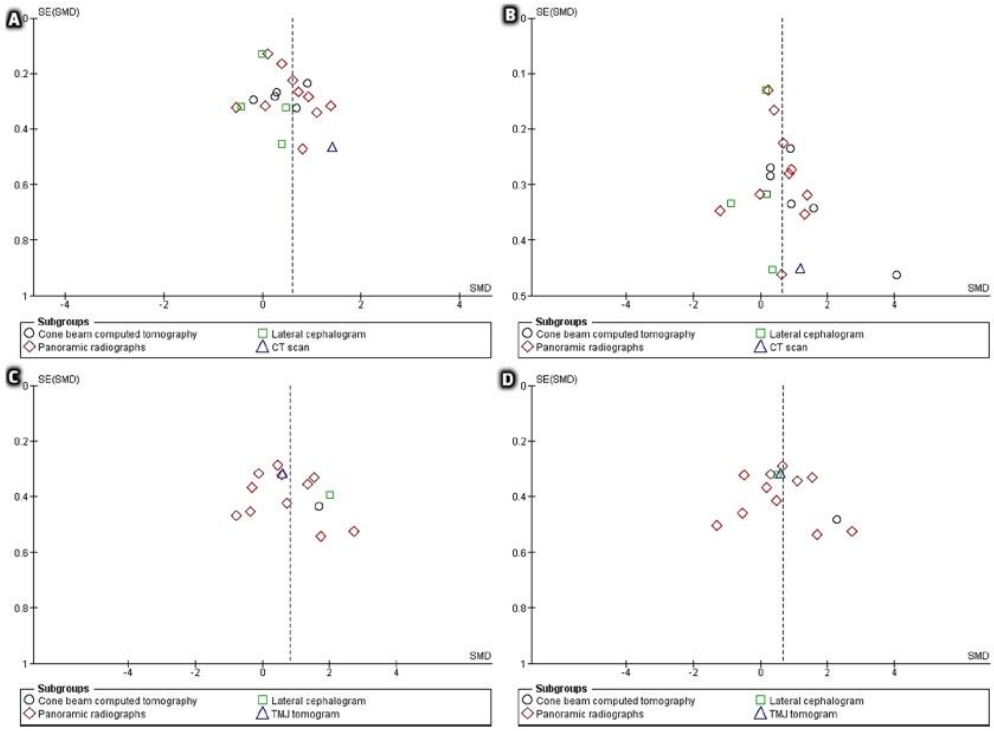

Figure 6. Funnel plot for horizontal condylar guidance angle, A: Right side dentulous patients, B: Left side dentulous patients, C: Right side edentulous patients, D: Left side edentulous patient. CT - Computed tomography, SE - Standard error, SMD- Standardized mean difference, TMJ - Temporo-mandibular 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 method[1] 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 method[44] 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 Vadodaria[43] 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 tomogram 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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Open Peer Review

Current Peer Review Status: ✔

Version 1

Reviewer Report 08 March 2022

https://doi.org/10.5256/f1000research.79207.r121335

✔ **Vineet Vinay**
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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 Airlingga, 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.