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Comparison Of the Accuracy of CAD CAM Milled And 3D Printed Surgical Guides in Implant Placement- A Systematic Review and Meta Analysis

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KEYWORDS

3D printing, accuracy, implants, milling, surgical guide

ABSTRACT:

Aim: Evaluating accuracy of of CAD CAM milled and 3D printed surgical guides in implant placement

Methods: Review was adhered and preferred reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines 2020 and registered in PROSPERO – CRD42023470684. Electronic databases were searched for studies evaluating accuracy of 3D printed surgical guides compared to CAD/CAM milled surgical guides in implant placement and reporting outcomes in terms of angular deviation, coronal deviation, apical deviation, depth deviation and deviation at apex. Screening and data extraction was done by two independent reviewers. Quality assessment of studies was evaluated through Cochrane risk of bias (ROB)-2 tool. The standardized mean difference (SMD) was used as summary statistic measure with random effect model and p value <0.05 as statistically significant through Review manager (RevMan) version 5.3.

Results: Seven studies were included in qualitative synthesis and five studies for meta -analysis with data evaluated from 357 implants placed. Included studies showed moderate to low ROB. Effectiveness between both implant placement techniques were evaluated for angular deviation, coronal deviation, apical deviation, depth deviation and deviation at apex. Meta-analysis revealed that 3D printing surgical guide had shown reduced angular deviation (SMD = -0.52 (-0.83 – 0.20), coronal deviation (0.29 (-0.13 – 0.72), apical deviation (-0.74 (-1.05 – 0.42), depth deviation (-0.53 (-0.84 – 0.22) and deviation at neck (SMD = -0.80 (-1.13 – 0.46) indicating that 3D printing guides implant placement technique being more efficient than CAD/CAM milled surgical guide (p<0.05). Funnel plot did not show presence of publication bias in meta-analysis.

Conclusion: It was found that better results with overall accuracy and safety margin was seen with 3D printed surgical guides, with fabrication ease, less time wastage and reduction of laboratory time with an increased cost-effectiveness.

INTRODUCTION

Edentulism is the most common condition treated in dental clinics. Implant rehabilitation has emerged as an ideal solution for such condition and it has steadily advanced towards greater accuracy and precision. With the ongoing development of oral implantology, osseointegration is no longer the sole objective of implant surgery. The ultimate goal now focuses on the precise placement of prostheses, as well as the restoration of both function and aesthetics, enhancing overall oral health and appearance.[1]

Osseo-integrated implants are a practical substitute to the conventional prosthesis; nevertheless, designing a prosthesis which is implant supported with proper function and aesthetics is a challenge.[1] Achieving precise accuracy in the planning and execution of surgical steps is crucial to ensuring a high success rate while minimizing the risk of iatrogenic damage.[2] The success of implant placement primarily relies on accurate treatment planning and correctly performed surgery. Improperly placed implant, is a very common problem that regularly complicates not only the clinical, but also the laboratory procedures of superstructures.[2] This actually dictates a close teamwork between prosthodontists and surgeons to work conjointly as a single unit that will help in the accurate fabrication of the surgical stent or surgical guide.[3]

A surgical guide is an appliance utilized for radiographic assessment of the available bone regarding height and width pre-operatively or intra-operatively to provide the ideal site for implant placements.[3] Surgical templates not only aid in diagnosis and treatment planning, but also eases proper positioning and correct angulation of the implant body in the bone.[4]

Surgical guides should be constructed of transparent material, stable and firm when in position. It should cover sufficient teeth to stabilize its location, and when teeth are absent, they should extend onto the un-reflected soft tissue regions.[3] A surgical guide is supported by the teeth, mucosa or bone and is usually made of polymer. These surgical guides have pre-drilled channels and during the dental implant surgery, the surgeon uses these channels to guide the osteotomy at the anticipated locations and angulations in the patient's subsequent implantation site.[4] Several computer-guided surgical stents fabrication methods have been advocated over the past several years including design related processing and milling based on coordinate synchronization.[5]

The use of surgical guides in dentistry has provided patients and dental surgeons with greater flexibility, accuracy and control of the procedure being executed[4,5], resulting in a more comfortable postoperative experience for the patient and, by reverse planning, delivery of the immediate prosthesis or optimization of the final prosthetic result.[6]

Traditionally, surgical guides were fabricated using Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) milling techniques. However, with advances in 3D printing technology, there has been a shift toward using 3D-printed surgical guides, which offer increased flexibility, lower costs and faster turnaround times.[3]

Computer-aided design/computer-aided manufacturing (CAD/CAM) allows the production of surgical guides that are virtually planned and designed using data accrued from 3D imaging utilizing computer software and digital workflow for planning and manufacturing. They have metallic sleeves that direct and allow precise implant placement in the x, y and z axes. CBCT scanning and digital imaging techniques, which allow visualization of the placement of dental implants in three dimensions, have gained popularity in their applications, given their ability to achieve predictable and accurate results.[10]

However, due to the limitations of bone mass and anatomy, it is necessary to perform adequate preoperative assessment to improve accuracy and to avoid complications.[11] Although cone beam computed tomography (CBCT) combined with computer-aided design (CAD) can assist in diagnosing problems and predicting rehabilitative effects, there are also difficulties in transferring the treatment plan to the surgical procedure.[12]

The trend of placing implants has shifted from free-hand implant placement techniques to computer-guided surgical systems using surgical guides. CAD/CAM surgical guides have been praised for reducing the deviation between planned and actual implant position after surgery.[5-7]

A previous study has reported that 3D-printed surgical guides from in-office 3D printers are ten times less expensive than laboratory CAD/CAM surgical guides. Therefore, in-office 3D printing will be more accessible and affordable for the dentists who have their own printer.[14,15]

CAD/CAM uses different approaches for manufacturing of surgical guides. Subtractive manufacturing is usually accomplished by the Computer Numerical Controlled (CNC) machining, creating objects by progressive removal or deformation of material (drilling, cutting, bending) from a large block or sheet in the form of chips.[6] While additive manufacturing or 3D printing is a manufacturing method in which objects are made by fusing or depositing materials - such as plastic,

metal, ceramics, powders, liquids, or even living cells - in layers to produce a 3D object.[7]
Fabrication of surgical guide requires preoperative steps, starting with CBCT acquisition, computer assisted implant planning and ending in fabrication and use of a surgical guide for drilling and implant insertion. With such a complex sequence, where every step is prone to errors, accuracy is of utmost importance.[8,9]

We updated our research for related articles and conducted a systematic review with the aim to provide updated evidence on the accuracy of 3D printed surgical guides compared to CAD/CAM milled surgical guides in implant placement with the hypothesis of study aimed to evaluate whether 3D printed surgical guides could be an ideal alternative to CAD/CAM milled surgical guides in implant placement.

METHODS

Protocol development

This review was carried out according to preferred reporting items for systematic review (PRISMA) 2020 checklist[16] and registered in PROSPERO-CRD42023470684.

Study design

Focused research question in the Participants (P), Intervention (I), Comparison (C) and Outcome (O) format was proposed “Is there any difference in the accuracy of 3D printed surgical guides compared to CAD/CAM milled surgical guides in implant placement?”

P – implant placement
I – 3D printed surgical guide
C – CAD/CAM milled surgical guides
O – evaluating accuracy in terms of angular deviation, coronal deviation, apical deviation, depth deviation and deviation at apex

Eligibility Criteria:

a) **Inclusion Criteria:**
   1) Studies published in English language
   2) Studies published from January 2000 – September 2024 and from open access journals
   3) Studies having sufficient comparative data on the accuracy of 3D printed surgical guides compared to CAD/CAM milled surgical guides in implant placement
   4) Studies reporting study outcomes as angular deviation, coronal deviation, apical deviation, depth deviation and deviation at apex
   5) Randomized controlled trial (RCT), comparative studies and in-vitro studies were selected
b) **Exclusion Criteria:** following were the exclusion criteria
   1) Any studies conducted before January 2000
   2) Articles in other than English language
   3) Reviews, abstracts, letter to the editor, editorials, animal studies and in vitro studies were excluded
   4) Articles not from open access journals

Search Strategy

Database search was performed till September 2024 for studies published within the last 24 years: PubMed, google scholar and EBSCO host. Key words and Medical Subject Heading (MeSH) terms were selected and combined with Boolean operators like AND/OR as shown below

Search Strategy according to PICO Format:

	Strategy
Population	"Dental implants"[MeSH Terms] OR "tooth supported surgical guide" OR "mucosa supported surgical guide" OR ("osseointegration"[MeSH Terms] OR "edentulism" OR "dental implantation".
Intervention	("surgical guide"[MeSH Terms] OR "3D print surgical guide" AND "3D

	surgical planning" OR "virtual guided surgery" OR "guided implant surgery" [MeSH Terms]
Comparator	("surgical guide" OR "computer aided design"[MeSH Terms] OR ("computer aided manufacturing" OR "non-guided implant surgery" AND ("angular deviation"[MeSH Terms] OR ("coronal deviation") AND "apical deviation" OR "depth deviation"
Outcome assessed	("accuracy"[MeSH Terms] OR "precision" OR ("angular deviation"[MeSH Terms] OR ("coronal deviation") AND "apical deviation" OR "depth deviation" OR ("deviation at neck") AND "randomized controlled trial" AND "in vitro study")

Screening Process

Two review authors (AP,PK,) independently screened the titles and abstracts obtained by search strategy and included them if they met the inclusion criteria. Later full texts of all the included studies were obtained. After obtaining the full texts of the articles they were screened by reading the whole article and then decided if they met the inclusion criteria. Whenever there was uncertainty regarding any study to be eligible for inclusion, the problem was resolved by discussing it amongst two reviewers. Finally, the search yielded 7 studies to be included in systematic review and. All the excluded studies were recorded with reason for exclusion for each study. None of the authors were blinded to the journal titles, study authors or the institutions where the studies were conducted.

Data extraction

For included studies, descriptive data was extracted under following heading: author(s), country of study, year of study, sample size, implant placed, outcome assessed, parameters evaluated and conclusion.

Quality assessment of studies

Quality assessment was performed by using Cochrane collaboration risk of bias (ROB) -2 tool[17] through its various domains in Review Manager (RevMan) 5.3 software.

Statistical analysis

Statistical analysis was performed with standardized mean difference (SMD) serving as the summary measure. Significance was determined at the threshold of $p<0.05$.[18]

Assessment of heterogeneity

The Cochranes test for heterogeneity was employed to assess the significance of any differences in treatment effect estimations among trials. Heterogeneity was deemed statistically significant if the P-value was <0.01.[19]

Investigation of publication bias

The study assessed publication bias using Begg's funnel plot, which plots the effect size against standard error. Asymmetry in the funnel plot may indicate potential publication bias.[20]

RISK OF BIAS OF INDIVIDUAL STUDIES

- The Cochrane collaboration's tool for assessing risk of bias was used to assess the quality of the included studies. Each study was assessed by two independent reviewers as having a low, unclear, or high risk of bias depending on information provided in the study.
- The randomization, allocation concealment, attrition bias, detection bias, reporting bias, blinding of outcome assessors, incomplete outcome data, selective outcome reporting and other sources of bias was assessed. Any disagreement between the two reviewers was resolved through discussion with a third reviewer.
- The risk of bias in individual studies will be assessed under the Objectives of the study mentioned, the population under the study, the setting in which study was conducted, eligibility criteria for including or excluding the participants, sampling strategy used, mention of calculating sample size for the study based on previous study, an index mentioned for calculating prevalence, outcome data

mentioned as the mean value of prevalence using index, generalizability of the results.

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Type of Bias	Domain	Description of domain
Selection bias	Sequence generation	Describe the methods used, if any, to generate the allocation sequence in sufficient detail to allow an assessment whether it should produce comparable groups.
	Baseline characteristics	Describe all the possible prognostic factors or animal characteristics, if any, that are compared in order to judge whether or not intervention and control groups were similar at the start of the experiment.
	Allocation concealment	Describe the method used to conceal the allocation sequence in sufficient detail to determine whether intervention allocations could have been foreseen before or during enrolment.
Performance bias	Random housing	Describe all measures used, if any, to house the animals randomly within the animal room.
	Blinding	Describe all measures used, if any, to blind trial caregivers and researchers from knowing which intervention each animal received. Provide any information relating to whether the intended blinding was effective.
Detection bias	Random outcome assessment	Describe whether or not animals were selected at random for outcome assessment, and which methods to select the animals, if any, were used.

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	Blinding	Describe all measures used, if any, to blind outcome assessors from knowing which intervention each animal received. Provide any information relating to whether the intended blinding was effective.
Attrition bias	Incomplete outcome data	Describe the completeness of outcome data for each main outcome, including attrition and exclusions from the analysis. State whether attrition and exclusions were reported, the numbers in each intervention group (compared with total randomized animals), reasons for attrition or exclusions, and any re-inclusions in analyses for the review.
Reporting bias	Selective outcome reporting	State how selective outcome reporting was examined and what was found
Other	Other sources of bias	State any important concerns about bias not covered by other domains in the tool.

Table 1: Types of bias

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RESULTS

Study Selection

After database search (n=125), duplicates removal (n=30) and putting all inclusion and exclusion criteria's, in the end seven studies were included in for qualitative synthesis (systematic review) and five studies for quantitative synthesis (meta-analysis) as illustrated in **Figure 1 below**

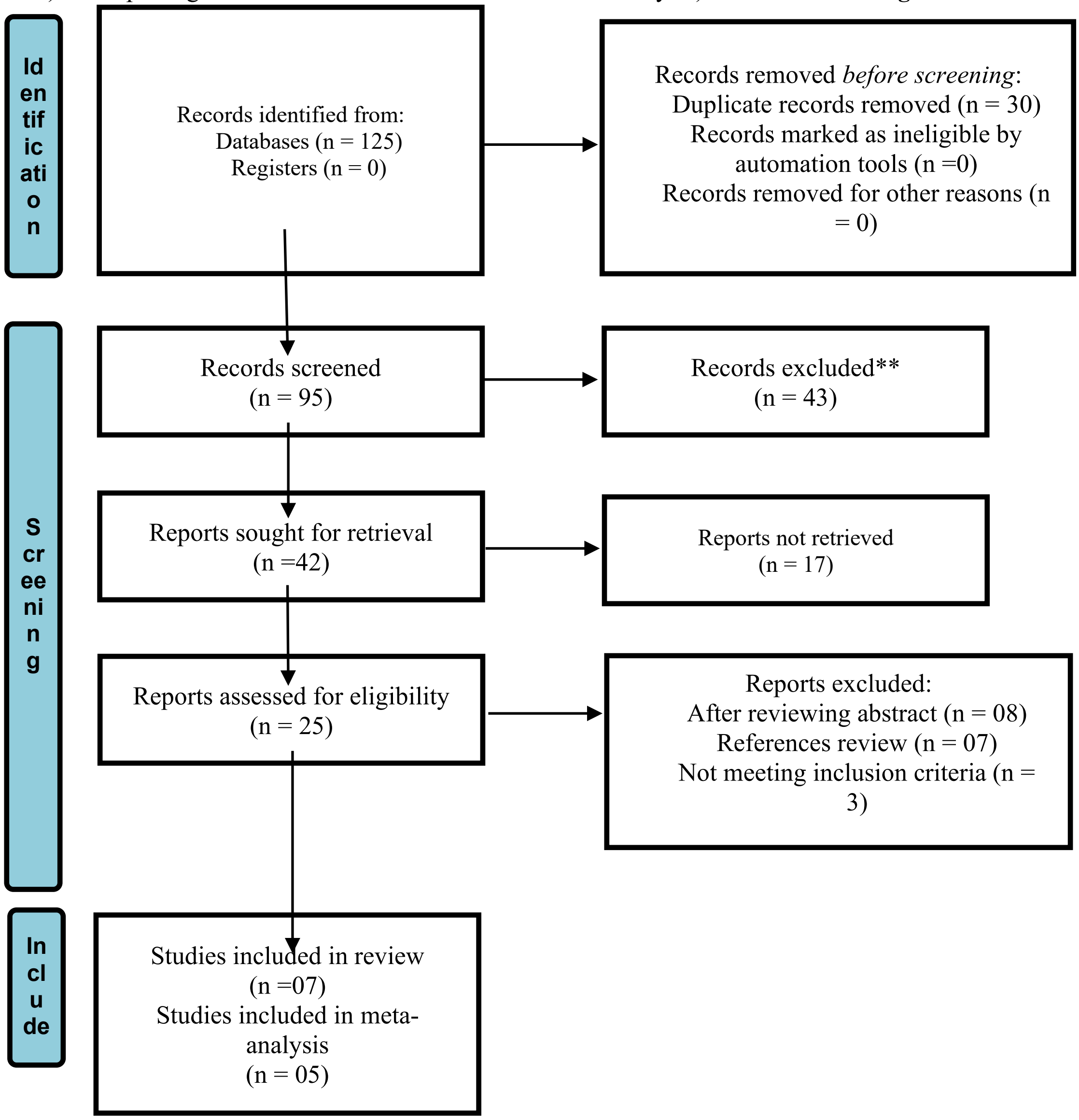

Figure 1. PRISMA 2020 Flow Diagram

Table 2: Strategy of electronic database search

S.no	Search strategy	Articles hit	Articles selected
1.	Implant placed through 3D printed surgical guide	80	60
2.	Implant placed through CAD/CAM milled surgical guides	95	65
3.	Comparative analysis between 3D printed surgical guide and CAD/CAM milled surgical guides	125	95
4.	Studies reporting outcome as angular deviation,	95	43
5.	Studies reporting outcome as coronal deviation	42	17
6.	Studies reporting outcome as apical deviation	25	18
7.	Studies reporting outcome as depth deviation	25	18
8.	Studies reporting outcome as deviation at apex	25	18
9.	Studies reporting outcome as angular deviation, coronal deviation, apical deviation, depth deviation and deviation at apex	07	07

Study Characteristics

As shown in **table 2** , data was evaluated from seven studies[21-27] from an aggregate of 357 implants placed on resin mandibular molars, edentulous jaws, Kennedy class II with missing maxillary third molars, right molars, and premolars and Kennedy class III edentulous area with missing maxillary third molars and a right first molar, and a second premolar and Kennedy class IV partially edentulous and patients with dentition defects. Among the included studies, two studies each were conducted in Egypt[21,24], China[22,26], USA[23,25] and one study in Brazil[27]. All the included studies aimed to compare accuracy of implants placed through 3D printed and machine milled surgical guides and reported outcomes in terms of evaluating accuracy in terms of angular deviation, coronal deviation, apical deviation, depth deviation and deviation at apex. From the results of the studies, it was found that tooth supported surgical guide was more accurate than mucosa supported surgical guide. One study[24] found that CAD/CAM milled surgical guides were more superior and accurate compared to 3D printed surgical guides, while two studies[23-27] found that both types of surgical guides showed equal accuracy while majority of the studies found that better results with overall accuracy and safety margin was seen with 3D printed surgical guides, with fabrication ease, less time wastage and reduction of laboratory time with an increased cost-effectiveness.

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Author, year of study	Country	Sample size	Implants placed	Outcome assessed	Parameters evaluated	Conclusion
Ahmed et al., 2015[21]	Egypt	Resin mandibular molars	36	To compare accuracy of implants placed through 3D printed and machine milled surgical guides	Angular deviation, coronal deviation, angle deviation	Better results with overall accuracy and safety margin was seen with 3D printed surgical guides
Geng et al., 2015[22]	China	Edentulous jaws	111	To evaluate accuracy of implants placed through different surgical guides support (tooth supported/mucosa supported)	Angular deviation, deviation at neck, deviation at apex, depth deviation	Tooth supported surgical guide was more accurate than mucosa supported surgical guide
Reyes et al., 2015[23]	USA	Kennedy class II with missing maxillary third molars, right molars, and premolars and III edentulous area with missing maxillary third molars and a right first molar, and a second premolar	80	To assess internal fit of dental implants surgical guide on dentate and edentulous ridges by using conventional and CAD/CAM fabricated surgical guides	Internal fit	Equal accuracy was observed between both surgical guides
Shen et al., 2015[24]	Egypt	Mandibular bounded partially edentulous patient	28	To compare accuracy of surgical guides (Milling, CAD/CAM) in implant placement	Angular deviation, coronal deviation and apical deviation	CAD/CAM milled surgical guides were more superior and accurate compared to 3D printing surgical guides
Henprasert et al.,2019[25]	USA	Partially edentulous mandibular model with different bone densities and soft tissue	30	To evaluate implant position accuracy using surgical guides (3D printing and Milling)	Angular difference (bucco-lingual, mesio-distal), depth difference (buccal, distal, lingual), coronal deviation, apical	3D printed surgical guides were more accurate, fabrication ease, less time wastage and reduction of

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					deviation	laboratory time with an increased cost-effectiveness
Sabet et al., 2020[26]	China	Dentition defects	52	To compare accuracy of implants placed using different surgical guides templates	Apical deviation, angular deviation, depth deviation	Surgical guide templates had shown better precision and accuracy
Mukai et al., 2021[27]	Brazil	Kennedy class IV edentulous area	20	To obtain better precision between 3D printing and milling method of surgical guide	Precision in terms of misalignment	Both types of surgical guides showed better results

CAD: computed-aided design; CAM: computer aided manufacturing

Table 2: showing descriptive study details of included studies

Quality assessment

All of the included studies reported moderate to lowest ROB. Ahmed et al., 2015[21] reported lowest ROB compared to other studies. Domains of allocation concealment, blinding of participants and personnel, blinding of outcome assessment, selective reporting and other bias were given the lowest ROB by included studies as depicted in **Figure 2 and 3.**

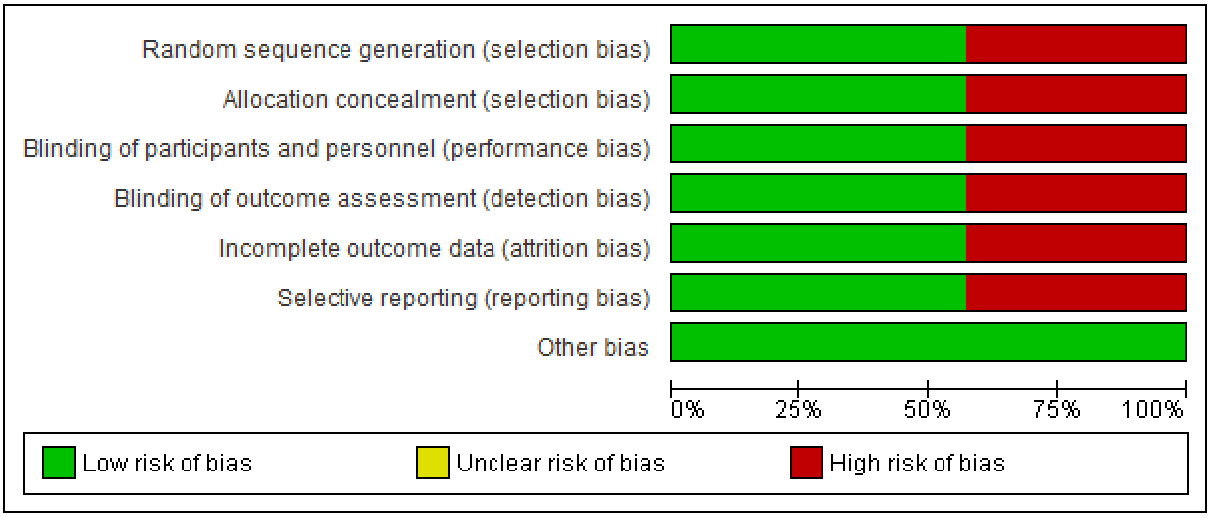

Figure 2: ROB: shown as percentages across all included studies.

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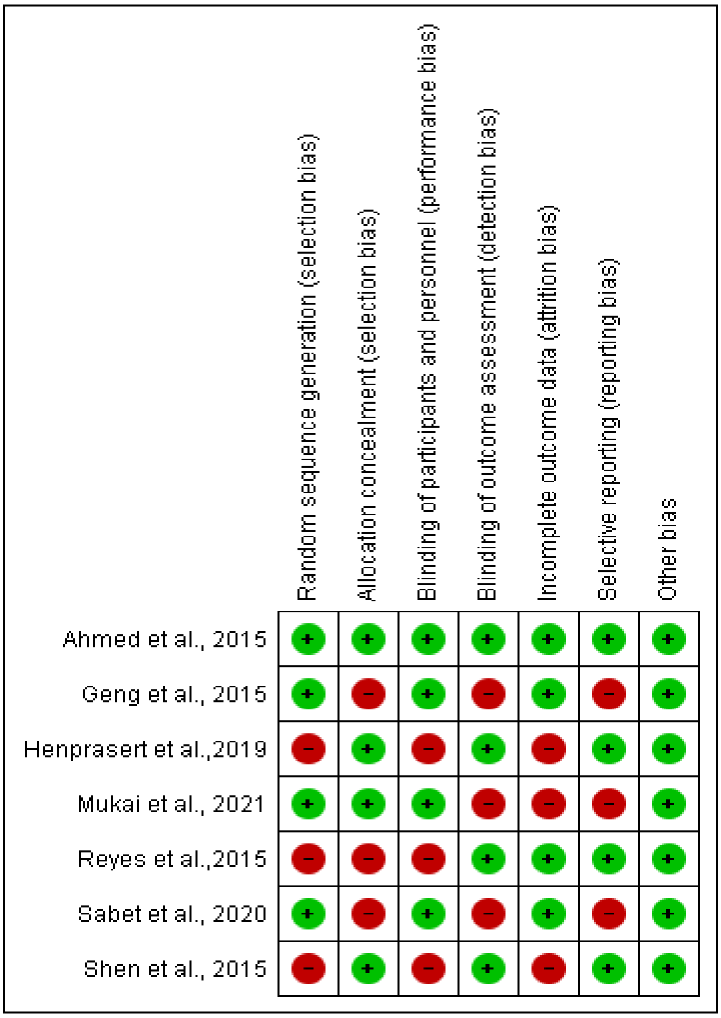

Figure 3: ROB summary: for each study

Synthesis of results/Meta-analysis

Accuracy of 3D printed surgical guides compared to CAD/CAM milled surgical guides in implant placement was assessed in terms of angular deviation, coronal deviation, apical deviation, depth deviation and deviation at apex **as shown in figures 4-13.**

A) Angular deviation

Four studies[21,24-26] containing data on 203 implants, of which (*n*=104) implants were placed by 3D printed surgical guide and (*n*=99) implants were placed by CAD/CAM milled surgical guide for evaluation of angular deviation. As shown in **Figure 4.** the SMD is -0.52 (-0.83 – 0.20) signifying that angular deviation on an average was 0.52 times lesser in 3D printed surgical guide ($p<0.05$).

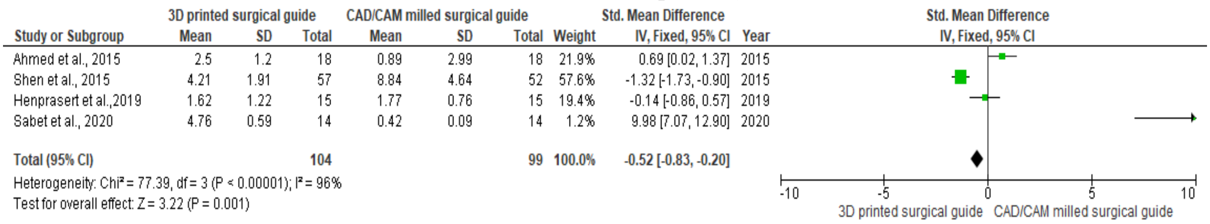

Fig 4: Comparison between 3D printed and CAD/CAM milled surgical guides for angular deviation

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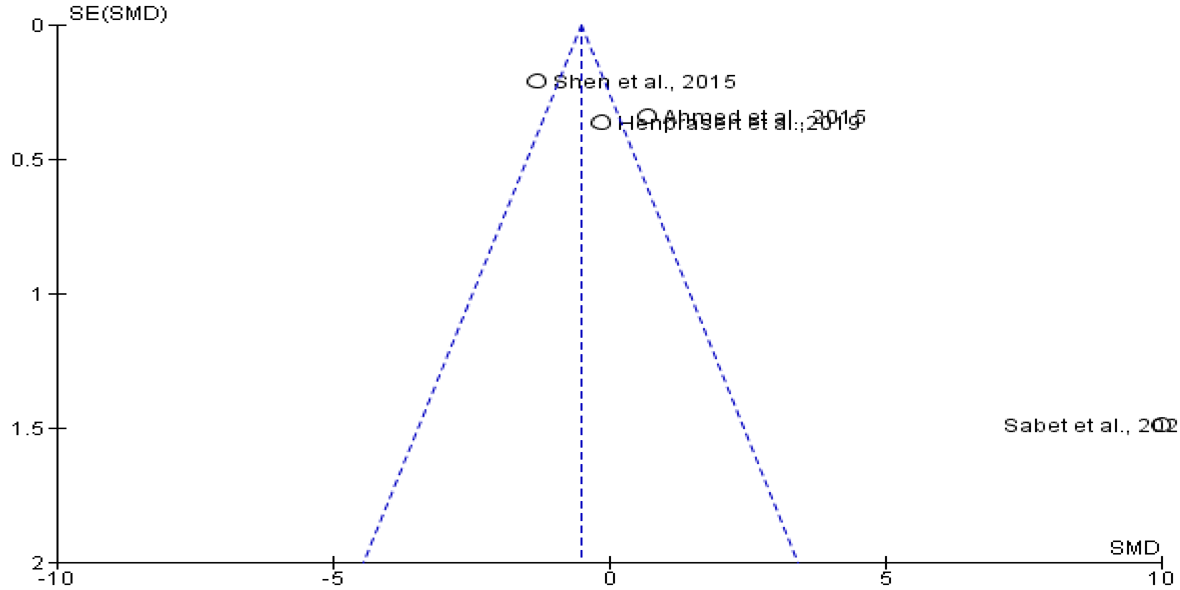

Fig 5: Funnel plot showing absence of possible publication bias

B) Coronal deviation

Three studies[21,25,26] containing data on 94 implants, of which (*n*=47) implants were placed by 3D printed surgical guide and (*n*=47) implants were placed by CAD/CAM milled surgical guide for evaluation of coronal deviation. As shown in **Figure 6.** the SMD is 0.29 (-0.13 – 0.72) signifying that coronal deviation on an average was 0.29 times more in CAD/CAM milled surgical guide ($p>0.05$).

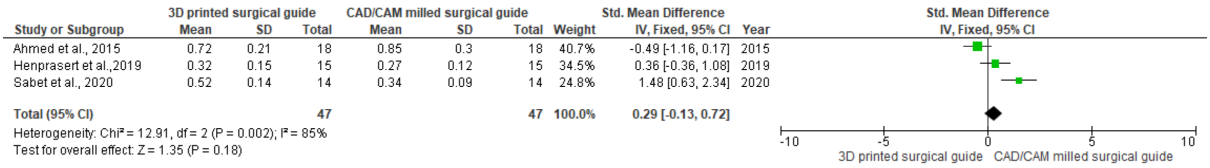

Fig 6: Comparison between 3D printed and CAD/CAM milled surgical guides for coronal deviation

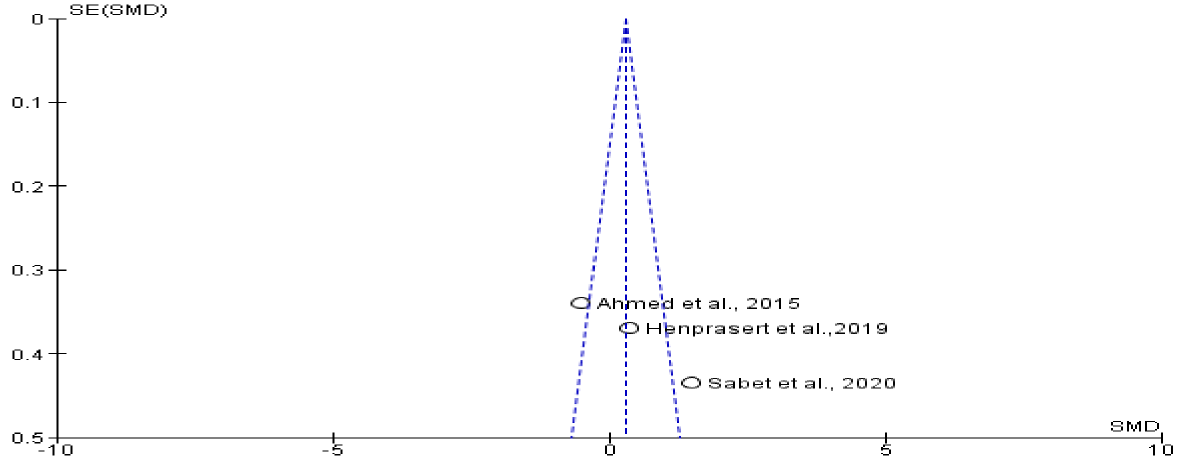

Fig 7: Funnel plot showing absence of possible publication bias

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C) Apical deviation

Four studies[21,24-26] containing data on 203 implants, of which (n=104) implants were placed by 3D printed surgical guide and (n=99) implants were placed by CAD/CAM milled surgical guide for evaluation of apical deviation. As shown in **Figure 8.** the SMD is -0.74 (-1.05 – 0.42) signifying that apical deviation on an average was 0.74 times lesser in 3D printed surgical guide (p<0.05).

Study or Subgroup	3D printed surgical guide Mean	SD	Total	CAD/CAM milled surgical guide Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
Ahmed et al., 2015	1.1	0.42	18	1.3	0.37	18	22.6%	-0.49 [-1.16, 0.17]	2015
Shen et al., 2015	4.21	1.91	57	8.84	4.64	52		-1.32 [-1.73, -0.90]	2015
Henprasert et al.,2019	0.84	0.47	15	0.81	0.28	15	19.5%	0.08 [-0.64, 0.79]	2019
Sabet et al., 2020	1.12	0.25	14	0.38	0.05	14	5.5%	3.99 [2.64, 5.33]	2020
Total (95% CI)			**104**			**99**	**100.0%**	**-0.74 [-1.05, -0.42]**	

Heterogeneity: Chi² = 69.03, df = 3 (P < 0.00001); I² = 96%
Test for overall effect: Z = 4.57 (P < 0.00001)

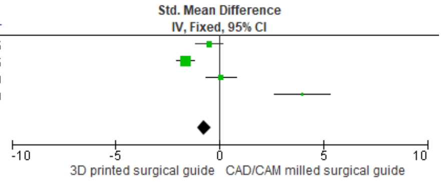

Fig 8: Comparison between 3D printed and CAD/CAM milled surgical guides for apical deviation

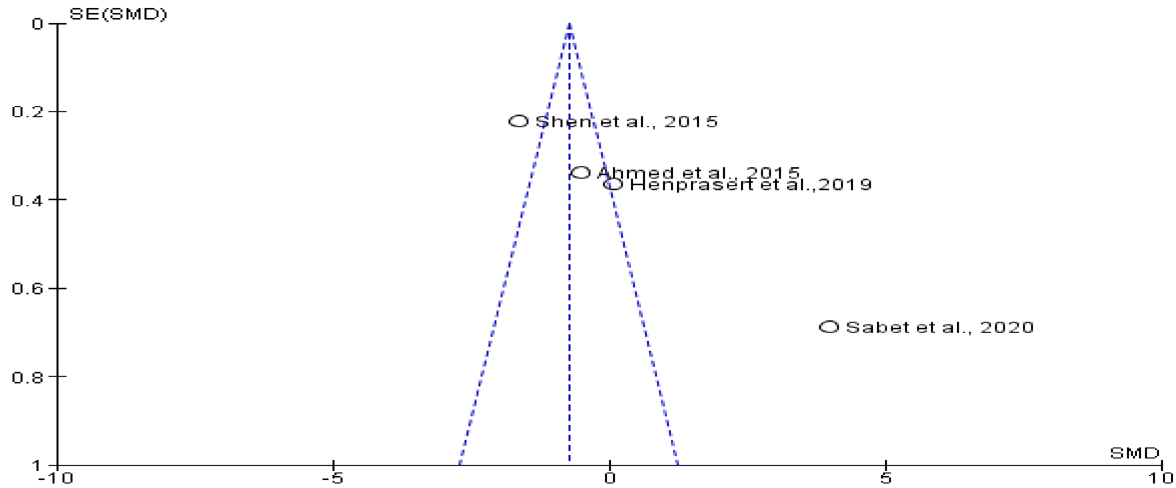

Fig 9: Funnel plot showing absence of possible publication bias

D) Depth deviation

Two studies[22,24] containing data on 168 implants, of which (n=87) implants were placed by 3D printed surgical guide and (n=81) implants were placed by CAD/CAM milled surgical guide for evaluation of depth deviation. As shown in **Figure 10.** the SMD is -0.53 (-0.84 – 0.22) signifying that depth deviation on an average was 0.53 times lesser in 3D printed surgical guide (p<0.05).

Study or Subgroup	3D printed surgical guide Mean	SD	Total	CAD/CAM milled surgical guide Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
Shen et al., 2015	0.54	0.29	57	0.78	0.33	52	63.2%	-0.77 [-1.16, -0.38]	2015
Geng et al., 2015	0.24	0.54	30	0.31	0.72	29	36.8%	-0.11 [-0.62, 0.40]	2015
Total (95% CI)			**87**			**81**	**100.0%**	**-0.53 [-0.84, -0.22]**	

Heterogeneity: Chi² = 4.06, df = 1 (P = 0.04); I² = 75%
Test for overall effect: Z = 3.33 (P = 0.0009)

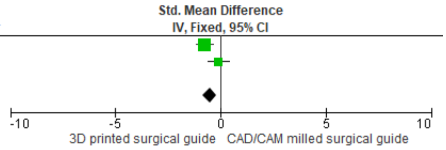

Fig 10: Comparison between 3D printed and CAD/CAM milled surgical guides for depth deviation

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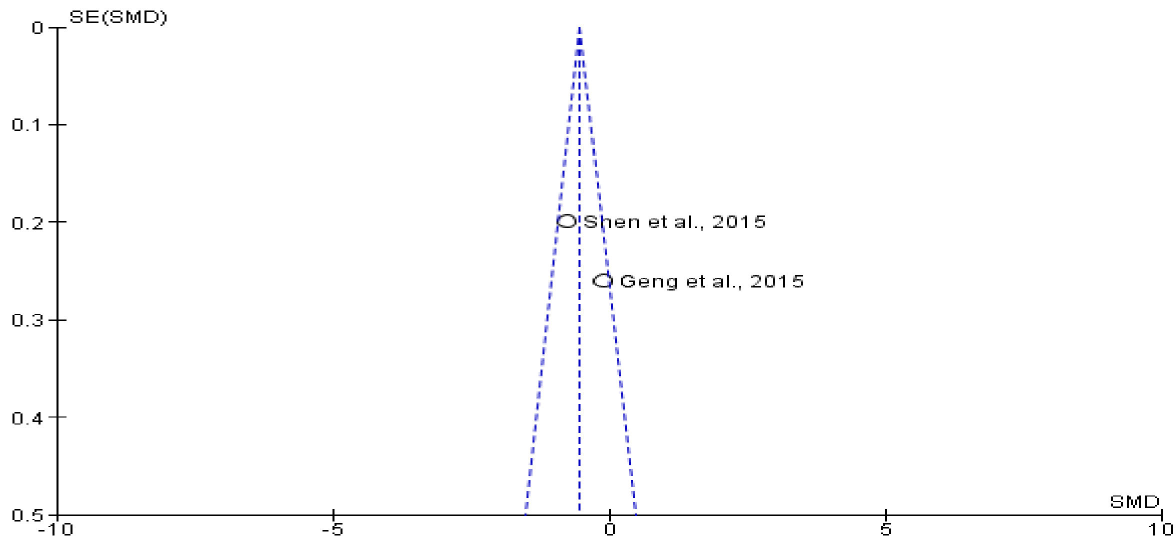

Fig 11: Funnel plot showing absence of possible publication bias

E) Deviation at apex

Two studies[22,24] containing data on 168 implants, of which (n=87) implants were placed by 3D printed surgical guide and (n=81) implants were placed by CAD/CAM milled surgical guide for evaluating deviation at apex. As shown in **Figure 12.** the SMD is -0.80 (-1.13 – 0.46) signifying that deviation at apex on an average was 0.80 times lesser in 3D printed surgical guide (p<0.05).

	3D printed surgical guide			CAD/CAM milled surgical guide				Std. Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI	Year
Shen et al., 2015	1.43	0.74	57	2.89	1.02	52	58.2%	-1.64 [-2.08, -1.20]	2015
Geng et al., 2015	1.1	0.85	30	0.81	0.64	29	41.8%	0.38 [-0.14, 0.89]	2015
Total (95% CI)			**87**			**81**	**100.0%**	**-0.80 [-1.13, -0.46]**	

Heterogeneity: Chi² = 34.32, df = 1 (P < 0.00001); I² = 97%
Test for overall effect: Z = 4.69 (P < 0.00001)

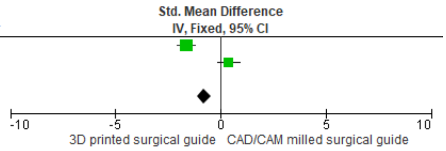

Fig 12: Comparison between 3D printed and CAD/CAM milled surgical guides for deviation at apex

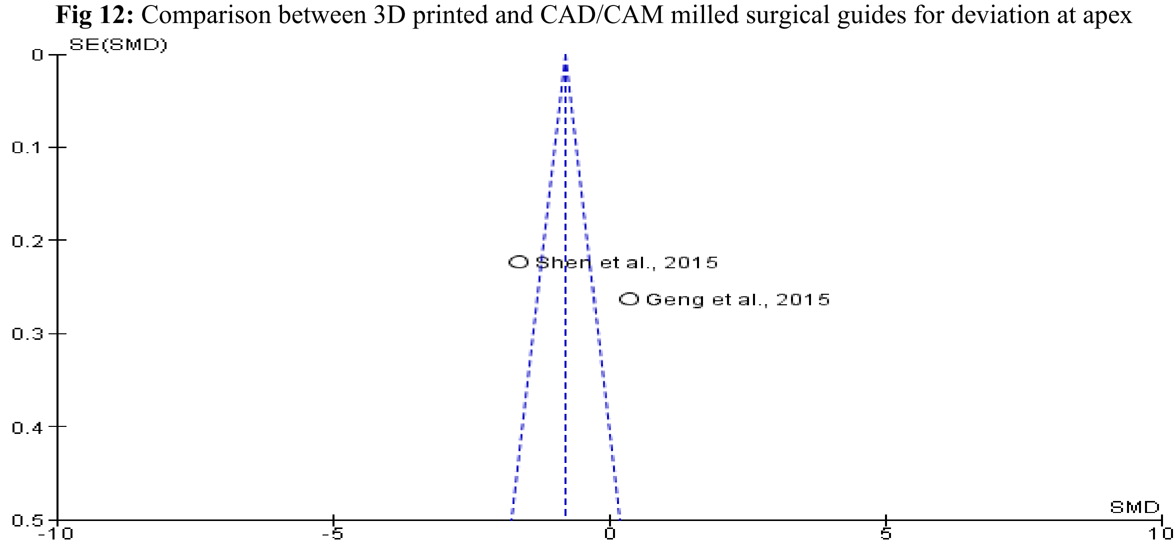

Fig 13: Funnel plot showing absence of possible publication bias

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DISCUSSION

The use of surgical guides in dentistry has provided patients and dental surgeons with greater flexibility, accuracy and control of the procedure being executed.[4,5] Conventional surgical guides are made in the dental laboratory, however, during implant placement, conventional surgical guides allow for potential clinician-mediated positioning errors due to inadvertent angular and linear deviations during osteotomy or drilling sequences, reducing the degree of accuracy.[9] Fabrication of surgical guides 3D printing or CAD CAM provides high accuracy of implant position during the surgical phase, allowing predictable outcomes for the restorative phase.

Lo Russo et al., 2023[28] conducted systematic review and meta-analysis to assess the overall dimensional accuracy of surgical guides for static computer-aided implant placement using milling or 3D printing. Database search was performed with no date restriction for studies assessing the surgical guides made by milling or 3D printing compared with computer aided design model and reported outcome measure in terms of accuracy of internal/external surface, angular deviation of sleeves and vertical or horizontal deviations of the sleeves access. 11 studies were included in the final review. All the included studies, assessed printed surgical guides while only two studies assessed both printed and milled templates. From the results of the studies, it was found that there is scarcity of evidences to explain which manufacturing technology provides surgical guide with better accuracy, although in terms of reduced variations milling showed better results.

Shi et al., 2023[29] conducted systematic review and meta-analysis to assess the effect of implant guides on surgical accuracy in regards to type of supporting (tooth supported/mucosa supported), manufacturing methods and design (fixation screws and sleeves). Databases were searched from 2018 to 2022 for in -vitro/ in -vivo studies. 41 studies were included in the final review. From the results of the studies, it was found that accuracy of implant surgery can be achieved with mean distance deviation < 2 mm and angular deviation $<8^0$ with bilateral tooth-supported guides showing high accuracy than unilateral tooth supported guides with milling exhibiting higher accuracy than 3D printing and surgical accuracy was affected by the fixation screws design and sleeves of implant guides. However, due to presence of considerable amount of data heterogeneity and lack of standard methods for implantation, accuracy remains a major drawback.

Abad-Coronel et al., 2024[30] carried out systematic review for studies to evaluate the implant accuracy using prosthetically-derived digital surgical guides. Databases were searched from 2013 to 2023 yielding ten studies which were included in the final analysis. The included studies, showed coronal deviations of 0.44 mm to 0.56 mm, apical deviations of 0.64 mm to 1.03 mm, angular deviations of 2.03^0 to 2.42^0 and vertical deviations of 0.19 mm to 0.45 mm with static guide techniques showing highest accuracy, while stability was seen with bilateral guides and cost-effectiveness was seen with printed guides.

There have been few systematic reviews and meta-analysis[28-30] published in the past but due to presence of data heterogeneity, none of them actually could provide a comprehensive qualitative and quantitative analysis in providing a comparative analysis on the accuracy of implants placed through 3D printed and machine milled surgical guides. According to our knowledge, this is the first systematic review and meta-analysis which assessed and evaluated the overall accuracy between the two techniques.

Databases were searched from January 2000 to September 2024 for RCTs, comparative and in-vitro studies comparing accuracy of 3D printed and machine milled surgical guides for implant placement. Seven studies[21-27] were included for qualitative synthesis and five studies for meta-analysis. Included studies reported presence of low risk of bias overall. Effectiveness between both implant placement techniques were evaluated for angular deviation, coronal deviation, apical deviation, depth deviation and deviation at apex. Meta-analysis revealed that 3D printing surgical guide had shown reduced angular deviation (SMD = -0.52 (-0.83 – 0.20), coronal deviation (0.29 (-

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0.13 – 0.72), apical deviation (-0.74 (-1.05 – 0.42), depth deviation (-0.53 (-0.84 – 0.22) and deviation at neck (SMD = -0.80 (-1.13 – 0.46) indicating that 3D printed guide assisted implant placement technique is more efficient than CAD/CAM milled surgical guide assisted implant placement ($p<0.05$). Funnel plot did not show presence of publication bias in meta-analysis.
The systematic review adhered to PRISMA guidelines, employing a comprehensive literature search and rigorous methodology, including Cochrane tool ROB assessment. This resulted in high-quality studies with minimal bias, providing a robust evidence base for therapeutic recommendations on optimizing the usage of 3D printed surgical guides for implant placement.
Systematic reviews and meta-analyses are considered the highest level of evidence, offering transparency and reproducibility in addressing specific research questions. However, the quality of included studies impact the strength of evidence. This review included sufficient studies with brief observation periods and known risk of bias.

Conclusion

It was found that better results with overall accuracy and safety margin were seen with 3D printed surgical guides along with ease of fabrication, less time consumption and an increased cost-effectiveness.

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