Concise Review

The Accuracy of Immediate Implantation Guided by Digital Templates and Potential Influencing Factors: A Systematic Review

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ABSTRACT

Background: Immediate implantation guided by digital templates has drawn a great attention in the aesthetic zone, while the accuracy of immediate implantation guided by digital templates has yielded mixed results and many potential factors are known to affect its accuracy. The purpose of our systematic review was to evaluate the accuracy of implant placement guided by the digital template and summarizing its potentials influencing factors.

Materials and methods: We conducted an electronic search of publications upto July 2023, using PubMed, Embase, the Cochrane Central Register of Controlled Trials, and Web of Science to identify studies on accuracy of immediate implant placement surgery guided by digital templates. We selected cohort studies (prospective and retrospective studies) and randomized controlled trials (RCTs). The primary outcome was accuracy of immediate implant placement surgery guided by digital templates.

Results: Seven studies in total fulfilled the inclusion criteria, comprising two prospective studies and five retrospective studies. We collected data including names of authors, publication period, study design, total sample size, clinical conditionas, planning/preoperative details, surgical procedure information, and evaluation criteria. Average global coronal deviation, apical deviation, depth deviation and angular deviation were respectively 0.74 mm (95% confidence interval [CI] 0.41-1.08, I^2 = 99.0%), 1.01 mm (95% CI 0.83-1.20, I^2 = 94.0%), 0.50 mm (95% CI 0.36-0.65, I^2 = 75.3%) and 2.34° (95% CI 1.68-3.00, I^2 = 94.5%). The quality assessment was conducted at a medium to high level.

Conclusions and practical implications: Our systematic review demonstrates that immediate implantation guided by digital templates generally achieves acceptable accuracy. Factors influencing accuracy include the type of surgical guide, method of guide fabrication, surgical protocols, anatomical variability, and preoperative planning challenges. To improve clinical application, it is crucial to enhance the reporting of patient-centred outcomes and socioeconomic benefits.

Introduction

Traditionally, dental implants require a 3-month waiting period for soft and hard tissue healing after tooth extraction, followed by an additional three to 6 months of unloaded osseointegration.[1] Thus, this treatment course lasts longer, requires multiple surgical interventions, and may compromise future dental implant sites through the collapse of the bone crest and the creation of gingival defects.[2,3]

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The application of immediate implant therapy has therefore gained popularity.[4] As the name implies, immediate implant placement refers to implanting an artificial dental implant immediately after tooth extraction,[5] with the benefits of reducing patient waiting times, minimizing the duration of the implant procedure, and better preserving the bone and gingival architecture, and meeting patients' aesthetic demands.[6,7] However, traditional freehand approaches often face challenges in achieving precise implant position and orientation during immediate implant placement surgery.[8] These challenges can arise due to factors such as buccal bone dimensions, peri-implant inflammation, and inadequate initial stability.[9] Malpositioned implants can cause functional challenges like speech impairment and aesthetic problems such as exposed implant necks, so the correct three-dimensional (3D) placement of the implant is a crucial prerequisite for the achievement of success in implant therapy.[10,11]

Surgical templates with embedded metal sleeves that guide the placement of implants in specific positions and orientations were created,[12] particularly in the field of immediate implant placement, because guided surgical techniques emerge as excellent solution to address the challenges associated with accurately predicting and controlling the position of immediate dental implants.[13] With advances in digital technology, hard and soft tissues of the alveolar ridge can be accurately evaluated with high-quality 3D images.[14] The introduction of static computer-assisted implantology in dentistry allows preoperative virtual implant position planning to be transferred to the patient's oral cavity.[7] Errors in each protocol can stem from different sources, thus understanding and evaluating impacted factors leading to inaccurate immediate implant placement guided by digital templates is crucial.

Various clinical studies have now examined the accuracy of using nonimmediate implant guides,[15-17] Gargallo-Albiol et al demonstrated that static computer-assisted surgical guides provide greater accuracy than conventional artificial implant placement.[18] Simultaneously, there has been corresponding headway in the investigation of the immediate implant guide accuracy. It is important to note that immediate implant guides' accuracy is uncertain and may be influenced by surgeon's experience,[19] impression materials,[20] etc. Therefore, good clinical studies and systematic reviews summarizing immediate implant guides' accuracy are essential for clinical outcomes and the development of digital therapies.

Although systematic reviews of the immediate implant placement accuracy and the accuracy of implantation employing computerized techniques have existed, there has been no specific systematic review concentrating on immediate implant placement accuracy guided by digital templates. In this article, accuracy is described as a measurement of the extent to which the implanted implant deviates in 3D from the virtually planned implant location. Hence, the objective of this article is to conduct a systematic review of the available literature pertaining to the accuracy of immediate implantation guided by digital guides and elucidate potential influencing factors.

Materials and methods

Protocol and registration

This review has been registered in the International Prospective Register of Systematic Reviews (PROSPERO) at the National Institute for Health Research (registration number CRD42023456132). This review designed the research program based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[21]

PICO strategy

The PICO strategy was used for the search: P (Population) = Edentulous patient received dental implant treatment; I (Intervention) = Immediate implantation of missing teeth using digital guides; C (Comparison) = Preoperative planned implant on software; O (Outcome) = Accuracy of implantation.

Using the PICO framework for evidence-based practice, the key question can be formatted as follows: In edentulous patients, what is the accuracy of immediate implantation guided by digital templates?

Search strategy

From inception until July 2023, in PubMed, the Cochrane Central Register of Controlled Trials (CENTRAL) database, Embase, and Web of Science, a comprehensive electronic search was conducted. Literature search was restricted to English language only. This study included randomized controlled trials (RCTs) and clinical cohort studies (retrospective and prospective) in this study. The electronic search of the database was conducted using the following search terms: (1) "immediate dental implant" AND (2) "computer-assisted surgery" or "computer-assisted design" or "computer-aided design" or "computer-aided surgery" or "computer-guided surgery" or "computer-guided design" or "digital dentistry" or "guided implant surgery" or "surgical guide" or "surgical template" AND (3) "accuracy" or "deviation" or "precision."

Eligibility criteria

Two reviewers (Q.X. and J.L.) independently assessed the titles and abstracts of the pertinent articles retrieved through the electronic search. Subsequently, the full text was assessed according to the inclusion and exclusion criteria. Inclusion and exclusion criteria are demonstrated below. Discrepancies were addressed through collaborative discussions between the reviewers. In the event of a disagreement between two reviewers, a third reviewer (M.Y.L.) will have the ultimate authority to make the final decision.

The inclusion criteria are as follows:

1) Patients undergoing immediate implant placement guided by digital templates;
2) Patients with no underlying medical conditions;
3) The outcomes included accuracy of implant placement, and the accuracy parameters should include at least coronal deviation, apical deviation, and angular deviation;

4) Prospective longitudinal studies (randomized controlled trials [RCT], controlled clinical trials, case-control studies, and prospective case series);
5) follow-up time of at least 1 year after implant placement;

The exclusion criteria are as follows:

1) Reviews, systematic reviews, case reports (such as individual cases);
2) Cadaver, in vitro studies, animal experiments (nonhuman experiments);
3) Insufficient data and information on outcomes;
4) Duplicate articles by the same author;
5) Conducted research on computerized navigation (dynamic) surgeries.

Data collection process

Two reviewers independently gathered and verified data from the articles. The collected information was then documented in an Excel spreadsheet (Microsoft Corp.) as follows: author, study year, study design, total sample, clinical condition, preoperative planning, surgical procedure, and evaluation method of accuracy. Data regarding the accuracy were extracted according to the following procedure: implant coronal deviation, implant apical deviation, implant depth deviation, and implant angular deviation.

Risk of bias assessment in included studies

Two authors conducted independent evaluations of the included studies' bias risk. Bias assessment in the prospective and retrospective studies was conducted using the Newcastle–Ottawa scale.[22] Three criteria were assessed: Selection, Comparability, Exposure. Each included study can receive a maximum of 9 points. High, medium, and low methodological quality scores of 7 to 9, 4 to 6 or lower, respectively. The risk of bias in the randomized controlled trials (RCTs) was evaluated using the Cochrane Collaboration's tool.[23]

Outcome measurement

The outcome measurement involved assessing the deviation between the implants actually positioned and the planned implantation. The average and standard deviation of coronal deviation, apical deviation, depth deviation, and angular deviation were calculated to assess the accuracy of implant placement.

Quantitative analyses were conducted using Stata (v16.0; StataCorp) Meta-analysis for continuous data in single-armed studies, including global coronal deviation, apical deviation, depth deviation, and angular deviation, was carried out using random effects. Meta-regression was employed for comparisons between different groups. Heterogeneity among the included studies was assessed using the I^2 statistic. The significance level was defined as $P < .05$.

Results

Study selection

The initial electronic database search on PubMed, Cochrane Database, Embase, and Web of Science yielded a total of 435 articles. An extra manual search discovered one more article, contributing to a total of 436 articles for assessment. Following the elimination of duplicates, 321 articles were eligible for initial screening. Subsequently, 309 articles were excluded based on their titles and abstracts. Qualifying full-text screening was then performed, and six articles were excluded because of incomplete data and lack of using digital templates. And seven studies satisfied inclusion criteria (Figure 1).

Study characteristics

The article included five retrospective studies,[24-28] and two prospective studies.[12,29] Some of the literature included was subjected to sample analyses at significance levels (usually alpha), etc. making the findings statistically strong enough to support them. Table 1 shows the characteristics of the incorporation articles. This study analysed the number of patients and implants using immediate implantation guided by digital templates was 202 and 215. In addition, the accuracy data of immediate implantation guided by digital templates are displayed in Table 2. It should be noted that sample size calculations were only performed in the studies by Feng et al, Han et al, and Huang et al.[12,25,29]

The included studies investigated different types of arches, including maxillary and mandibular, and explored the impact of maxillary and mandibular on implant accuracy. Overall, five studies concentrating on maxillary,[12,24,25,27,29] and two studies further investigated mandibular arch.[24,25] In addition, the studies covered different implant positions, including the anterior[12,24,25,26,29] and posterior regions.[24] In the included studies, two methods were employed to transfer intraoral conditions to the implant planning software. Optical scanning incorporated herein includes extraoral and intraoral scans. Five studies used intraoral scanning procedures,[12,24-26,28] one study used extraoral scanning procedures,[29] and one study was unspecified.[27] Surgical guide fabrication may be subdivided into stereolithographic technologies (computer-aided design/computer-aided manufacturing [CAD/CAM]) and laboratory-based procedures.[17] In this study, most of the studies focused on laboratory manufacturing procedures,[12,25-29] and only one study used CAD/CAM surgical guides.[24] Various flap methods were employed in the implant placement procedures across the included studies, and four studies used flap methods,[12,25,26,28] while another four used the flapless approach.[12,25,27,29] Four studies used a fully guided protocol,[12,25,26,29] one study used both a fully guided protocol and a half-guided protocol,[28] and two study was unspecified.[24,27] Out of the seven studies, only five employed radiographic methods to evaluate implant placement accuracy,[25-29] comparing computed tomography (CT) scans before and after the surgery; one study used nonradiographic methods (intraoral optical scanning of the inserted implant)[12] and another study combined radiographic and nonradiographic methods.[24]

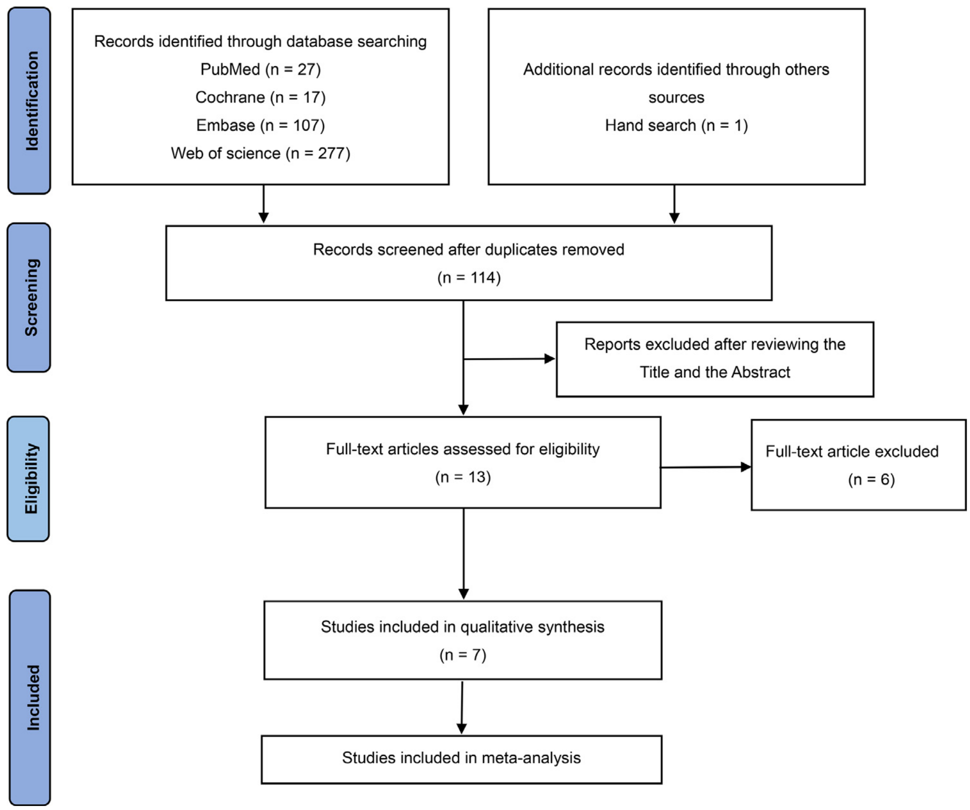

Fig. 1 – Flow diagram of the PRISMA guidelines for conducting a literature search.

Risk of bias result

The clinical cohort studies (both retrospective and prospective) included in this systematic review scored between 6 and 8 after a risk of bias assessment, indicating a methodological quality that falls between moderate and high (Tables 2 and 3 and Figure 2).

Global accuracy

The global accuracy analysis included studies reporting on coronal deviation, apical deviation, depth deviation, and angular deviation. Figure 3A coronal deviation total effect size is 0.74 (0.41, 1.08) with a 95% confidence interval (CI). The CI does not touch the 0 line, indicating that this effect size is statistically significant. The I^2 value is 99% and the P value is .000, indicating significant heterogeneity among the studies. Figure 3B apical deviation has a total effect size of 1.01 (0.83, 1.20) with a 95% CI. The CI does not touch the 0 line, indicating that this effect size is statistically significant. The I^2 value is 94% with a P value of .000, indicating a large degree of heterogeneity among the studies. Figure 3C angular deviation has a total effect size of 2.34 (1.68, 3.00) with a 95% CI. The CI does not touch the 0 line, indicating that this effect size is statistically significant. The I^2 value is 94.5% with a P value of .000 indicating that there is significant heterogeneity among the studies. Figure 3D depth deviation effect size is 0.50 (0.36, 0.65) with a 95% CI. The CI did not touch the 0 line indicating that this effect size is statistically significant. The I^2 value was 75.3% with a P value of .007 indicating moderate heterogeneity among studies.

Subgroup analysis: maxillary dental implant

For the maxillary dental implant subgroup, Figure 4A apical deviation overall combined effect size of 0.61 (0.11, 1.11) with a CI of 95%. The CI does not contain 0, indicating that the overall combined result is statistically significant. The I^2 value of 99.5% and the associated P value (P = .000) suggest that there is significant heterogeneity among studies. Figure 4B apical deviation overall combined effect size is 0.88 (0.62, 1.15) with a CI of 95%. The CI does not contain 0, indicating that the overall combined result is statistically significant. The I^2 value of 96.0% and the associated P value (P = .000) indicate substantial heterogeneity among studies. Figure 4C angular deviation overall combined effect size was 2.01 (1.01, 3.00) with a CI of 95%. The CI does not contain 0, indicating that the overall combined result is statistically significant. The I^2 value of 96.7% and the associated P value (P = .000) indicate a high degree of heterogeneity among studies. The studies included in this analysis were cited as.[12,27,29]

Subgroup analysis: anterior dental implant

In the anterior dental implant subgroup, Figure 5A coronal deviation overall combined effect size is 0.81 (0.69, 0.93) with a CI of 95%. The CI does not contain 0, indicating that the overall combined result is statistically significant. An I^2 value of 71.3% and a P value (.015) indicated moderate

Table 1 – Characteristics of studies included in the article.

Study	Study design	Total sample			Clinical condition		Planning/preoperative			Surgical procedure			Evaluation
		Patient	Implant	Failure	Type of arch	Implant position	Optical scanning	Surgical guide type	Software	Flap method	Guide support	Surgical protocol	Method
Alzoubi et al[24]	Retro	29	40	0	Max; Man	Ante; Post	IOS	CAD/CAM	Anatomage	NR	Tooth	NR	Radiographic; nonradiographic
Chen et al[28]	Retro	63	76	0	NR	NR	IOS	Laboratory	Nobel Clinician; SimPlant	Flap	Tooth	Fully; half	Radiographic
Huang et al[25]	Retro	40	52	0	Max; Man	Ante	IOS	Laboratory	3 Shape Dental System; NobelClinician	Flap; Flapless	NR	Fully	Radiographic
Zhang et al[26]	Retro	25	30	0	NR	Ante	IOS	Laboratory	3 Shape Dental System; NobelClinician	Flap	NR	Fully	Radiographic
Han et al[29]	Prospect	60	102	0	Max	Ante	EOS	Laboratory	3 Shape Dental System	Flapless	NR	Fully	Radiographic
Caggiano et al[27]	Retro	95	95	0	Max	NR	NR	Laboratory	NR	Flapless	Tooth	NR	Radiographic
Feng et al[12]	Prospect	40	40	0	Max	Ante	IOS	Laboratory	Exocad Dental CAD; NobelClinician	Flap; Flapless;	NR	Fully	Nonradiographic

Ante, anterior; CAD/CAM, computer-aided design/manufacturing; Man, mandibular; Max, maxillary; NR, not reported; Post, posterior; Prospect, prospective study; Retro, retrospective study.

Table 2 – Newcastle–Ottawa scale (NOS) for assessing the quality of cohort studies.

Study	Selection (max 4 points)				Comparability (max 2 points)	Outcome (max 3 points)			Score (out of 9)
	Representativeness of the exposed cohort	Selection of the nonexposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study	Comparability of cohorts on the basis of the design or analysis	Assessment of outcome	Was follow-up long enough for outcomes to occur?	Adequacy of the follow-up of cohorts	
Alzoubi et al[24]	1			1	2	1	1	1	7
Chen et al[28]	1		1	1	2	1	1	1	8
Huang et al[25]	1				2	1	1	1	6
Zhang et al[26]	1			1	2	1	1	1	7
Han et al[29]	1		1	1	2	1	1	1	8
Caggiano et al[27]	1			1	2	1	1	1	7
Feng et al[12]	1				2	1	1	1	6

Table 3 – Descriptive statistics of the accuracy of immediate implantation guided by digital templates.

Coronal deviation			
Study	N	Mean	SD
Alzoubi et al[24]	25	0.85	0.65
Chen et al[28]	40	0.91	0.63
Han et al[29]	50	0.74	0.21
Huang et al[25]	29	0.91	0.3
Zhang et al[26]	14	0.7	0.3
Caggiano et al[27]	37	0.14	0.07
Feng et al[12]	20	0.99	0.63
Apical deviation			
Study	N	Mean	SD
Alzoubi et al[24]	25	1.1	0.65
Chen et al[28]	40	1.23	0.63
Han et al[29]	50	0.81	0.16
Huang et al[25]	29	1.11	0.4
Zhang et al[26]	14	1	0.4
Caggiano et al[27]	37	0.56	0.24
Feng et al[12]	20	1.5	0.75
Angular deviation			
Study	N	Mean	SD
Alzoubi et al[24]	25	3.49	2.46
Chen et al[28]	40	2.2	1.4
Han et al[29]	50	2.17	0.92
Huang et al[25]	29	3.24	1.87
Zhang et al[26]	14	1.7	1
Caggiano et al[27]	37	1.04	0.56
Feng et al[12]	20	3.07	2.18
Depth deviation			
Study	N	Mean	SD
Chen et al[28]	40	0.73	0.66
Huang et al[25]	29	0.47	0.66
Han et al[29]	50	0.39	0.12
Zhang et al[26]	14	0.5	0.3

N, number of immediate implantation guided by digital templates; SD, standard deviation.

heterogeneity among studies. Figure 5B apical deviation overall combined effect size for apical deviation is 1.07 (0.82, 1.32) with a CI of 95%. The CI does not contain 0, indicating that the overall combined result is statistically significant. Overall, 90.7% of the I^2 value and the P value (.000) indicate that there is a high degree of heterogeneity among studies. Figure 5C depth deviation overall combined effect size for depth deviation was 2.46 (1.84, 3.08) with a CI of 95%. The CI did not contain 0, indicating that the overall combined result was statistically significant. The I^2 value of 80.7% and the P value (.001) indicated a high degree of heterogeneity among studies. Figure 5D angular deviation overall combined effect size for angular deviation is 0.40 (0.35, 0.45) with a CI of 95%. The CI does not contain 0, indicating that the overall combined result is statistically significant. The I^2 value of 7.9% and the P value (.338) indicate little heterogeneity among studies. The studies contributing to this analysis were cited as.[12,25,26,29]

Effect of planting methods (delayed implantation vs immediate implantation)

Five studies were reviewed to compare the accuracy between delayed and immediate implantation guided by digital templates.[24-28] Figure 6A coronal deviation overall combined effect size is 0.07 (−0.09, 0.22) with a CI of 95%. The CI contains 0, indicating that the overall combined result may not be statistically significant. An I^2 value of 73.7% and a P value (.004) indicated moderate heterogeneity among studies. Figure 6B apical deviation overall combined effect size of 0.05 (−0.12, 0.22) with a CI of 95%. The CI contains 0, indicating that the overall combined result may not be statistically significant. The I^2 value of 58.7% and the P value (.046) indicate a degree of heterogeneity among studies. Figure 6C depth deviation overall combined effect size for depth deviation is −0.18 (−0.38, 0.02) with a CI of 95%. The CI contains 0, indicating that the overall combined result is not statistically significant. An I^2 value of 0.0% and a P value (.927) indicated little heterogeneity among studies. Figure 6D angular deviation overall combined effect size for angular deviation is 0.16 (0.01, 0.31) with a CI of 95%. The CI does not contain 0, indicating that the overall combined result was statistically significant. The I^2 value of 0.0% and the P value (.698) indicate little heterogeneity among studies. The studies providing data on depth deviation included only three articles.[25,26,28]

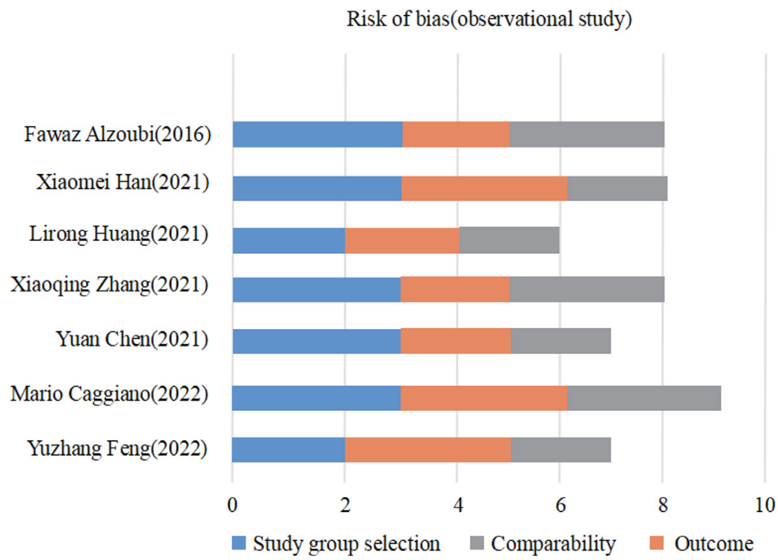

Fig. 2 – Risk of bias for inclusion of articles.

Discussion

Proper 3D implant position is vital for longevity and osseointegration of implants, as well as for achieving the biological, functional, and aesthetic success of prosthetic restoration.[30,31] Improper implant placement not only reduces the success rate and aesthetic parameters, but also leads to serious problems such as bone resorption and peri-implantitis.[32,33] The concept of immediate implant placement entails the insertion of an implant into the socket right after the extraction of the tooth.[34] Immediate implant placement may shorten treatment times, require fewer surgical interventions,[35,36] and result in reduced loss of peri-implant alveolar ridge bone, along with improved soft-tissue healing, potentially leading to enhanced aesthetic results.[37] It should be noted that placing an implant in a fresh extraction socket is more challenging than in a healed alveolar ridge because of the complexities involved in the anatomical characteristics of the alveolar process, the gap between the implant surface and the interior of the alveolar wall, and other factors.[38,39] Therefore, caution must be exercised when performing immediate implant surgical treatment.

The introduction of digital template-guided implantation can improve the accuracy of immediate implantation.[31] Preoperative 3D planning followed by printing of 3D surgical templates through CT imaging, which include cone-beam CT and multislice CT, improves the predictability of treatment.[40,41] Furthermore, the utilization of digital guides not only enhances the accuracy of implant placement but also concurrently reduces the risk of technical and biological complications.[30,42] Additionally, for anterior dental implants, digital guides deliver aesthetic-oriented results that enhance patient comfort and satisfaction.[43] Taking into account the clinical, biological, functional, and aesthetic benefits provided by guided implant surgery and its close association with 3D implant placement accuracy, this procedure is now also employed in immediate implant surgery.[12,14,32] In cases of immediate implant placement, which are susceptible to deviations, the use of guides enhances implant stability and facilitates the achievement of biologically stable results in an ideal 3D positioning environment.[31] In addition, traditional flap surgery requires extensive incision and separation of soft tissues, increasing tissue trauma and postoperative pain. By avoiding flap flipping, computer-guided surgery can dramatically reduce soft tissue damage, decrease postoperative complications, speed recovery, and ultimately improve surgical accuracy.[44]

Five retrospective studies[24-28] and two prospective studies[12,29] were included in this study. The results determined average coronal deviation, apical deviation, depth deviation, and angular deviation to be 0.74 mm, 1.01 mm, 0.50 mm, and 2.34°, respectively. When comparing our study with that of Schneider et al,[7] this review observed differences in coronal deviation (1.16 vs 0.74 mm) and apical deviation (1.96 vs 1.01 mm). Based on this comparison, our preliminary finding suggests that immediate implantation with guide plates achieves relatively high accuracy. However, it is crucial to note the substantial heterogeneity present in this study. When comparing the accuracy data between delayed and immediate implantation, this review found no significant differences in coronal deviation, apical deviation, and angular deviation. However, it's important to highlight that there was substantial heterogeneity in coronal deviation, indicating significant variability among different studies. In terms of depth deviation, immediate implantation demonstrated a slightly higher degree of accuracy in comparison to delayed implantation, although this difference was not statistically significant.

While, the accuracy of implant surgery under digital guides is affected by many factors, such as types of sleeve-designed,[45] partially edentulous spaces,[46] supporting tissues of the surgical guide,[47] among others. The accuracy of surgical guides may be influenced by the methodology employed in their fabrication. The guides can be made by CAD/CAM technology or they can be manually fabricated in the dental

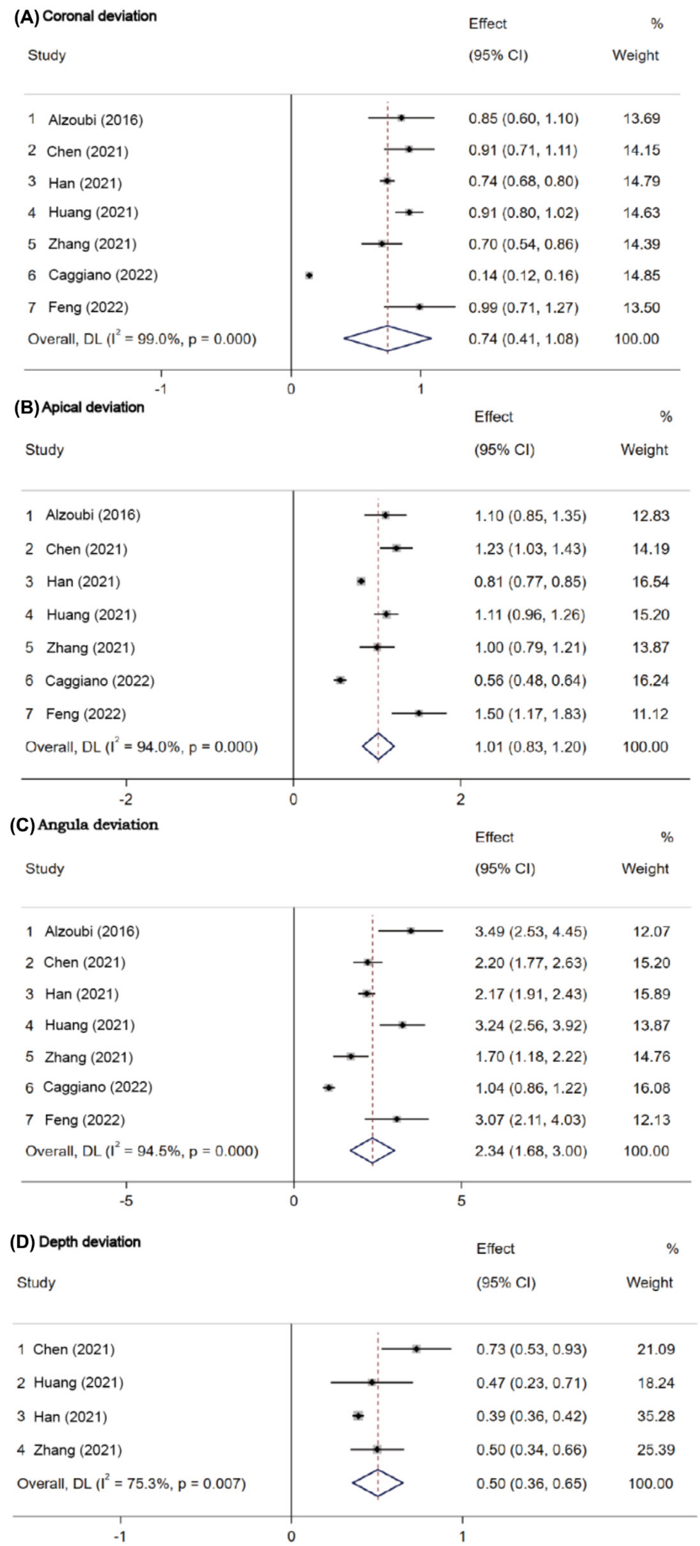

Fig. 3 – Forest plots of deviations in immediate implantation guided by digital templates: (A) coronal deviation, (B) apical deviation, (C) angular deviation, (D) depth deviation.

laboratory.[48] Putra et al[30] stated in their study that conventional implant surgery exhibited a higher mean angular deviation than CAD/CAM template-guided implant surgery, with both having a mean angular deviation of 1.45 mm. In addition, different supporting tissues, including tooth-supported, bone-supported and mucosa-supported, in the surgical guide may also affect the accuracy results.[49] Partially edentulous patients commonly utilize tooth-supported surgical guides.[30] Previous research (Yolanda et al) reported that tooth-supported guides offer higher accuracy compared to bone or

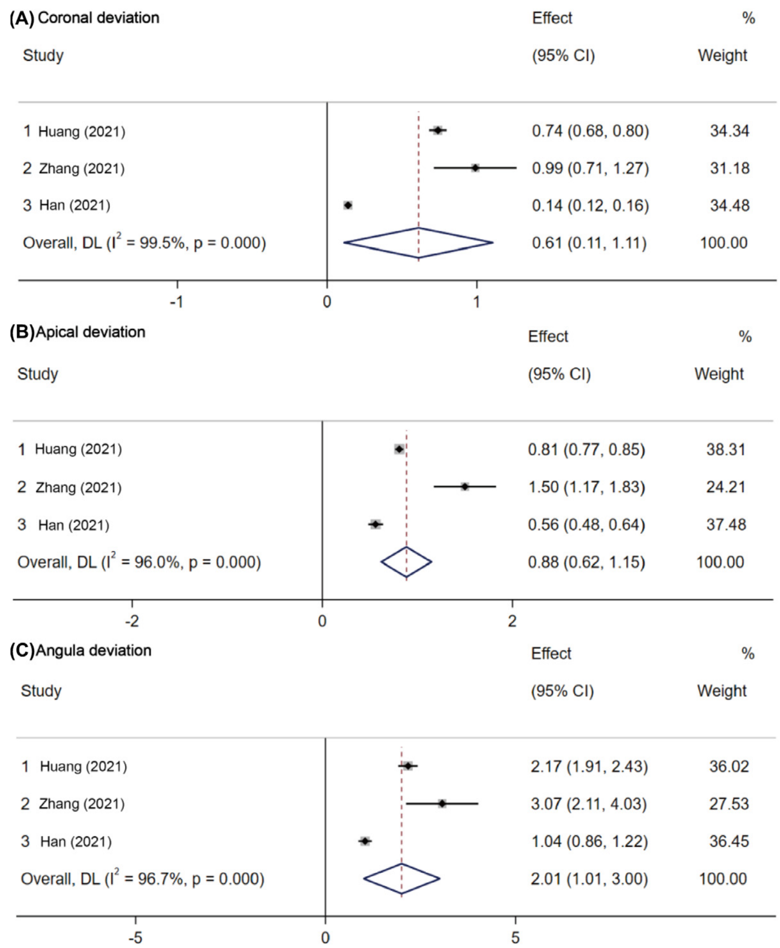

Fig. 4 – Forest plots for single-arm analysis of maxillary teeth deviations in immediate implantation guided by digital templates: (A) coronal deviation, (B) apical deviation, (C) angular deviation.

mucosal-supported guides.[46] Moreover, the types of arch are another factor that could impact the accuracy of implant surgery under digital guides. Zhou et al[50] concluded that implant surgery under digital guides procedures performed in the mandible were more accurate than those performed in the maxilla due to the fact that the maxilla is rounded, limiting angular control. Different guided surgical protocols also affect the accuracy of the guides. Fully guided surgery relies on that directs each stage of the procedure, from the initial drilling to the implantation, by using the guide sleeve in the guide. In the fully guided surgery, the surgical guide directs each stage of the surgery. In the half-guided surgery, after completing the osteotomy preparation under the surgical guide, the guide is removed, and the implant is placed freehand.[51-53] In included study Chen et al.[28] coronal and depth deviations were more accurate in fully guided surgery than in half-guided surgery, a result consistent with a retrospective study conducted by Cassetta et al.[54] The accuracy of static fully guided surgery was significantly higher than that of static half-guided surgery, as reported in a systematic review by Gargallo-Albiol et al.[18] Whereas most of the studies this study included used fully guided procedures, this may be one of the reasons why we obtained the conclusion that the accuracy of immediate implant procedures was relatively high. In summary, the accuracy of digital guides is affected by a variety of factors. Therefore, precise surgical planning and comprehensive consideration of these factors are important in implant surgery under digital guides to ensure optimal clinical outcomes.

During the process of immediate implant placement, the anatomical structure of the alveolus results in greater resistance from the lingual side as opposed to the buccal side. Consequently, the drill bit has a tendency to deviate towards the buccal side, thereby impacting the accuracy of implantation.[39] Digital-guided templates play a critical role in immediate implant surgery, assisting dentists in precise surgical planning to ensure the accurate position and stability of implants. Results of our study further supported this opinion through a systematic review of articles on the accuracy of immediate implantation using different digital templates.

In addition, the guides cannot be tried on in advance of the immediate implant procedure because the teeth have not yet been extracted. This limitation may affect the fit of the guides and the accuracy of the procedure. Even though digital guide templates play a key role in preoperative planning, unexpected adjustments, and challenges may be encountered during the procedure due to the inability to try them on in advance. Therefore, future research should focus on ways to

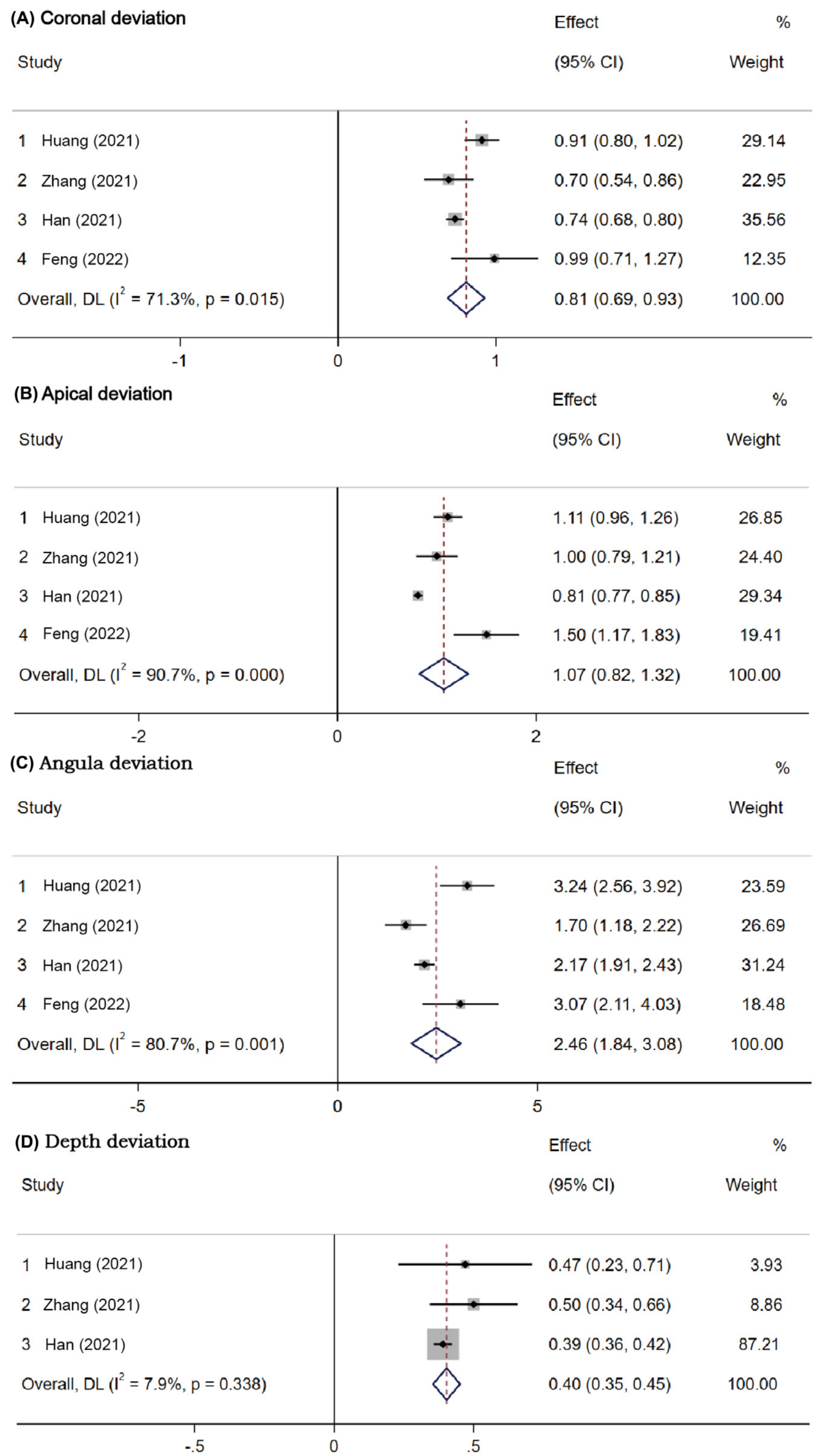

Fig. 5 – Forest plots for single-arm analysis of anterior teeth deviations in immediate implantation guided by digital templates: (A) coronal deviation, (B) apical deviation, (C) angular deviation, (D) depth deviation.

overcome this limitation, such as developing adaptable guide plate designs or improving preoperative planning techniques to improve the precision and success of immediate implantation.

Limitations and future scope

The content of included articles was low, the number of patients was limited, and the heterogeneity of articles was

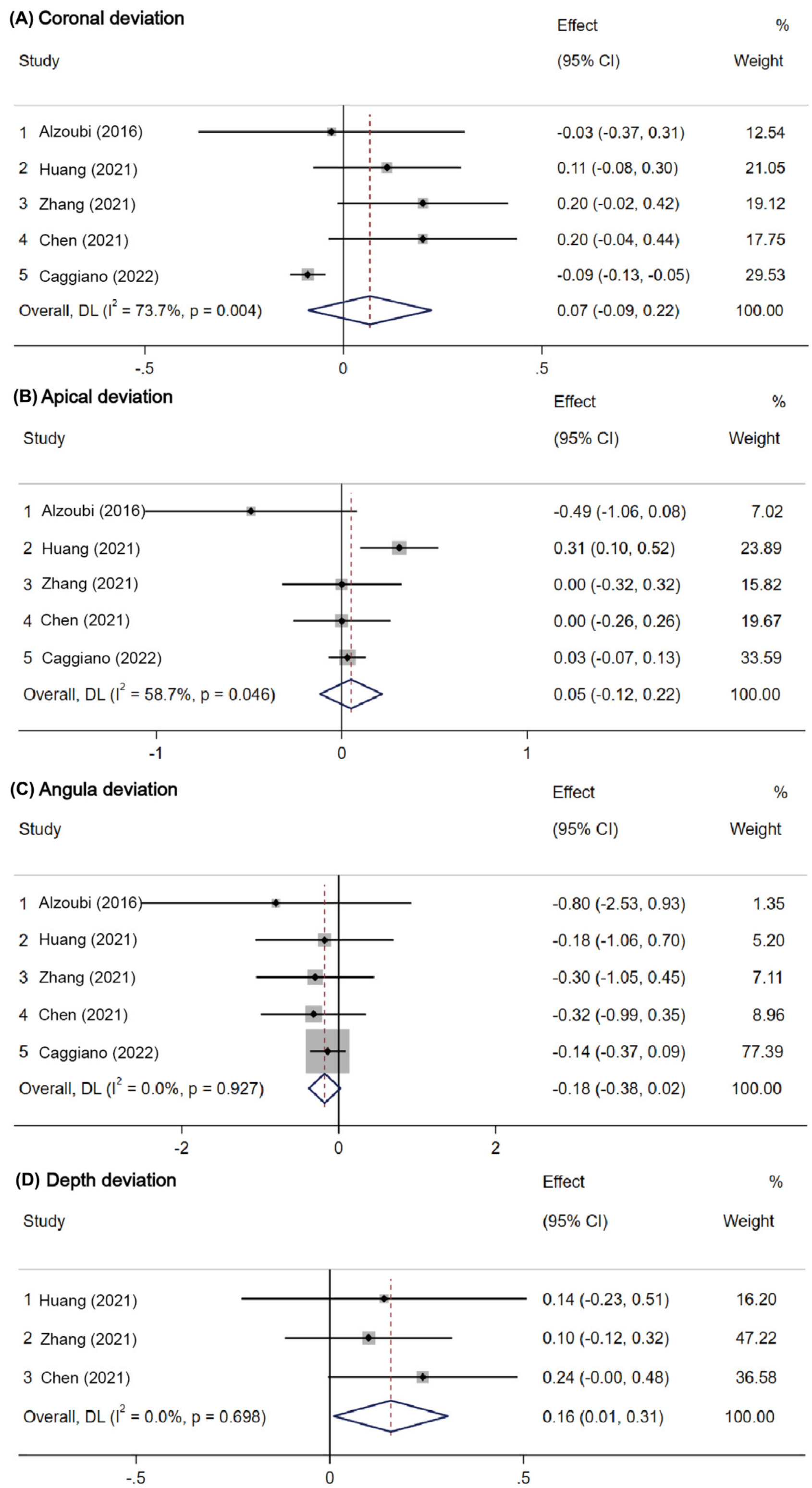

Fig. 6 – Forest plot evaluating the deviations in planting methods (delayed implantation vs immediate implantation) guided by digital templates: (A) coronal deviation, (B) apical deviation, (C) angular deviation, (D) depth deviation.

high, while some articles did not provide *P* values for precision. In addition, our study focused on the accuracy of digital templates in immediate implantation for clinical application, which is insufficient to fully understand its clinical value. Therefore, patient-centred outcomes such as satisfaction, comfort, and postoperative recovery, which are essential for evaluating treatment effects and long-term quality of life should also have been considered in future research. For example, socioeconomic benefits are equally important, and studies should explore the potential of immediate implantation to reduce treatment time, lower medical costs, and improve patient compliance. Additionally, evaluating the feasibility and promotability of digital template immediate implantation across different socioeconomic contexts will help establish a more comprehensive and multidimensional evaluation system, providing a robust basis for clinical decision-making.

Conclusion

Based on the systematic review, immediate implantation guided by digital templates appears to have generally acceptable accuracy. Various factors impact the accuracy of the implantation, such as the type of guide used, the surgical technique (flap or flapless), and the site (maxilla or mandible). Although the timing of implant placement did not significantly affect the accuracy of implantation, other factors, such as the surgeon's experience, the type of digital planning software, and the quality of preoperative imaging, are crucial for achieving optimal results during immediate implantation.

Author contributions

Qi Xing contributed to conception and design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript; Jie Lin contributed to data interpretation, critically revised the manuscript; Mingyue Lyu contributed to conception and design, data analysis and interpretation, critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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Conflict of interest

The paper is original and free of any conflict of interest. Neither the entire paper nor any part of its content has been published or accepted by another journal. The article is also not being submitted to any other journal.

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