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Accuracy of Implant Placement Using Guided and Freehand Protocols in Edentulous Maxillae Restored with Zygomatic or Short Implants: A Systematic Review

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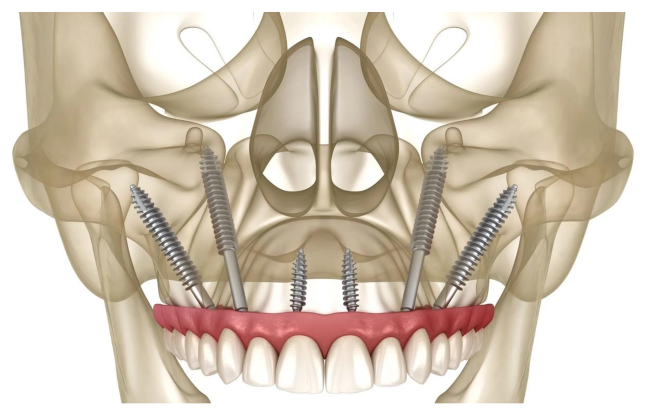
Introduction

Severe maxillary atrophy presents a substantial challenge in implant rehabilitation. Advanced resorption, sinus pneumatization, and reduced bone quality often preclude the placement of standard-length implants without bone grafting procedures [1,2]. In scenarios, where bone augmentation procedures are limited, contraindicated, or declined by patients, zygomatic and short implants (<8 mm) present graftless alternatives for full-arch rehabilitation [3,4]. Zygomatic implants engage the dense cortical bone of the zygoma to bypass posterior maxillary deficiency, while short implants utilize residual alveolar bone height to avoid vertical augmentation [4]. Given the anatomical complexity of the atrophic maxilla, especially the extended trajectory required for zygomatic implant placement, high surgical accuracy is essential to minimize the risk of sinus, orbital, or soft tissue complications and to ensure accurate~~,~~ prosthetically driven positioning [5]. Computer-assisted guidance systems, including static and dynamic navigation, and robotic technologies, have been developed to enhance the accuracy of implant placement procedures [6-8]. However, fully edentulous maxillae remain challenging due to limited guide support, reduced anatomical reference structures, and potential instability during surgery [7-10].

This systematic review evaluates the accuracy and clinical outcomes of guided versus freehand implant placement protocols in fully edentulous maxillae restored with zygomatic or short (<8 mm) implants.

Accuracy of Guided vs Freehand Zygomatic Implant Placement

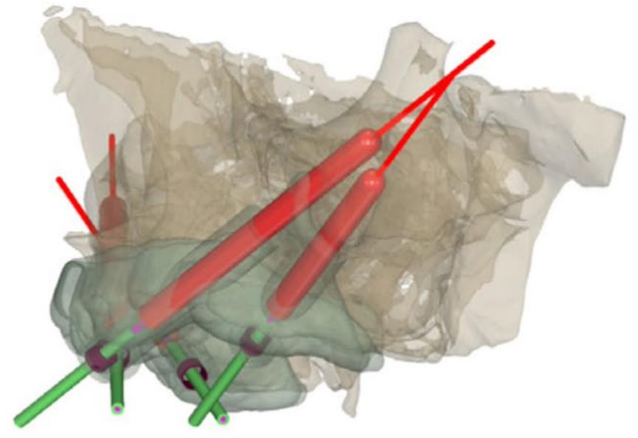


Study Overview
21 Studies
945 Implants

- 11 Clinical (52%)
  - 2 RCTs
  - 4 Cohorts
  - 5 Case Series
- 10 In Vitro (48%)

Guidance Systems

Dynamic
Static
Robotic
Combined



Key Findings: Accuracy Outcomes

Static Guides
Best Overall Accuracy
Entry Point:
1.44 ± 0.22 mm
Exit Point:
1.01 ± 0.49 mm
Angular:
2.17 ± 1.09°

Dynamic Navigation
Real-time Feedback
Entry Point:
2.63 ± 1.50 mm
Exit Point:
3.10 ± 1.26 mm
Angular:
5.32 ± 2.44°

Robotic-Assisted
Highest Precision
Entry Point:
0.57 ± 0.19 mm
Exit Point:
1.07 ± 0.48 mm
Angular:
0.91 ± 0.51°

Clinical Outcomes
Survival Rate: 92–100%
Follow-up: 72 hours to 5 years

Risk of Bias
Low: 9.5% | Moderate: 66.7% | High: 23.8%
Limited by few RCTs and in vitro studies

Conclusions

- ✓ Static guides demonstrated superior accuracy (1.44mm entry, 1.01mm exit, 2.17°).
- ✓ Robotic systems show promise but require validation (limited evidence).
- ✓ High survival rates (92–100%) across all guidance modalities.
- ✓ Guided surgery recommended for complex cases and less experienced surgeons.
- ✓ Quality of evidence limited: only 2 RCTs, 47.6% in vitro studies.
- ✓ Future research: High-quality RCTs with long-term follow-up needed.

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Materials & Methods

This systematic review was conducted in accordance with PRISMA guidelines and addressed following PICO-formulated focus question: In patients with a fully edentulous maxilla receiving a complete implant-supported maxillary prosthesis on zygomatic or short (<8 mm) implants (P), do statically or dynamically guided implant placement protocols (I) compared to freehand implant placement protocols (C) impact implant placement accuracy (O)?

A comprehensive electronic search of PubMed/MEDLINE, Embase, Web of Science and the Cochrane Central was performed. Randomized controlled clinical trials (RCT), prospective and retrospective clinical studies, comparative and non-comparative studies, case series with at least 10 patients and in-vitro studies, all evaluating fully edentulous patients who will receive implant-supported restorations in the maxilla on zygomatic or short implants, and reporting the used implant placement protocol (freehand, guided (static and dynamic), robotic) and accuracy outcomes, were included. Two independent reviewers screened titles, abstracts, and full texts according to predefined eligibility criteria. Data extraction was performed independently by two reviewers and included study design, implant characteristics, surgical protocol, guide support type, and accuracy measures (coronal deviation, apical deviation, and angular deviation). Implant survival and complications were also recorded when available. The primary outcome was implant placement accuracy; secondary outcomes included survival and complication rates.

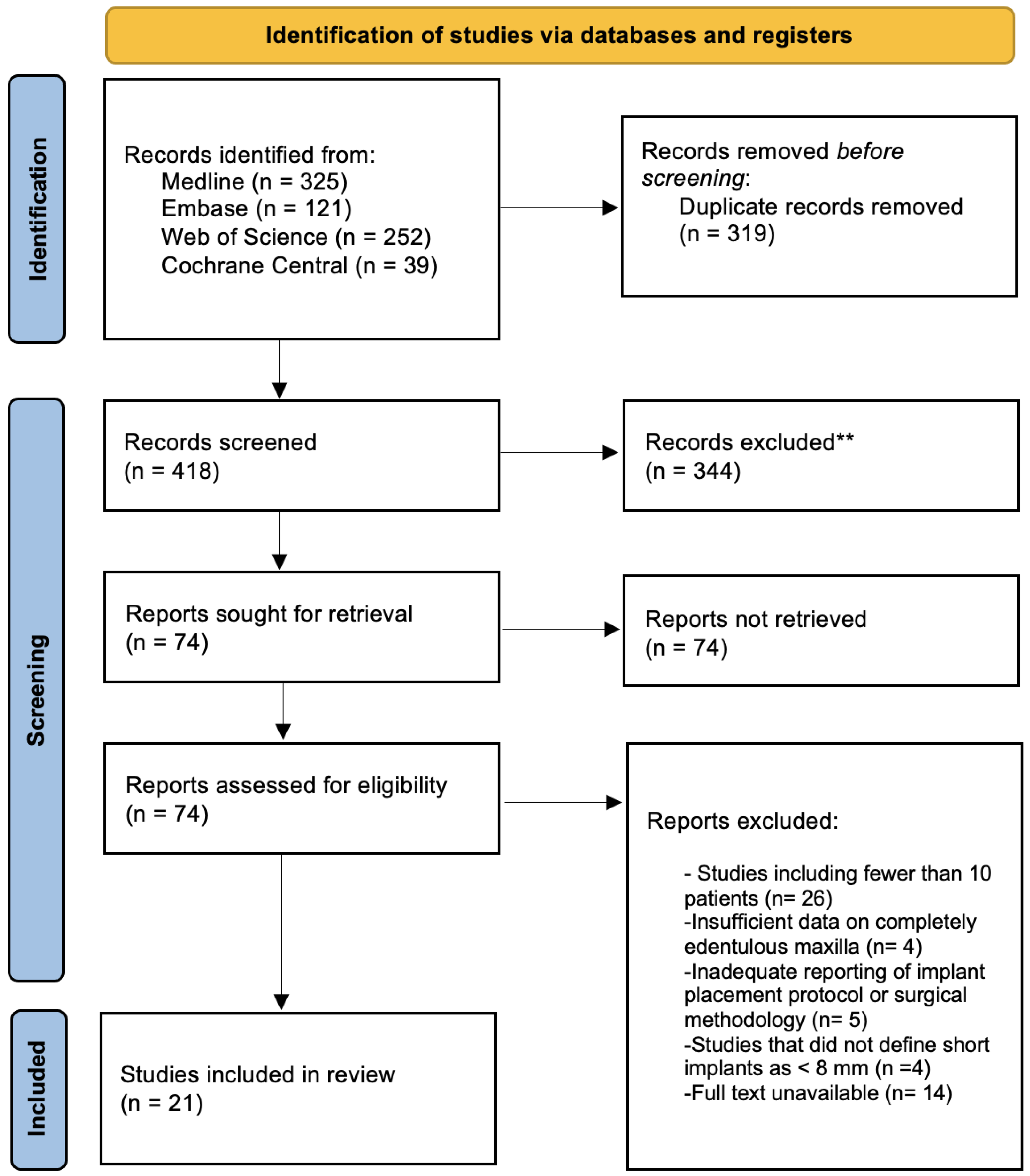
Due to heterogeneity in study designs and outcome reporting, a qualitative synthesis was performed. Risk of bias was assessed independently by two reviewers using RoB 2 for randomized trials, ROBINS-I for non-randomized clinical studies, and a modified appraisal framework for in vitro and cadaver studies.

Table 1. Summary of Included Study Characteristics

Characteristic	Clinical Studies	In Vitro/Cadaver Studies
Number of studies	11 (52.4%)	10 (47.6%)
Total implants	416	529
Patients/Models/Cadavers	143 patients	216 models/cadavers
Study designs	RCT (2), Prospective cohort (3), Pilot (2), Case report (2), Retrospective cohort (1), Technical report (1)	Model-based (8), Cadaver (2)

Table 2. Distribution of Guidance Systems and Technologies

Guidance System Type	Number of Studies	Percentage
Dynamic Navigation	9	42.9%
Static Surgical Guides	6	28.6%
Comparative Studies (Multiple Arms)	5	23.8%
Robotic-Assisted	1	4.8%
Combined Static and Dynamic	1	4.8%



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Results

Table 3. Implant Placement Accuracy by Guidance System Type

Guidance System	Entry Point Deviation (mm)	Exit Point Deviation (mm)	Angular Deviation (°)
Static Guides	1.44 ± 0.22 (0.88-2.04) n=4	1.01 ± 0.49 (0.66-1.81) n=2	2.17 ± 1.09° (0.56-4.15°) n=3
Dynamic Navigation	2.63 ± 1.50 (1.35-5.43) n=6	3.10 ± 1.26 (1.76-5.00) n=5	5.32 ± 2.44° (2.05-8.47°) n=4
Robotic-Assisted	0.57 ± 0.19 n=1	1.07 ± 0.48 n=1	0.91 ± 0.51° n=1
Combined Static+Dynamic	1.21 ± 0.45 n=1	1.67 n=1	1.99 ± 0.17° n=1
Overall	**2.27 ± 1.53 (0.48-5.64) n=17**	**2.58 ± 1.40 (0.66-5.33) n=14**	**3.23 ± 2.29° (0.56-8.47°) n=12**

Note: Values presented as mean ± SD (range). n = number of studies reporting data.

Table 4. Comparison of Accuracy Outcomes Between Clinical and In Vitro Studies

Study Type	Entry Point Deviation (mm)	Exit Point Deviation (mm)	Angular Deviation (°)
Clinical Studies	1.96 mm (n=7)	2.80 mm (n=5)	3.17° (n=6)
In Vitro/Cadaver Studies	2.49 mm (n=10)	2.45 mm (n=9)	3.29° (n=6)

Table 5. Implant Survival Rates by Guidance System

Study	Guidance System	Survival Rate	Follow-up Period
Pellegrino et al. 2020	Dynamic Navigation	97.1%	5 years (mean 39.9 months)
Guo et al. 2023	Dynamic Navigation	100%	6 months
Wang et al. 2018	Dynamic Navigation	100%	Early healing
Vrielinck et al. 2003	Static Guide	92%	12-24 months
Rigo et al. 2021	Static Guide	NR (1 patient lost all implants)	3-4 years
Du et al. 2025	Combined Static+Dynamic	1 failure reported	Median 14.5 months

Table 6. Reported Complications by Guidance System

Study	Guidance System	Reported Complications
Vrielinck et al. 2003	Static Guide	Acute bilateral maxillary sinusitis (2 patients)
Bhalerao et al. 2023	Dynamic Navigation	1 osseointegration failure; Schneiderian membrane perforation (3 cases)
Pellegrino et al. 2020	Dynamic Navigation	Biological and mechanical complications (details not specified)
Du et al. 2025	Combined Static+Dynamic	None during operation

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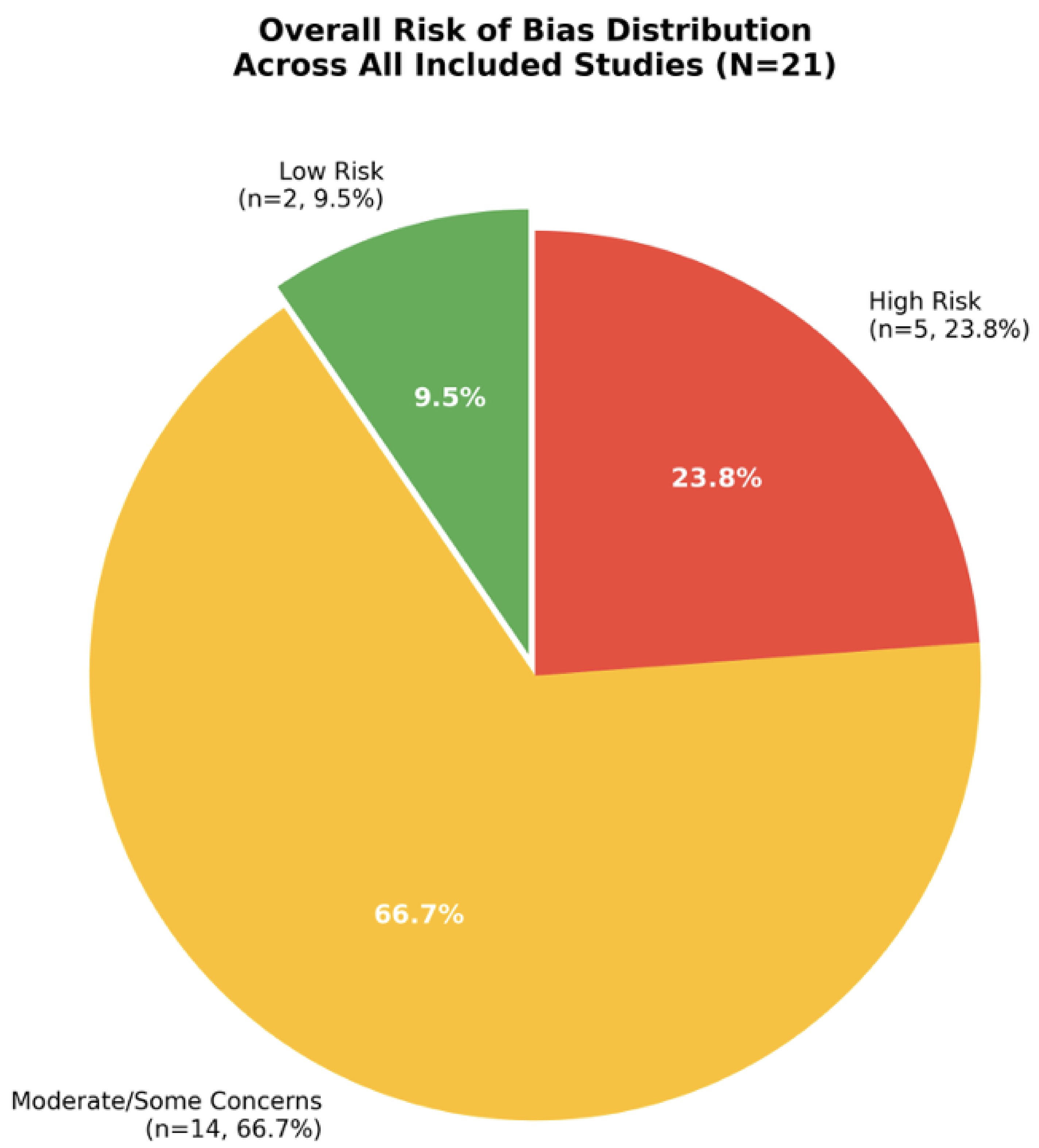
Table 7. Summary of Findings from Comparative Studies

Study	Study Design	Comparison	Key Finding
Grecchi et al. 2022	In vitro (Cadaver)	Static Guide vs Freehand	Static guide significantly more accurate (Entry: 0.88 vs 2.04 mm; Exit: 0.79 vs 3.23 mm; Angular: 1.19° vs 4.92°)
González-Rueda et al. 2023	In vitro (Models)	Static vs Dynamic vs Freehand	Freehand more accurate for exit deviation (3.20 vs 5.33 vs 4.92 mm); Static best for angular deviation (5.30° vs 7.36° vs 8.47°)
Traboulsi-Garet et al. 2025	In vitro (Models)	Dynamic (D-CAIS) vs Freehand	D-CAIS reduced coronal deviation by 2.26 mm, apical by 3.37 mm, angular by 5.33° compared to freehand
Penmetsa et al. 2024	Clinical (RCT)	Dynamic Navigation vs Freehand	Dynamic navigation more effective and accurate than freehand for all parameters
Chen et al. 2025	In vitro (Models)	Robotic (RAIS) vs Dynamic	RAIS superior to dynamic for all parameters (Entry: 0.48 vs 1.29 mm; Exit: 0.88 vs 1.96 mm; Angular: 0.92° vs 2.03°)
Guo et al. 2024	In vitro (Models)	Robotic vs Dynamic	Similar entry accuracy; Dynamic superior for exit (1.83 vs 2.39 mm, p=0.006); Similar angular accuracy



- Guided implant placement improved positional accuracy compared with freehand techniques
- Overall pooled deviations: Entry 2.27 mm, Exit 2.58 mm, Angular 3.23°
- Static surgical guides showed the most consistent clinical accuracy
  Entry ≈1.44 mm, Exit ≈1.01 mm, Angular ≈2.17° (Mean values)
- Dynamic navigation systems demonstrated moderate accuracy with greater angular deviation
- Robotic-assisted systems achieved the highest precision (Entry ≈0.57 mm, Angular ≈0.91°), though evidence remains limited
- Implant survival rates: 92–100% across studies
- Follow-up periods: 72 hours to 5 years
- Complications were infrequent, including isolated cases of maxillary sinusitis, Schneiderian membrane perforation, and implant failure
- 90.5% of studies demonstrated moderate to high risk of bias with significant methodological heterogeneity

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Conclusion

- Static surgical guides demonstrated superior and most consistent accuracy across studies
- Robotic-assisted systems show highest precision but require validation through larger clinical trials
- Dynamic navigation offers real-time feedback and adaptability, valuable for complex cases
- All guidance modalities achieved high implant survival rates (92-100%)
- Guided surgery recommended for complex cases, less experienced surgeons, or situations requiring optimal prosthetic positioning
- Surgical guides are adjuncts to, not replacements for, sound surgical technique and anatomical knowledge
- Evidence quality is moderate - limited by few RCTs and high proportion of in vitro studies
- Future research priorities: Well-designed RCTs with long-term follow-up, standardized outcome reporting, cost-effectiveness analyses

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