

SINGLE-TOOTH IMPLANT PLACEMENT, LOADING AND PERI-IMPLANT SOFT TISSUE MANAGEMENT

Ph.D. Thesis

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Budapest

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***“But before the road of Excellence the
immortal gods have placed sweat.”***

Hesiod

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1. LIST OF ABBREVIATIONS

AHA	Anatomic Healing Abutments
BBT	Buccal Bone Thickness
BOP	Bleeding On Probing
CENTRAL	Cochrane Central Register of Controlled Trials
CHA	Cylindrical-Shaped Prefabricated Healing Abutments
CI	Confidence Intervals
CNKI	China National Knowledge Infrastructure
EP	Emergence Profile
GMH	Gingival Margin Height
IIP	Immediate Implant Placement
IPLP	Implant Placement and Loading Protocol
IS	Implant Survival
ITI	International Team for Implantology
JBI	Joanna Briggs Institute
MBL	Marginal Bone Loss
MD	Mean Difference
MEDLINE	MEDical Literature Analysis and Retrieval System Online
PES	Pink Esthetic Score
PICOST	Population, Intervention, Comparison, Outcome, Study type, and Time
PPD	Periodontal Probing Depth
PPDc	Change in Periodontal Probing Depth
PR	Provisional Restoration
PRISMA	Preferred Reporting Items for Systematic Review and Meta-Analysis
PROSPERO	International Prospective Register of Systematic Reviews
RCT	Randomized Controlled Trial
RMS	Root Mean Square
RoB-2	Risk of Bias 2
ROBINS-I	Risk Of Bias In Non-randomized Studies of Interventions
RW	Ridge Width
SC	Supracrestal Complex

SISR	Single-Tooth Implant-Supported Restoration
STR	Soft Tissue Recession
VAS	Visual Analog Scale
VIP	Chinese Scientific Journal Database
WES	White Esthetic Score
WoS	Web of Science

2. STUDENT PROFILE

2.1. Vision and mission statement, specific goals

My vision is to provide the highest-quality implant-restorations with the most time- and cost-effective workflow, while minimizing patient discomfort based on scientific and clinical evidence, and my mission towards achieving this is to implement the best implant-prosthodontic treatment for the anterior region into everyday practice.



My specific goals are to compare the effect of implant placement and loading protocols, anatomic vs non-anatomic healing abutments, and digital vs conventional impression techniques, on hard and soft tissues around single anterior maxillary implants.

2.2. Scientometrics

Number of all publications:	13
Cumulative IF:	79.9
Av IF/publication:	6.15
Ranking (SCImago):	D1: 9, Q1: 2, Q2: 1
Number of publications related to the subject of the thesis:	3
Cumulative IF:	29.3
Av IF/publication:	9.77
Ranking (SCImago):	D1: 3
Number of citations on Google Scholar:	38
Number of citations on MTMT (independent):	22
H-index:	3

The detailed bibliography of the student can be found on pages 84-85.

2.3. Future plans

I plan to continually advance my scientific and clinical expertise, improving patient care through evidence-based dentistry.

3. SUMMARY OF THE THESIS

This thesis addresses three key stages of single implant rehabilitation from implant placement to prosthodontic rehabilitation by synthesizing current evidence with three systematic reviews and meta-analyses. The studies investigated the following topics: 1) the timing of implant placement and loading, 2) the application of anatomic healing components for emergence profile conditioning, and 3) the accuracy of digital impression methods in capturing the conditioned emergence profile for definitive rehabilitation. Together, these analyses help pave an evidence-based workflow for single implant rehabilitation with coordinated work phases and also highlight the importance of correct peri-implant tissue management.

The network meta-analysis on implant placement and loading demonstrated that immediate implant placement combined with immediate provisionalization (protocol 1A) consistently ranked among the most favorable protocols with significant esthetic advantage, aligning with the prior International Team for Implantology (ITI) 7th Consensus Statement from 2023. However, strict criteria need to be met in order to perform immediate implantation to avoid early implant failure.

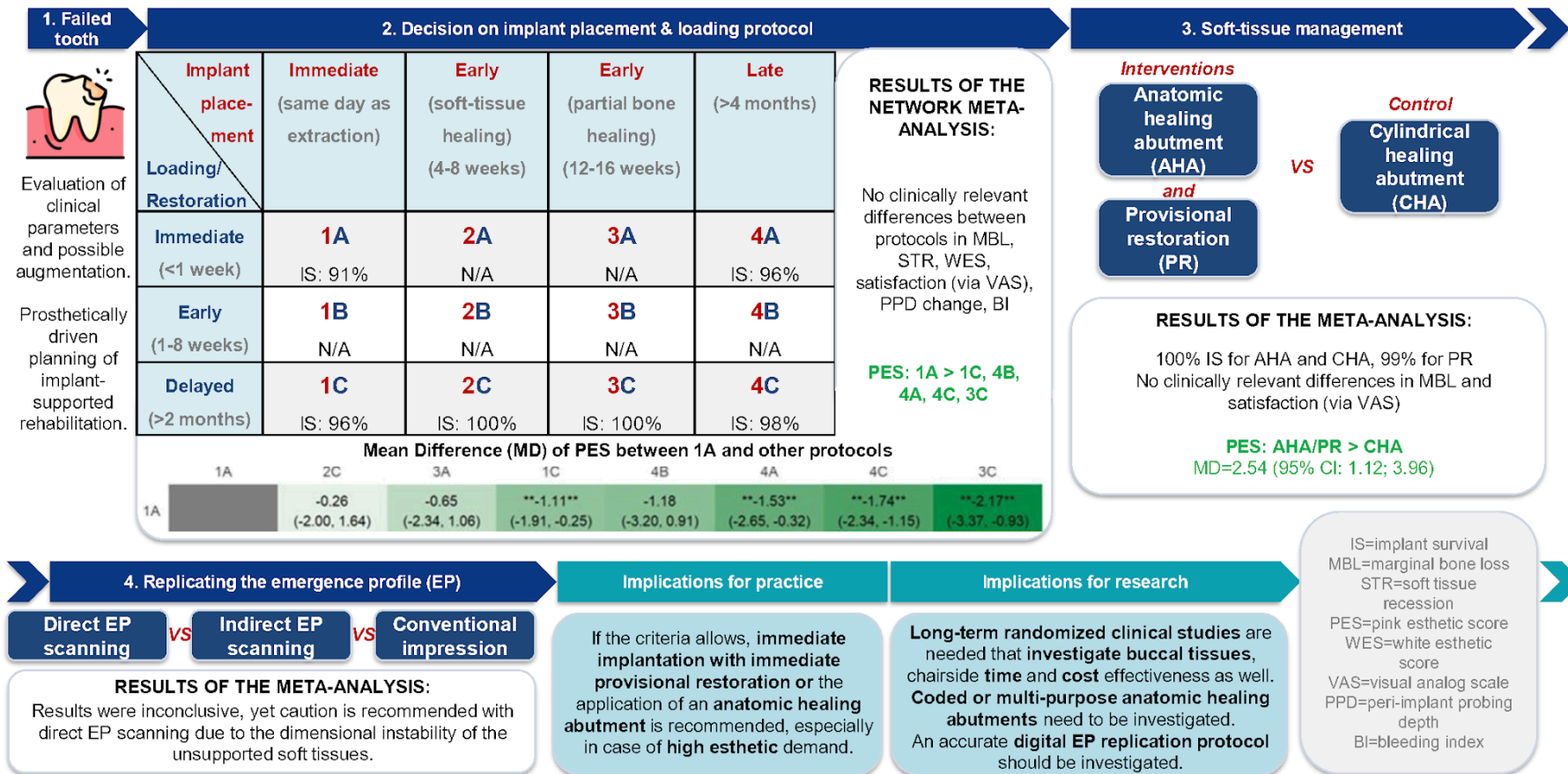
Our second study evaluated anatomically shaped healing abutments (AHA) and provisional restorations (PR) compared to conventional cylindrical healing abutments (CHA) with a meta-analysis, with which we found clear esthetic advantage of AHA and PR over CHA. Furthermore, anatomical healing abutments resulted in lower failure rates than immediate provisionalization.

In order to maintain the anatomically formed emergence profile (EP), it is crucial to apply the most accurate impression method to replicate the shape of the AHA or PR to the final restoration. Our third study aimed to investigate the accuracy of digital EP replication methods. Although no clear recommendation can be made based on the current evidence, caution is recommended when applying direct EP scanning, as the peri-implant tissues lose their dimensional stability quickly after the removal of the restoration. Further investigations are needed to find the optimal EP replication technique for digital implant-prosthodontic workflows.

4. GRAPHICAL ABSTRACT

CLINICAL PATHWAY FOR SINGLE IMPLANT REHABILITATION

Based on the choice of implant placement and loading times, and the methods of emergence profile management and replication



5. INTRODUCTION

5.1. Overview of the topic

5.1.1. What is the topic?

This thesis examines the optimal management of single-tooth implant-supported restorations (SISRs), covering the timing of implant placement and loading, soft-tissue management during the provisional phase, and the selection of the most suitable impression technique for the final restoration, to achieve harmonious esthetics and biology.

5.1.2. What is the problem to solve?

To meet the increasing patient standards and achieve predictable long-term results, dentists must plan and execute clinical workflows with precision, which is particularly crucial when we aim to simulate natural biology with implant-prosthodontics.

5.1.3. What is the importance of the topic?

The timing of rehabilitation, as well as the correct maintenance and accurate reproduction of the peri-implant soft tissues, directly determine the success and long-term stability of implant restorations. The timing of implant placement and loading determines the stability of the implant-supported restoration and the potential for early tissue-preservation. The provisional phase determines the correct formation of the supracrestal complex, crucial for the biological integrity of peri-implant soft and hard tissues. Choosing the optimal impression method to replicate this emergence profile (EP) onto the final restoration seals the results of the soft tissue management. Complications such as implant loss, peri-implant inflammation, increased marginal bone loss, soft-tissue recession, and poor esthetics may occur when the steps of treatment are not carried out in a biologically coherent manner.

5.1.4. What would be the impact of our research results?

The evidence presented in the three studies covering these topics provides a comprehensive evidence-based workflow from surgery to final rehabilitation of SISRs. The expected impact of this research is the formulation of a clinical protocol that optimizes soft-tissue parameters and esthetic predictability of SISRs.

5.2. Single-Tooth Implant Supported Rehabilitation

Implant-supported restorations have become the treatment of choice for replacing missing teeth due to their minimal invasiveness compared to fixed partial dentures and their ability to mimic natural dentition; however, differences still exist between implant-supported restorations and natural teeth, which makes it particularly challenging to harmonize the restorations with neighboring dentition when replacing single-tooth gaps, especially in the anterior region (1–9). Given the high patient demands for excellent esthetics and short rehabilitation times, it is essential to prepare individual treatment plans based on the latest scientific and clinical evidence to ensure optimal outcomes.

5.3. Timing of Implant Placement and Loading

The timing of implant-prosthodontic rehabilitation following tooth extraction may affect the amount of bone resorption and soft tissue changes, which is especially crucial in the maxillary esthetic region, where thin buccal bone and rapid bone resorption could complicate correct implant positioning, prosthetic design, and supportive therapy, which are the basis of long-term success (10–17). Previously, the timing of implant placement and loading has been analyzed separately, yet according to the 2018 and later Consensus reports of the International Team for Implantology (ITI), the timing of implantation and loading should always be considered together and decided before tooth extraction (16,18–20). Twelve types of implant placement and loading protocols (IPLPs: 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B, 3C, 4A, 4B, and 4C) have been defined (**Table 1**)(16,18,19).

Table 1. 2018 ITI guideline: implant placement and loading protocols (16,18,19).

Implant place- ment Loading/ Restoration	Immediate (same day as extraction)	Early (soft-tissue healing) (4-8 weeks)	Early (partial bone healing) (12-16 weeks)	Late (>4 months)
Immediate (<1 week)	1A	2A	3A	4A
Early (1-8 weeks)	1B	2B	3B	4B

Delayed (>2 months)	1C	2C	3C	4C
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Although several authors have emphasized that immediate implantation may preserve alveolar bone and soft tissue contour compared with delayed implantation, mid-facial gingival recession appears to be more common with the former, especially in patients with thin mucosal phenotypes (2,12). However, only few authors have discussed the effect of the other alternatives, type 2 and 3 early placement protocols, which have often been combined as type 2-3 protocol in previous reviews due to missing data for separate analysis, even though they may integrate the benefits of immediate and delayed protocols (13,16).

Until this study, no comprehensive review had been conducted that analyzed and ranked all 12 types of implant placement and loading protocols according to their effects on both hard and soft tissue parameters in the anterior maxilla.

5.4. Implant Supracrestal Complex

The implant supracrestal complex (SC) is the soft tissue complex above the marginal bone, including the connective tissue, the junctional epithelium, and the sulcus (21,22). As opposed to natural dentition, the soft-tissue attachment around implants is a scar-like, circular cuff of epithelial and connective tissue adhesion with fewer and less organized fibers, no periodontal ligaments, and weaker vascularization, therefore, the seal is weaker and less able to resist mechanical and bacterial invasion, and inflammatory responses could be more destructive and progressive (21,22).

The integrity of the SC is crucial for the long-term survival and success of implant prosthodontics (14,16,17). Due to its structural fragility, it depends heavily on prosthetic design to enhance stability (21–23). The correctly formed emergence profile (EP)—which is the contour of the implant-restoration complex relating to and forming the circumscribed soft tissues (24)—mimics the root convexity of a natural tooth, guiding soft tissue into a stable, scalloped shape, creating a pseudo-seal that enhances the mucosal barrier against harm and improves oral hygiene access (**Figure 1**)(21–23). The correct formation of the supracrestal complex not only promotes the biological and functional integrity of peri-implant tissues but is also necessary to achieve natural

esthetics, meeting the increasing patient demands, which can be especially challenging when rehabilitating single-tooth gaps, particularly in the esthetic region (10,11,13,15,21–23).

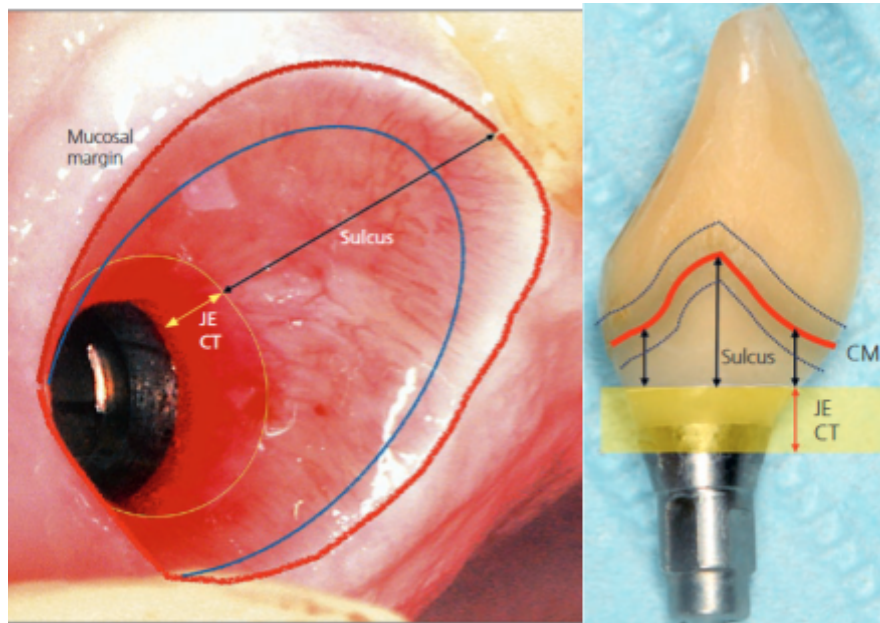


Figure 1. Emergence profile on the peri-implant supracrestal complex formed by the respective areas of the prosthodontic restoration. CM=cervical margin, CT=connective tissue, JE=junctional epithelium. Image by Mattheos et al. (22).

5.4.1. Forming the Emergence Profile

The conventionally applied cylindrical-shaped prefabricated healing abutments (CHA) create a uniform, narrow, and unnatural cylindrical emergence profile. To avoid this, one may fabricate a customized anatomic healing abutment (AHA) matching the individual anatomy of the replaced tooth, which could create more natural esthetics, and potentially allows for the preservation of additional cortical bundle bone besides original soft tissue contours by supporting the peri-implant tissues more similar to the lost tooth (**Figure 2**)(25–28). Esthetics and patient satisfaction can be further improved with immediate provisionalization, where the provisional restoration (PR) is also connected to the implant within one week of immediate implant placement (IIP)(8,16,18,19). However, the latter might increase masticatory implant loading and hinder the implant integration process (29). Moreover, AHAs and PRs are more costly and labor-intensive to fabricate compared to stock CHAs (25,26,30), and the question remains unanswered whether the clinical parameters are significantly better, thus

making it worth the additional effort to obtain anatomically shaped restorations that can be delivered together with implant placement.

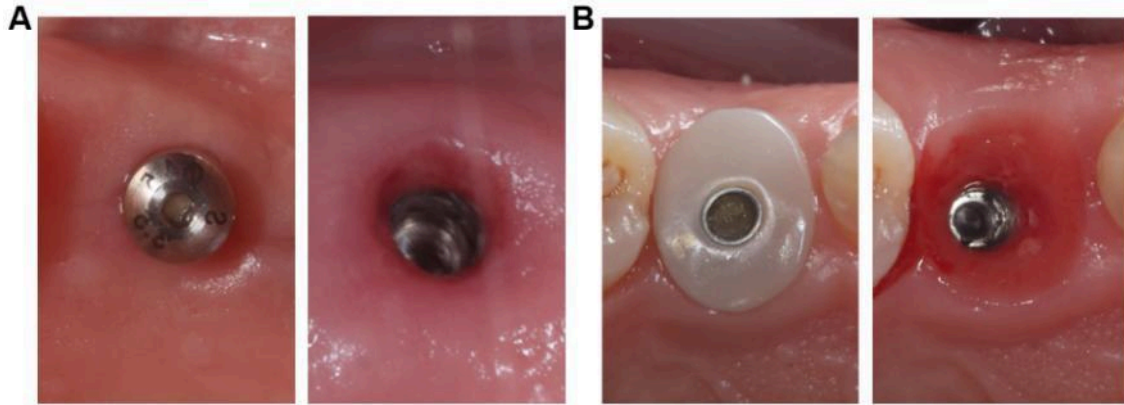


Figure 2. Emergence profile formed with **A)** cylindrical and **B)** anatomic healing abutment. From the works of Xinyi Qian and Krisztina Mikulás.

5.5. Emergence Profile Impression Methods

Accurately transferring the implant position and the correctly formed EP when fabricating the definitive restoration is crucial to achieving long-term success while minimizing the risk of mechanical and biological complications in implant therapy (31–33). However, the precise translation of this preestablished EP onto the working cast may be challenging (34–40).

For capturing soft tissue information, both analog and digital methods are available. Conventional methods include the use of elastic impression materials, which, despite their long-standing use, are associated with disadvantages such as patient discomfort and extended chairside time (**Figure 3**)(41,42). Digital methods, which replace conventional impressions with intraoral scans, are gaining importance for single-unit restorations and have the potential to reduce the aforementioned disadvantages (43,44).

The direct digital EP scanning procedure for a definitive single-unit restoration involves three distinct scans: (1) the initial scan, including the PR in situ along with the surrounding soft tissue; (2) the direct EP scanning of the peri-implant soft tissue taken immediately after PR removal; and (3) a scanbody screwed in place, enabling the precise 3D localization of the implant (**Figure 3**)(38). However, the accuracy of this method is questionable, as some studies have indicated that PR removal can induce a

considerable, time-dependent alteration in the EP due to the rapid peri-implant soft tissue collapse following the loss of support (45–47).

Recently, an indirect EP scanning protocol, which involves an additional extraoral scanning of the PR, has been proposed, with the aim of eliminating the inaccuracies of direct scanning by directly scanning the subgingival EP of the PR instead of the unstable mucosa (**Figure 3**)(48,49). However, there is no clear evidence regarding the accuracy of the digital EP scanning technologies.

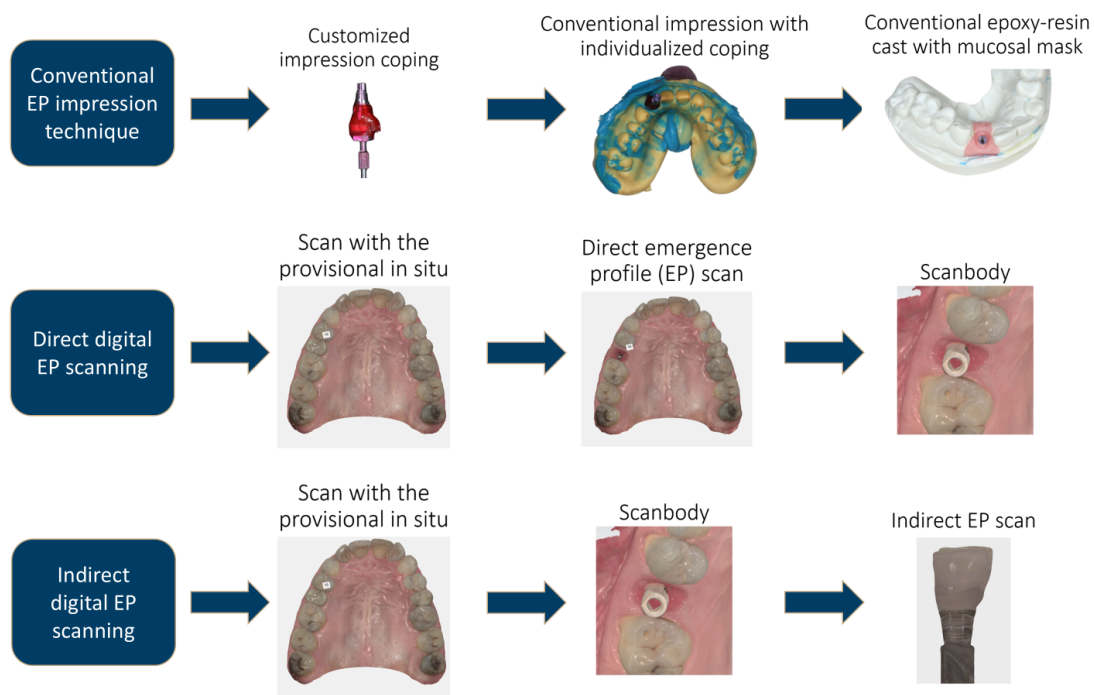


Figure 3. Conventional and digital impression workflows for single implant rehabilitation with emergence profile replication. From the works of Xinyi Qian and Krisztina Mikulás, also published by Mikulás et al. (50).

6. OBJECTIVES

6.1. Study I. – Comparison of implant placement and loading protocols for single anterior maxillary implants

The aim of this systematic review and network meta-analysis was to compare hard- and soft-tissue outcomes, as well as patient satisfaction, across all 12 types of IPLPs for single maxillary anterior implants, and to rank these protocols using a network meta-analysis based on randomized controlled trials (RCTs). The null hypothesis was that there would be no differences between any IPLPs.

6.2. Study II. – Peri-implant hard and soft tissue outcomes with anatomic vs non-anatomic healing abutments on immediate implants

This systematic review and meta-analysis aimed to compare hard- and soft-tissue parameters and patient satisfaction resulting from the use of AHA or PR versus CHA on immediately placed single implants. The null hypothesis was that there would be no differences between different forms of healing.

6.3. Study III. – Accuracy of digital impression methods for capturing the peri-implant emergence profile

The primary objective of this systematic review and meta-analysis was to assess the accuracy of direct and indirect digital impression methods in capturing peri-implant EP compared to the conventional impression around single implant-supported crowns. The null hypothesis was that there would be no differences in the accuracy of the impression methods.

7. METHODS

Three studies were conducted to investigate the optimal workflow for single-tooth rehabilitations, with particular focus on the esthetic region. All studies were systematic reviews performed following the Cochrane Handbook guidelines and reported according to the recommendations of the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines (51,52).

7.1. Study I.: Comparison of implant placement and loading protocols for single anterior maxillary implants – Network meta-analysis

7.1.1. Methodology and Protocol

The protocol was prospectively registered on the International Prospective Register of Systematic Reviews (PROSPERO; registration number: CRD42022364995).

7.1.2. Eligibility Criteria

Studies that matched our PICOST (Population, Intervention, Comparison, Outcome, Study type, and Time) framework were eligible for inclusion.

The Population (P) consisted of healthy adults who required a single tooth replacement with implantation in the anterior maxillary region (positions 15-25).

The patients were randomly selected into at least two Intervention (I1-12) groups in which they received treatment according to any of the 12 different types of IPLPs (1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B, 3C, 4A, 4B, and 4C); hence, the eligible Study type (S) was randomized controlled trial (RCT) only.

The Outcomes (O) investigated were implant survival, marginal bone loss, soft tissue changes, esthetics, and patient satisfaction at a minimum of 1-year follow-up Time (T).

Studies were excluded if they did not comply with this framework or included participants with acute periapical or periodontal infection, parafunctional movements, or multiple adjacent implants.

7.1.3. Information Sources and Search Strategy

A systematic search was conducted in October 2022 and last updated in January 2024 in seven electronic databases: MEDLINE (via PubMed), Embase, Cochrane CENTRAL, Web of Science (WoS), China National Knowledge Infrastructure (CNKI), Wanfang Data, and Chinese Scientific Journal Database (VIP). The search queries applied for the

systematic search can be found in **Table 2**.

Table 2. Search keys and filters applied in each database for the first study (53).

Database	Query	Filters
MEDLINE (PubMed), Embase, Cochrane CENTRAL, Web of Science (WoS)	(dental) AND (maxilla OR maxillary OR upper jaw OR esthetic OR aesthetic) AND (implant* OR implant supported OR implant-supported) AND (solo OR single OR solo crown OR solo restoration) AND (placement OR place* OR immediate OR early OR delayed OR conventional OR late) AND (loading OR load* OR immediate OR early OR delayed OR late)	• since 2000.01.01
China National Knowledge Infrastructure (CNKI)	FT='种植' and (FT % '前牙'+ '美学') and (FT % '即刻'+ '常规'+ '延期'+ '早期') and FT='随机'	• since 2000.01.01 • oral science
Wanfang Data	全部:"种植" AND 全部:("前牙" OR "美学") AND 全部:("即刻" OR "常规" OR "延期" OR "早期") AND 全部:"随机"	• since 2000.01.01 • oral science
Chinese Scientific Journal Database (VIP)	U="种植" AND U=("前牙" OR "美学") AND U=("即刻" OR "常规" OR "延期" OR "早期") AND U="随机"	• since 2000.01.01 • oral science

7.1.4. Study Selection and Data Extraction

Search results were imported into EndNote 20 program (54) for duplicate removal, then the study selection was conducted on www.rayyan.ai (55) webpage by a pair of independent authors (X.Q. and B.V.) by title, abstract, then full text, using predefined selection criteria. Interrater agreement for title-abstract and full-text selection of English language articles was measured with Cohen's kappa (κ) coefficient (56). Chinese articles were translated and discussed together.

Data was collected by the two independent investigators (X.Q. and B.V.) from eligible articles in a specific Excel template (57). Any disagreements were resolved through discussion and consultation with a third investigator.

The first author and year of publication, baseline information of the study population, data on the received intervention and the following outcomes were extracted from the study articles: implant survival (IS), marginal bone loss (MBL), periodontal probing depth (PPD), soft tissue recession (STR), bleeding on probing (BOP), pink esthetic

score (PES), white esthetic score (WES), and satisfaction with visual analogue scale (VAS) at each follow-up year.

7.1.5. Risk of Bias and Quality of Evidence Assessment

Risk of bias (RoB) of the included studies was determined by the two independent investigators (X.Q. and B.V.) based on the recommendations of the Cochrane Collaboration, using the Cochrane RoB-2 tool (51). Disagreements were resolved by a third party. The certainty of evidence was determined using the Confidence in Network Meta-Analysis (CINeMA) web application, considering within-study bias, reporting bias, indirectness, imprecision, heterogeneity, and incoherence (58,59).

7.1.6. Data Synthesis and Analysis

7.1.6.1. Network Meta-analysis

The synthesis of each outcome began with the creation of a network plot to check whether the network was fully connected based on the available comparisons. Pairwise and network meta-analyses (NMAs) were performed using random-effects models with Bayesian methods. Consistency checks were excluded by visual inspection of plots. All networks were consistent.

Networks were represented using diagrams, with nodes representing the protocols and edges representing direct comparisons, the node size proportional to the number of studies and edge thickness proportional to the number of studies providing direct comparison.

Mean differences (MD) with 95% credible intervals (CrI) were calculated for continuous data. The model was optimized using Monte Carlo methods running in four chains and posterior samples were generated, specifying at least 20,000 adaptation iterations and 10,000 simulation iterations to achieve convergence. Network estimates (pooled estimates of direct and indirect data) for each intervention were ranked relative to each other. Interventions were ranked according to their posterior likelihood by calculating the surface under the cumulative ranking (SUCRA) curve values. Cumulative probabilities for each treatment were expressed as single values ranging from 0 to 100%. Applying the ranking probabilities yields an easily interpretable conclusion ("There is a 55% chance that intervention A is the best"). The higher the percentage or the SUCRA score, the more likely the intervention would be the best or

one of the best.

All computations were performed using the R (version 4.1.1) package *BUGSnet* (version 1.1.0)(60,61).

7.1.6.2. Proportional Meta-analysis

Given the considerable between-study heterogeneity in all cases, a random-effects model was used to pool effect sizes. Proportion with 95% confidence interval (CI) was used for effect size measure. To calculate the study proportions and the pooled proportion, the total number of patients and those with the event of interest was extracted from each study. Additionally, between-study heterogeneity was described by the Higgins & Thompson's I^2 statistics (62).

All statistical analyses were performed with R (version 4.1.2) using the *meta* (version 6.2.1) package for basic meta-analysis calculations and plots, and *dmeter* (version 0.0.9) package for additional influential analysis calculations and plots (60,63–66).

The inverse variance method was used to pool proportions. A Hartung-Knapp adjustment was used for CIs (67,68). The Clopper-Pearson method was used for CI of proportion calculation of individual studies (69). For a cell count of 0, the individual study proportion with 95% CI was calculated by adding 0.01 as a continuity correction.

7.2. Study II.: Peri-implant hard and soft tissue outcomes with anatomic vs non-anatomic healing abutments on immediate implants – Meta-analysis

7.2.1. Methodology and Protocol

The study protocol was prospectively registered in the PROSPERO database (registration number: CRD42023458206).

7.2.2. Eligibility Criteria

The study applied the PICO framework to investigate (P) healthy adults who underwent a non-adjacent single tooth replacement with immediate implantation in either jaw and received (I1) an anatomic healing abutment (AHA) or (I2) immediate provisionalization (PR) compared to (C) a non-anatomic, cylindrical stock healing abutment (CHA), to compare their effect on (O) implant survival (IS), marginal bone loss (MBL), esthetics, and patient satisfaction.

Studies were excluded if they did not match our question framework or included

subjects with multiple adjacent implants, periodontal infection, or parafunctional movements.

7.2.3. Information Sources and Search Strategy

A systematic search was conducted in four electronic databases (MEDLINE (PubMed), Embase, Cochrane CENTRAL, Web of Science) on July 18, 2023, and was last updated on September 8, 2025. A date filter was applied for publications since January 1st, 2000. The following search key was applied: *(dental implant*) AND immediate* AND (single OR single-tooth OR single-crown OR single-implant OR single-gap) AND ((heal* AND abutment*) OR provisional* OR temporiz* OR temporary OR restorat* OR custom* OR individual* OR "CAD/CAM" OR "CAD-CAM" OR "computer aided" OR anatomic* OR "one abutment one time" OR "one-abutment-one-time" OR ("soft tissue" OR "soft-tissue") AND (manage* OR form*)) OR "emergence profile")*.

7.2.4. Study Selection and Data Extraction

Two independent authors (X.Q. and B.V.) screened the search results by title, abstract, and then full text (55). Interrater agreement was calculated with Cohen's Kappa (56). Any disagreements were resolved by a third party.

Data were collected from eligible articles in a specific Excel template (57), extracting first author, year of publication, study population, interventions, and the outcomes, including implant survival (IS), marginal bone loss (MBL), pink esthetic score (PES), and patient satisfaction with visual analog scale (VAS).

7.2.5. Risk of Bias and Quality of Evidence Assessment

Risk of bias was assessed using the RoB-2 and Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tools for randomized controlled trials (RCTs) and non-randomized cohort studies, respectively (51). The certainty of evidence was determined using the GRADEpro web application (70).

7.2.6. Data Synthesis and Analysis

The meta-analysis was conducted in R (version 4.4.1) with the *meta* package (version 7.0.0). Random-effects models were applied to synthesize data (60,63–66). For binary outcomes (IS), the proportion of events in each intervention group was pooled using the *metaprop* function, then proportions were back-transformed for interpretation.

Continuity corrections (0.5) were applied to studies with zero events, using the "if0all" method for binary data. For continuous outcomes (MBL, PES, VAS), mean differences (MDs) were calculated and pooled with the *metacont* function. Ninety-five percent confidence intervals (95% CI) were calculated for all estimates. Heterogeneity across studies was assessed using the I-squared statistic (62). Tau-squared was calculated using the restricted maximum-likelihood estimator, and prediction intervals were presented where appropriate (71). Subset or subgroup analyses were performed for specific interventions (e.g., types of healing restorations used) and follow-up durations (e.g., 3–6 months, 12–16 months). The Hartung-Knapp adjustment was applied to enhance the robustness of the random-effects estimates (68). Results were displayed in forest plots, and funnel plots were created to investigate publication bias.

7.3. Study III.: Accuracy of digital impression methods for capturing the peri-implant emergence profile – Systematic review

7.3.1. Methodology and Protocol

The study protocol was prospectively registered in the PROSPERO database (registration number: CRD42023459484).

7.3.2. Eligibility Criteria

Studies that matched our PICO framework were included. Studies were deemed eligible for qualitative synthesis if they investigated the (O) accuracy of (I) digital EP scanning methods vs (C1) conventional impression methods or (C2) the virtual model containing the original EP in (P) patients with single implant-supported crowns.

Only randomized and non-randomized comparative clinical trials were included for quantitative synthesis.

Questionnaires, in vitro and animal studies, systematic reviews, and conference abstracts were excluded.

7.3.3. Information Sources and Search Strategy

A comprehensive search was conducted on August 7, 2024 in MEDLINE (PubMed), Embase, Web of Science, and Cochrane CENTRAL to select eligible studies with the following keywords: (*dental implant*) AND *digital* AND (*impression OR replication OR*

capturing OR scan) AND ((emergence profile) OR (soft tissue) OR (peri-implant mucosa)).*

7.3.4. Study Selection and Data Extraction

Following automatic and manual duplicate removal, two reviewers (X.Q. and K.M.) independently selected the articles based on titles, abstracts, and full texts. Disagreements were resolved by discussion between the two reviewers. The following parameters were extracted from eligible articles: first author, year of publication, study type, number of participants, implant type and position, phenotype, impression technique, type of cast, type of intraoral scanner applied, definitive prosthetic restoration, esthetic outcomes, and study results, including main findings and numerical data for measurement results regarding EP discrepancies between different impression methods.

7.3.5. Risk of Bias and Quality of Evidence Assessment

Risk of bias of the included studies was determined with RoB-2 tool for RCTs, ROBINS-I for non-randomized comparative clinical trials and Joanna Briggs Institute (JBI) critical appraisal tools for case reports and case series (51,72).

7.3.6. Data Synthesis and Analysis

Primary data extraction and organization was carried out in Microsoft Excel (57). Statistical analysis was carried out in R (version 4.1.3)(60,64,66). The pooled effect size was the mean of measurements, for which the *metamean* function of the R package was used (version 6.1.0)(73). A random effects approach was used to account for the inherent variability and heterogeneity among individual studies. The method for calculating the between-study variance tau-squared was the restricted maximum-likelihood estimator. Knapp-Hartung adjustments were used to estimate the standard error.

For the RMS variable, the mean and sd values given for multiple locations in Li 2019 (74) were transformed to an overall MEAN and SD value the following way:

$$MEAN = \frac{\sum mean_i \cdot n_i}{\sum n_i}$$

$$SD = \sqrt{\frac{\sum [sd_i^2 \cdot n_i + (mean_i - MEAN)^2 \cdot n_i]}{\sum n_i}}$$

MEAN and SD are the overall values; mean and sd are the individual values for each site; n is the number of measurements for each site—as this was not given, we assumed it to be a constant large number through all sites.

For the GMH variable, Duran 2018 (75) and Li 2019 (74) published only the mean and SD values of the difference “control minus intervention”; in case of Ling 2023 (76) the mean and SD of the difference were calculated from the given control and intervention parameters the following way:

$$MEAN = mean_{control} - mean_{intervention}$$

(a height decrease, i.e., a collapse, is a positive number)

$$SD = \sqrt{sd_{control}^2 + sd_{intervention}^2}$$

For the EP collapse variable, Joda 2015 (47) gave mean and SD of relative area change ($\Delta A/A_0$), whereas Galibourg 2021 (77) gave relative volume change ($\Delta V/V_0$) instead, and data were given for each patient. Here we assumed that the emergence profile has a conical frustum shape and the collapse predominantly affects its radius (i.e., mantle circumference but not mantle height). Accordingly, area change was estimated using the following formula:

$$1 - \frac{\Delta A}{A_0} = \frac{A_{after}}{A_0} = \frac{r_{after}}{r_0} = \sqrt{\frac{V_{after}}{V_0}} = \sqrt{1 - \frac{\Delta V}{V_0}}$$

After converting the individual patient data to relative area change, mean and SD were calculated.

8. RESULTS

8.1. Study I.: Comparison of implant placement and loading protocols for single anterior maxillary implants – Network meta-analysis

8.1.1. Study Search and Selection

A total of 6,882 articles (4,522 from English and 2,360 from Chinese databases) were identified through the systematic search, from which 21 English and 20 Chinese published articles of 35 eligible studies were eventually included, then two more publications were found with citation chasing, yielding a total of 43 articles (**Figure 4**). Characteristics of the demographics and the interventions of each study are included in **Appendix Tables 1 and 2** (78–120).

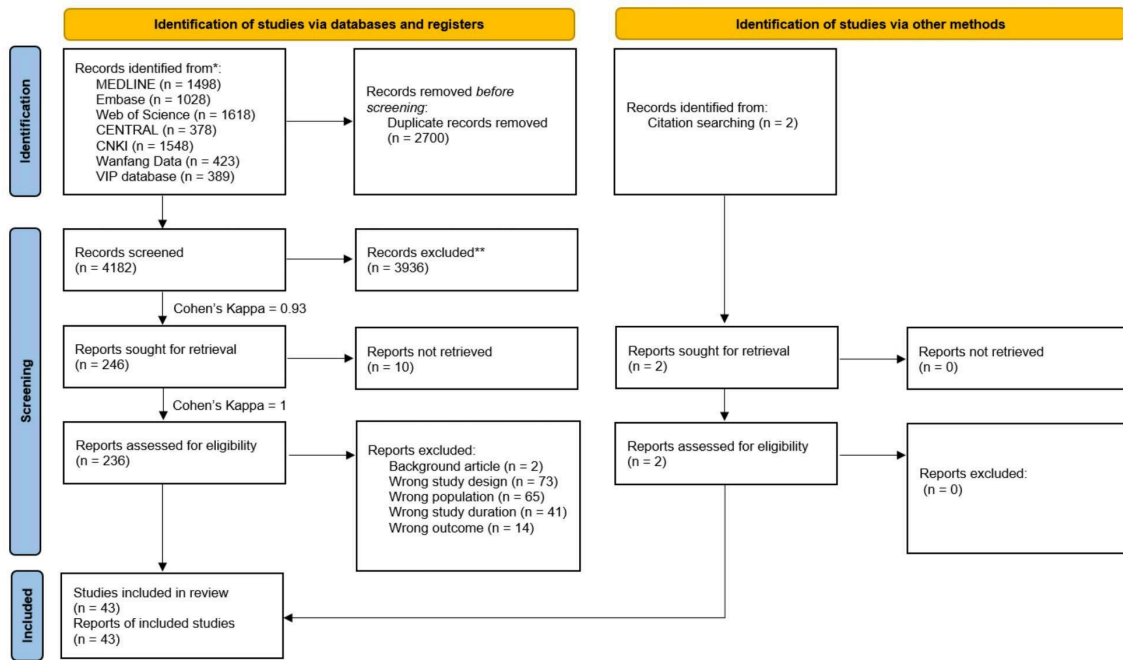


Figure 4. PRISMA 2020 flowchart of the study selection process for the first study (52,53).

8.1.2. Implant Survival (IS)

A total of 33 studies were analyzed for 1-year implant survival, but a network meta-analysis was not feasible due to extremely low implant failure rates; thus, cumulated implant survival rates with 95% confidence intervals were calculated for each protocol using a proportional meta-analysis (78,80–94,96–98,100–107,109,111–116,120).

Survival rates were 1A (n=762) = 91% (95% CI: 86%; 94%), 1C (n=477) = 96% (95% CI: 92%; 98%), 2C (n=45) = 100% (95% CI: 100%; 100%), 3C (n=168) = 100% (95% CI: 100%; 100%), 4A (n=178) = 96% (95% CI: 93%; 98%), and 4C (n=517) = 98% (95% CI: 94%; 99%).

Forest plots with the included articles and sample sizes are presented in **Figures 5-10**.

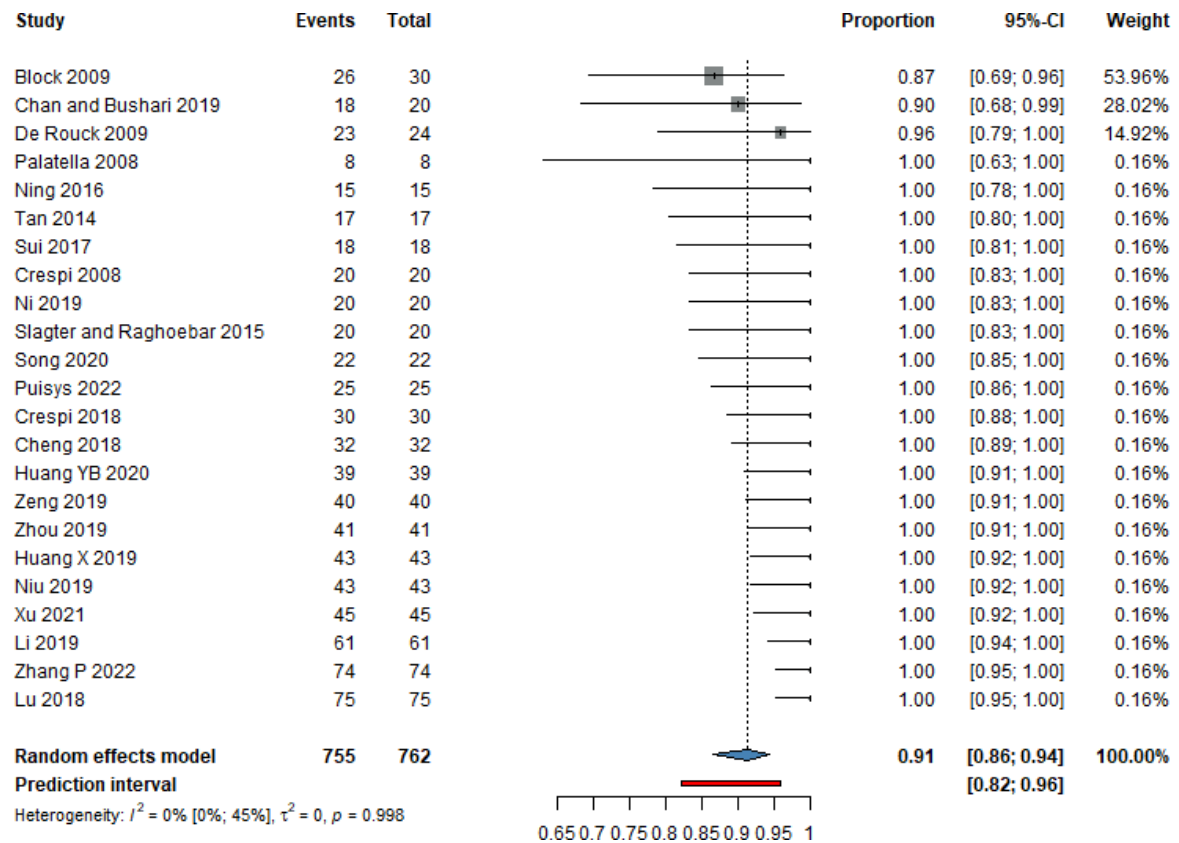


Figure 5. Forest plot of 1A protocol's 1-year survival. Overall implant survival rate: 91% (95% CI: 86 to 94%)(53).

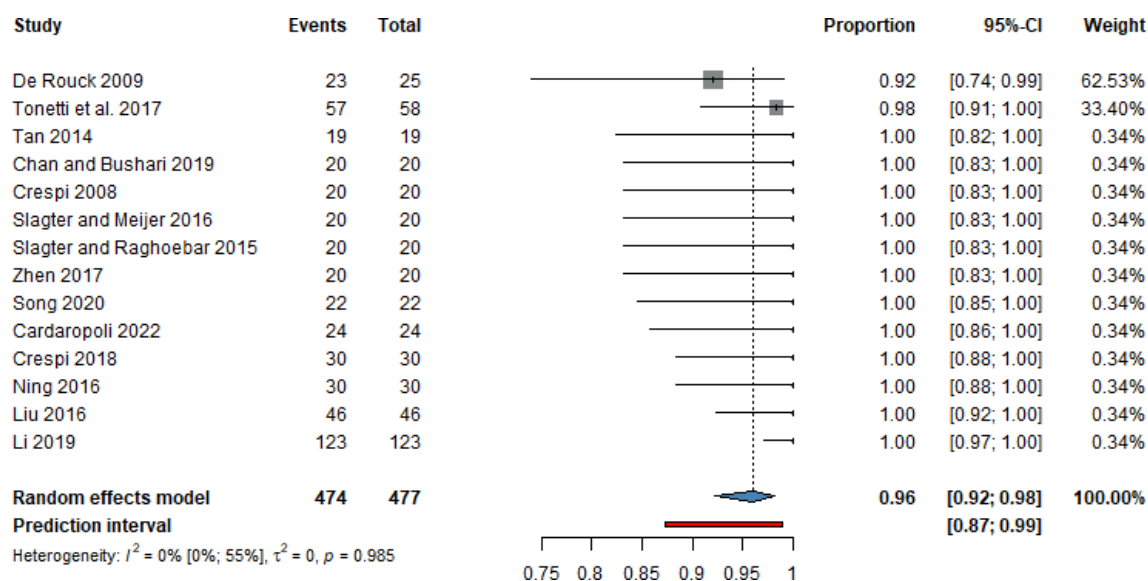


Figure 6. Forest plot of 1C protocol's 1-year survival. Overall implant survival rate: 96% (95% CI: 92 to 98%)(53).

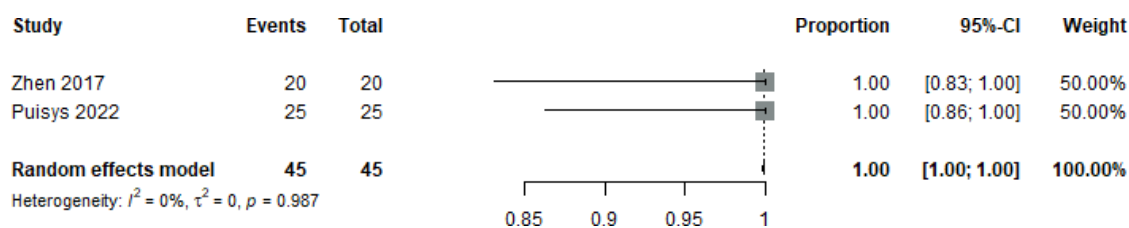


Figure 7. Forest plot of 2C protocol's 1-year survival. Overall implant survival rate: 100% (95% CI: 100 to 100%)(53).

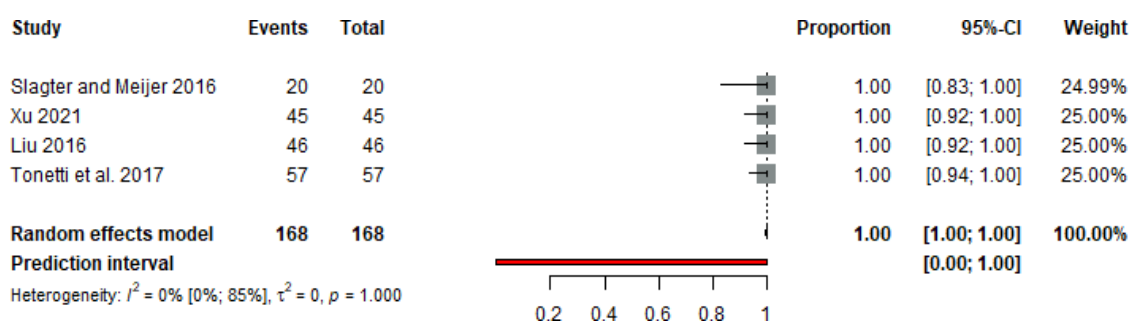


Figure 8. Forest plot of 3C protocol's 1-year survival. Overall implant survival rate: 100% (95% CI: 100 to 100%)(53).

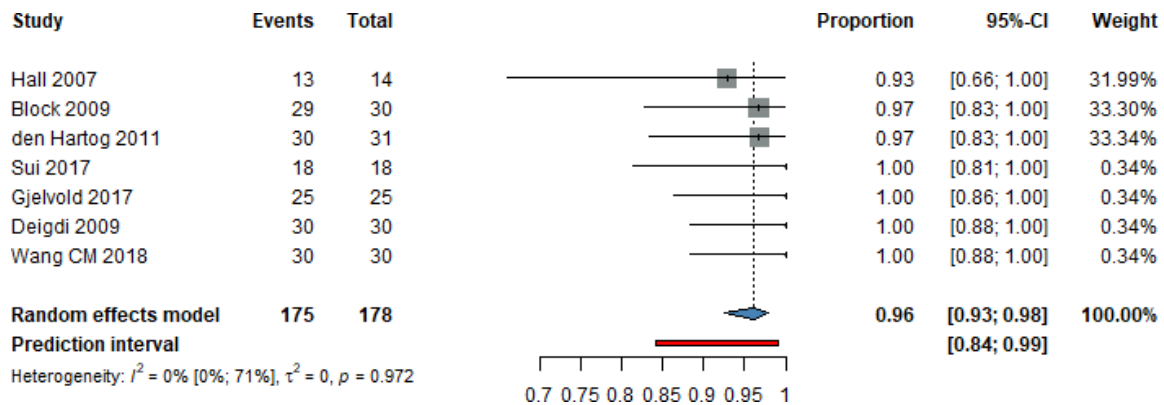


Figure 9. Forest plot of 4A protocol's 1-year survival. Overall implant survival rate: 96% (95% CI: 93 to 98%)(53).

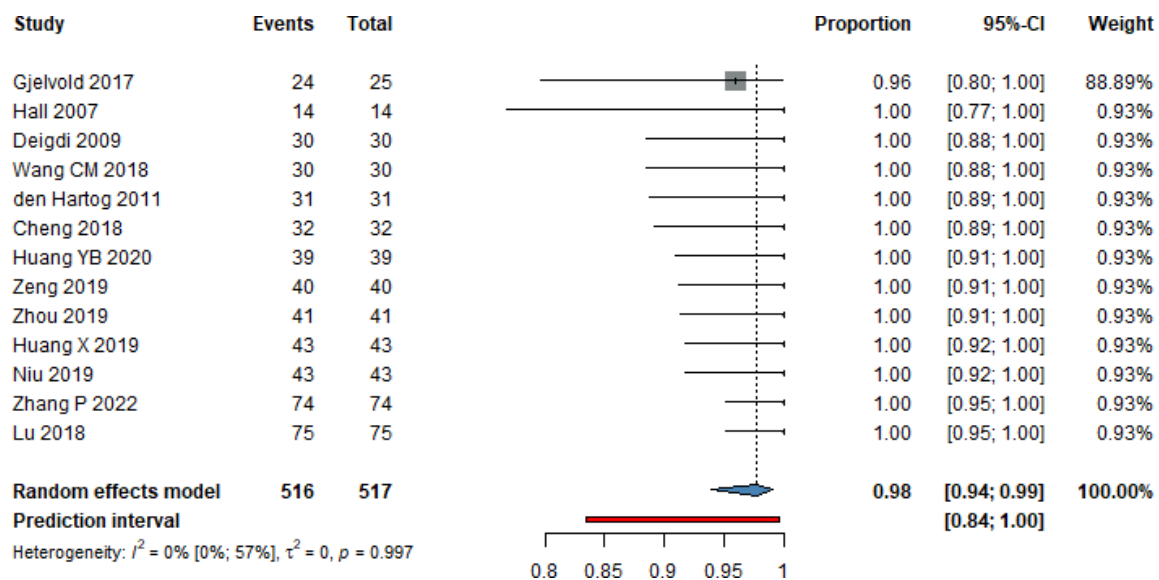


Figure 10. Forest plot of 4C protocol's 1-year survival. Overall implant survival rate: 98% (95% CI: 94 to 99%)(53).

8.1.3. Marginal Bone Loss (MBL)

Eighteen studies (n=1,055) were analyzed for 1-year MBLs, comparing seven protocols by mean differences (MD) with 95% credible intervals (CrI) (81,84,87–89,91,95,97,100,102,105–107,109,111,112,114–116). The SUCRA values for each protocol in order from highest to lowest rank in the network were 4B=88.16%, 4A=71.5%, 1A=62.26%, 2C=39.95%, 1C=37.56%, 4C=25.36%, and 3C=25.18% (Figure 11).

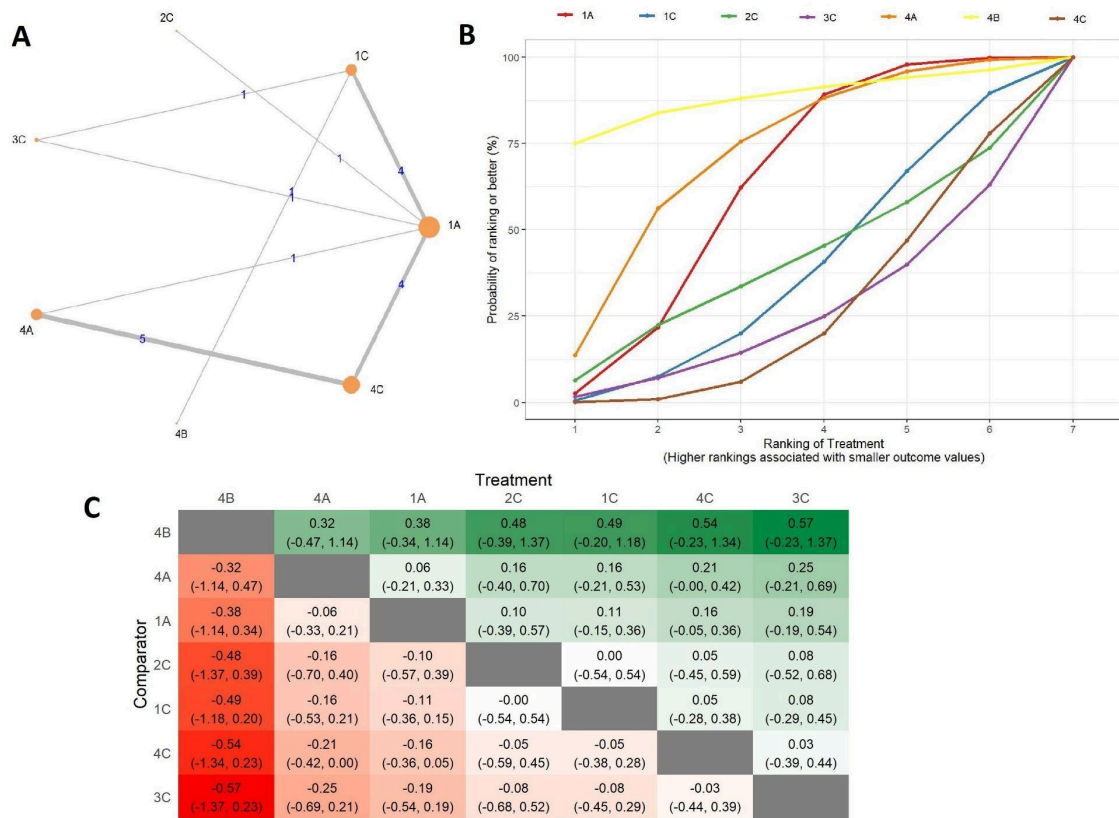


Figure 11. A) 1-year MBL network diagram. The nodes indicate the investigated protocols, and the thickness of the edges are proportional to the number of studies included.; **B)** 1-year MBL SUCRA curves. The x axis shows the number of possible rankings matching the number of protocols analyzed. The y axis indicates the probability in % to reach a given rank or higher.; **C)** 1-year MBL league plot showing mean differences and credible intervals in mm between the protocols shown at the top and left side of the table. Protocols are in order from best to worst starting at the top-left corner. Values above and below the grey grids show the same differences in opposite direction. No significant differences are observable (53).

Five studies involving a total of 209 patients were synthesized to compare 2-year MBLs across five protocols (98,102,104,106,113). SUCRA values of each protocol in descending order were 2A=67.26%, 1C=58.49%, 1A=58.14%, and 4A=44.31%, 4C=21.79% (**Figure 12**).

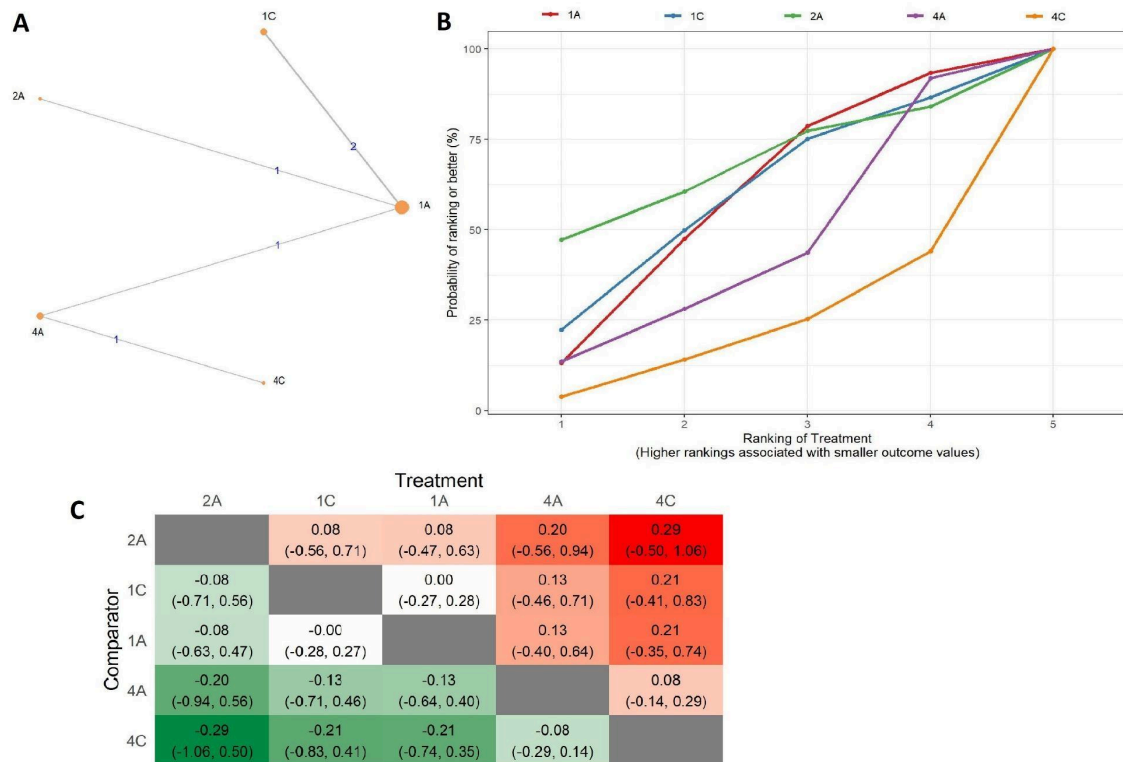


Figure 12. *A*) 2-year MBL network diagram. The nodes indicate the investigated protocols, and the thickness of the edges are proportional to the number of studies included.; *B*) 2-year MBL SUCRA curve. The x axis shows the number of possible rankings matching the number of protocols analyzed. The y axis indicates the probability in % to reach a given rank or higher.; *C*) 2-year MBL league plot showing mean differences and credible intervals in mm between the protocols shown at the top and left side of the table. Protocols are in order from best to worst starting at the top-left corner. Values above and below the grey grids show the same differences in opposite direction. No significant differences are observable (53).

There was no statistically or clinically significant difference between any protocol at 1 or 2 years.

8.1.4. Soft Tissue Recession (STR)

Separate data of 1-year mid-facial, mesial and distal STR were available for quantitative synthesis, comparing each protocol by MD with 95% CrI. There were no statistically or clinically significant differences between protocols in any of the measured areas.

Six studies (n=262) were synthesized for mid-facial STR, comparing five protocols (101,102,105,107,109,111,112,114–116). SUCRA values were 2C=73.2%, 1A=63.64%, 4B=50.45%, 1C=37.64%, and 3C=25.07% (**Figure 13**).

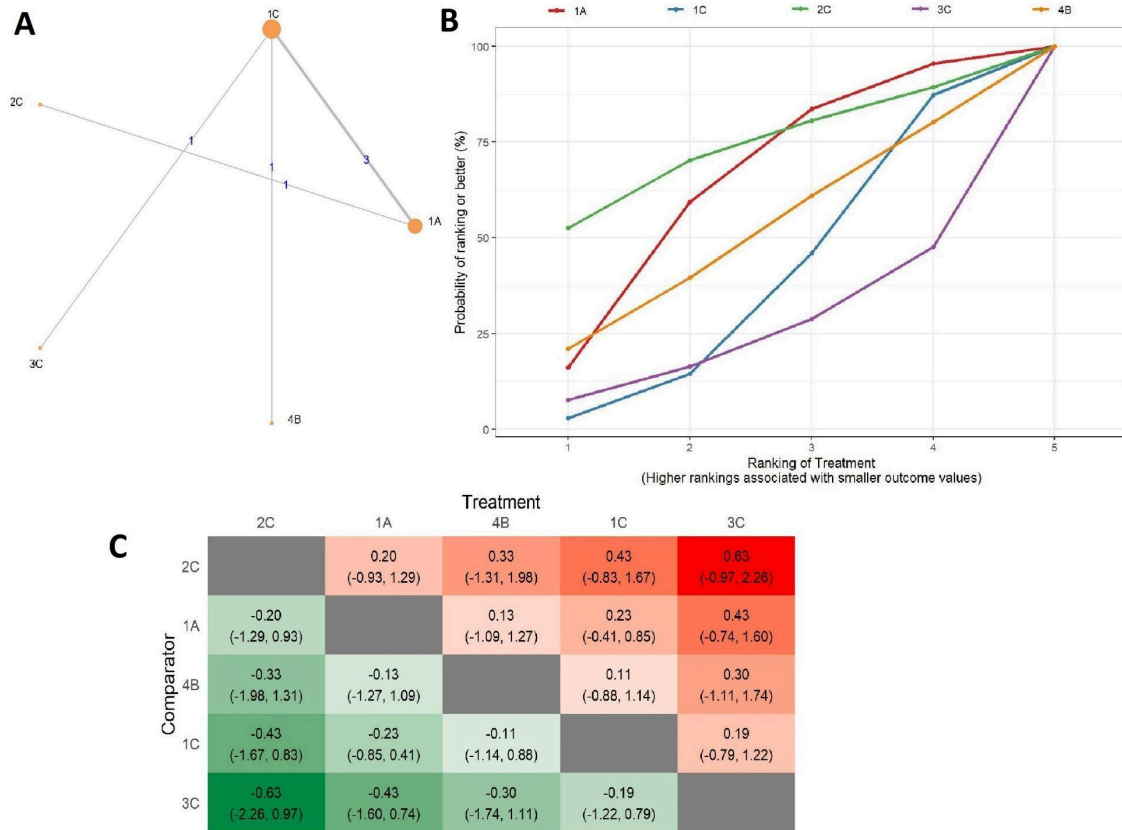


Figure 13. *A) 1-year mid-facial STR network diagram. The nodes indicate the investigated protocols, and the thickness of the edges are proportional to the number of studies included.; B) 1-year mid-facial STR SUCRA curve. The x axis shows the number of possible rankings matching the number of protocols analyzed. The y axis indicates the probability in % to reach a given rank or higher.; C) 1-year mid-facial STR league plot showing mean differences and credible intervals in mm between the protocols shown at the top and left side of the table. Protocols are in order from best to worst starting at the top-left corner. Values above and below the grey grids show the same differences in opposite direction. No significant differences are observable (53).*

For mesial and distal STR, the same five studies (n=212) were synthesized, comparing four protocols (101,102,105,115,116). For mesial STR, SUCRA values were 4B=63.05%, 1C=55.21%, 3C=44.91%, and 1A=36.83% and SUCRA values for distal STR were 1A=56.85%, 4B=53.08%, 3C=50.17%, and 1C=39.91% (**Figure 14**).

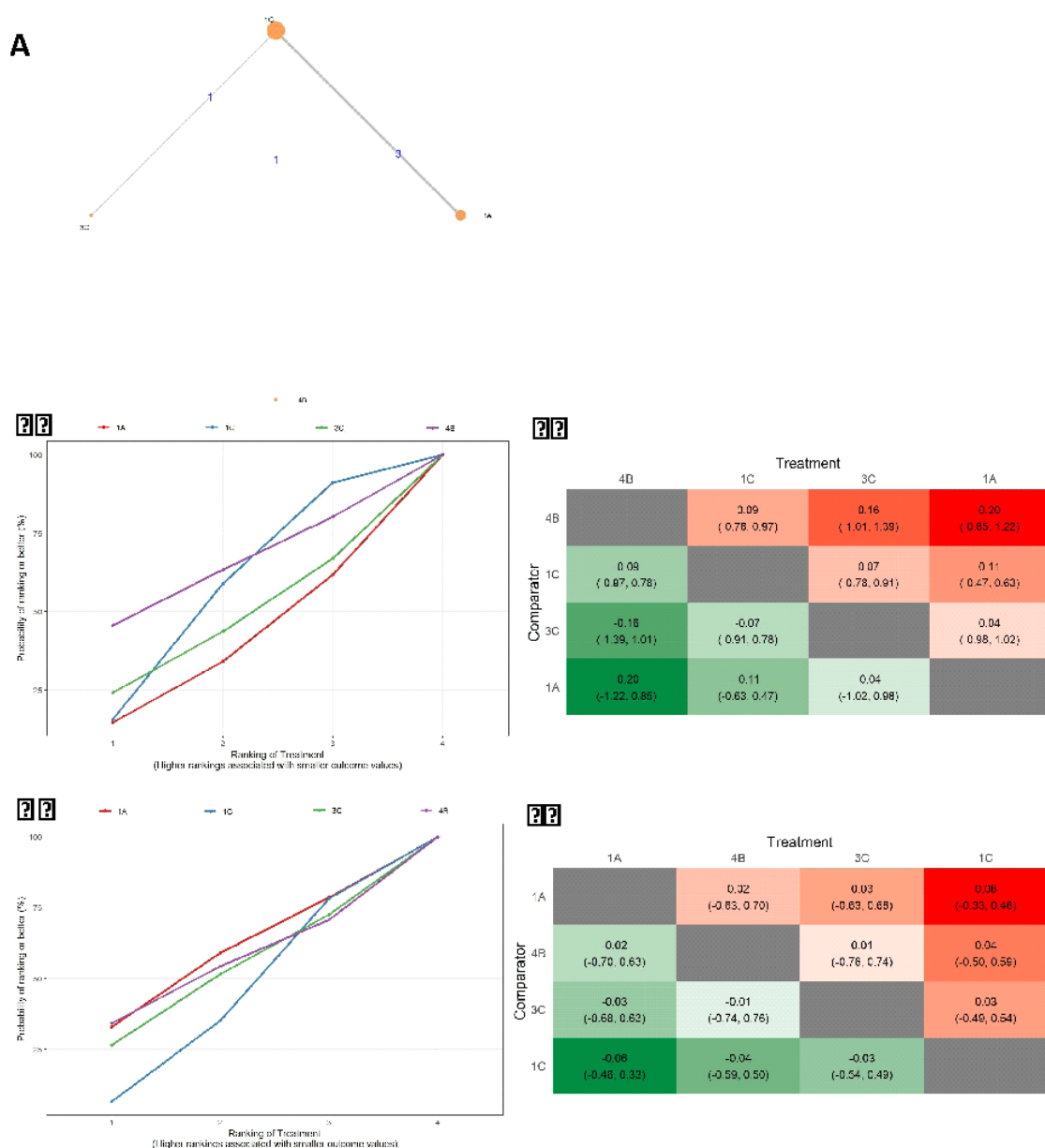


Figure 14. A) 1-year mesial and distal STR network diagram. The nodes indicate the investigated protocols, and the thickness of the edges are proportional to the number of studies included.; **B)** 1-year mesial STR SUCRA curve. The x axis shows the number of possible rankings matching the number of protocols analyzed. The y axis indicates the probability in % to reach a given rank or higher.; **C)** 1-year mesial STR league plot showing mean differences and credible intervals in mm between the protocols shown at the top and left side of the table. Protocols are in order from best to worst starting at the top-left corner. Values above and below the grey grids show the same differences in opposite direction. No significant differences are observable.; **D)** 1-year distal STR

SUCRA curve. The x axis shows the number of possible rankings matching the number of protocols analyzed. The y axis indicates the probability in % to reach a given rank or higher.; E) 1-year distal STR league plot showing mean differences and credible intervals in mm between the protocols shown at the top and left side of the table. Protocols are in order from best to worst starting at the top-left corner. Values above and below the grey grids show the same differences in opposite direction. No significant differences are observable (53).

8.1.5. Esthetics

8.1.5.1. Pink Esthetic Score (PES)

Twenty-two studies (n=1665) were analyzed for 1-year PES, comparing eight protocols by MD with 95% CrI (79–90,92–94,97,101,107,109,114–116). SUCRA values were 1A=89.61%, 2C=76.71%, 3A=64.77%, 1C=52.21%, 4B=47.58%, 4A=34.4%, 4C=23.67%, and 3C=11.05% (**Figure 15**).

Differences between protocols 1A-1C (MD: -1.11, CrI: -1.91; -0.25), 1A-4A (MD: -1.53, CrI: -2.65; -0.32), 1A-4C (MD: -1.74, CrI: -2.34; -1.15) and 1A-3C (MD: -2.17, CrI: -3.37; -0.93) were statistically significant (**Figure 15**). The threshold of clinical significance for PES was set at 1; therefore, only the difference between protocols 1A-4C were clinically relevant taking the whole credible interval into consideration.

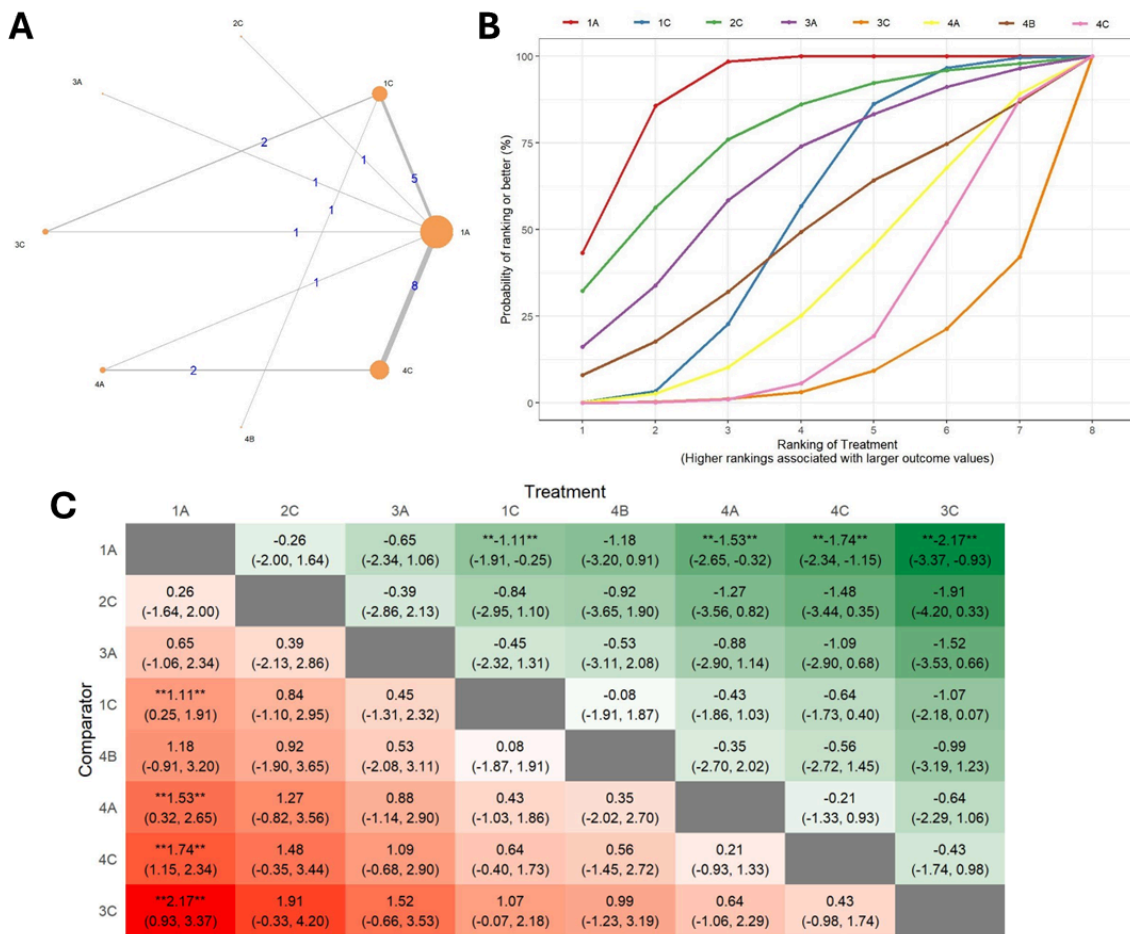


Figure 15. *A*) 1-year PES network diagram. The nodes indicate the investigated protocols, and the thickness of the edges are proportional to the number of studies included.; *B*) 1-year PES SUCRA curve. The x axis shows the number of possible rankings matching the number of protocols analyzed. The y axis indicates the probability in % to reach a given rank or higher.; *C*) 1-year PES league plot showing mean differences and credible intervals in mm between the protocols shown at the top and left side of the table. Protocols are in order from best to worst starting at the top-left corner. Values above and below the grey grids show the same differences in opposite direction. The double asterisks indicate statistically significant differences (53).

8.1.5.2. White Esthetic Score (WES)

Four studies (n=310) were analyzed for 1-year WES, comparing four protocols by MD with 95% CrI (94,97,115,116). Differences between 1A-4C (MD: -1.41, CrI: -2.66; -0.15) were statistically significant but not clinically relevant (**Figure 16**).

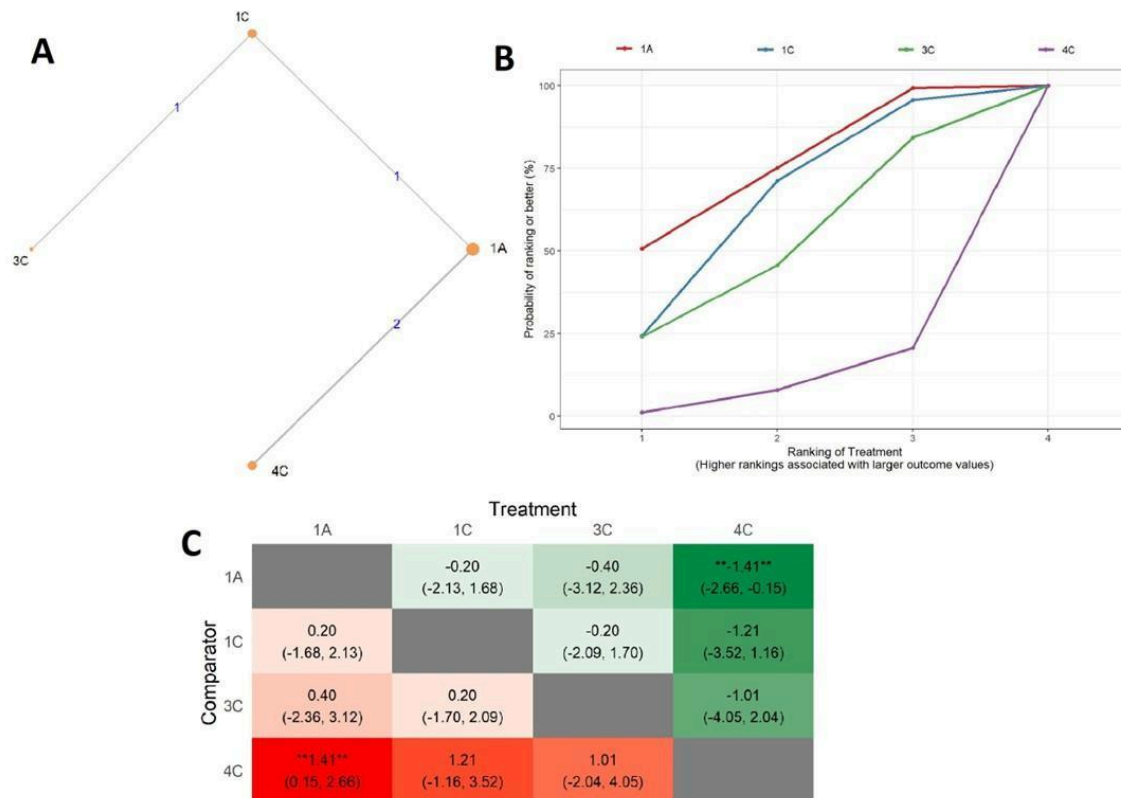


Figure 16. *A)* 1-year white esthetic score (WES) network diagram. The nodes indicate the investigated protocols, and the thickness of the edges are proportional to the number of studies included.; *B)* 1-year WES SUCRA curve. The x axis shows the number of possible rankings matching the number of protocols analyzed. The y axis indicates the probability in % to reach a given rank or higher.; *C)* 1-year WES league plot showing mean differences and credible intervals in mm between the protocols shown at the top and left side of the table. Protocols are in order from best to worst starting at the top-left corner. Values above and below the grey grids show the same differences in opposite direction. The double asterisks indicate statistically significant differences (53).

8.1.6. Patient Satisfaction – Visual Analogue Scale (VAS)

Thirteen studies (n=982) were analyzed for 1-year satisfaction, all measured with visual analog scales (VAS), comparing six protocols by MD with 95% CrI (79,80,82,85,87,88,92,93,97,107,109,115,116). SUCRA values were 1A=84.85%, 3C=51.81%, 4A=48.74%, 1C=40.59%, 4C=37.27%, and 3A=36.75%.

Though protocol 1A was much more likely to be ranked first, there was no statistically significant difference between the protocols analyzed (**Figure 17**).

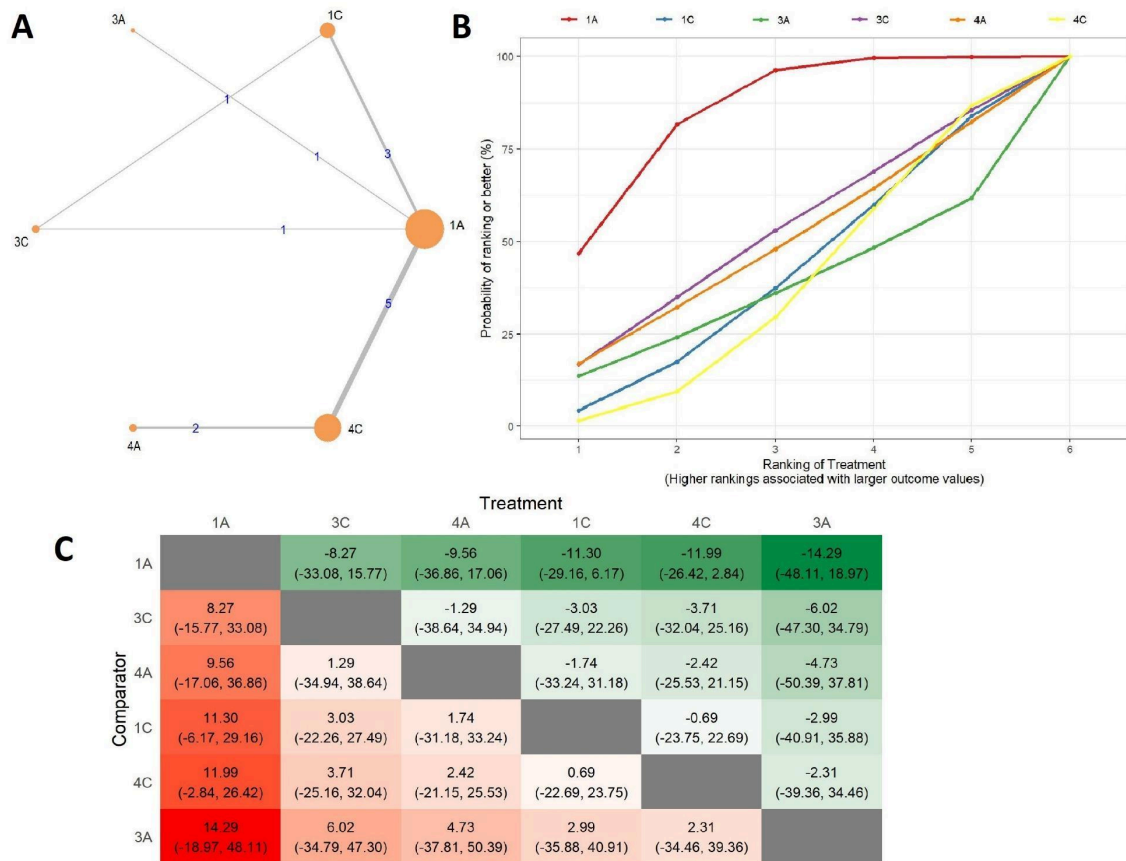


Figure 17. A) 1-year VAS network diagram. The nodes indicate the investigated protocols, and the thickness of the edges are proportional to the number of studies included.; B) 1-year VAS SUCRA curve. The x axis shows the number of possible rankings matching the number of protocols analyzed. The y axis indicates the probability in % to reach a given rank or higher.; C) 1-year VAS league plot showing mean differences and credible intervals in mm between the protocols shown at the top and left side of the table. Protocols are in order from best to worst starting at the top-left corner. Values above and below the grey grids show the same differences in opposite direction. No significant differences are observable (53).

8.1.7. Change in Peri-implant Probing Depth (PPDc) and Bleeding Index (BI)

Seven studies (n=462) were analyzed for 1-year PPDc, comparing six protocols by MD with 95% CrI (**Figure 18**)(80,83,85,114–116,120).

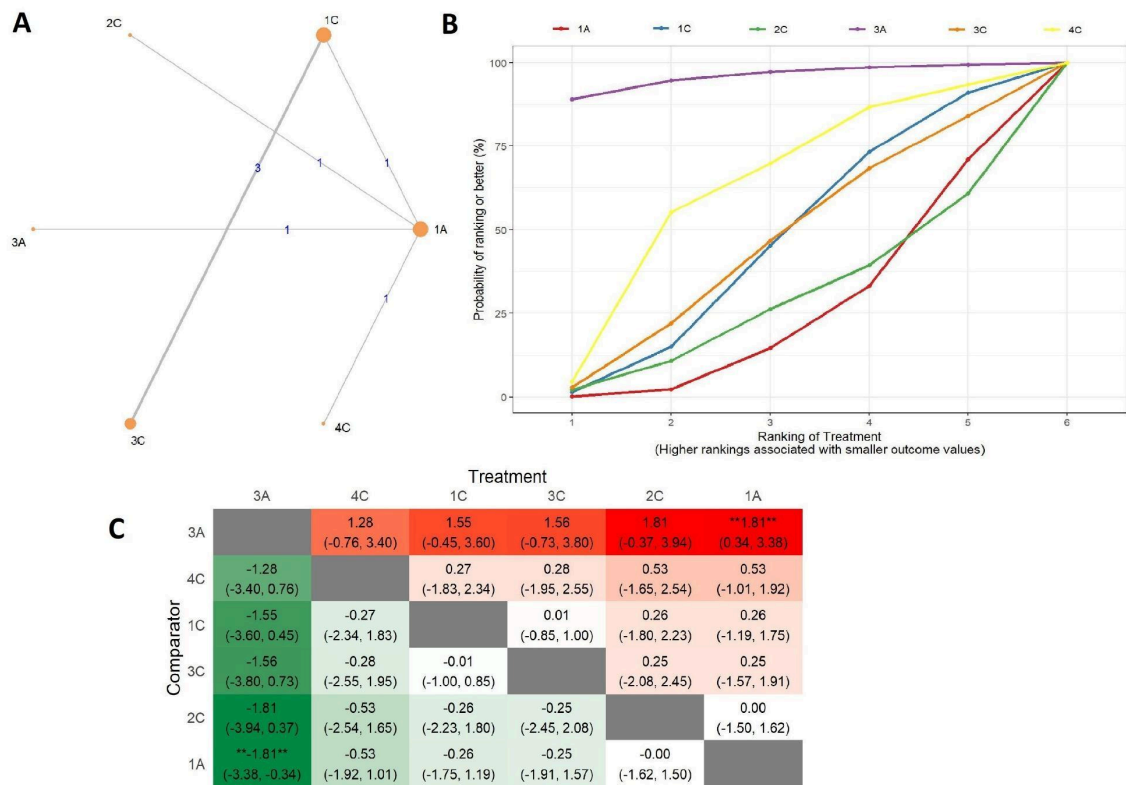


Figure 18. A) 1-year change in periodontal probing depth (PPDc) network diagram.

The nodes indicate the investigated protocols, and the thickness of the edges are proportional to the number of studies included.; **B)** 1-year PPDc SUCRA curve. The x axis shows the number of possible rankings matching the number of protocols analyzed.

The y axis indicates the probability in % to reach a given rank or higher.; **C)** 1-year PPDc league plot showing mean differences and credible intervals in mm between the protocols shown at the top and left side of the table. Protocols are in order from best to worst starting at the top-left corner. Values above and below the grey grids show the same differences in opposite direction. The double asterisks indicate statistically significant differences (53).

Seven studies (n=517) were analyzed for 1-year BI, comparing six protocols by MD with 95% CrI (**Figure 19**)(83,93,94,105,114,115).

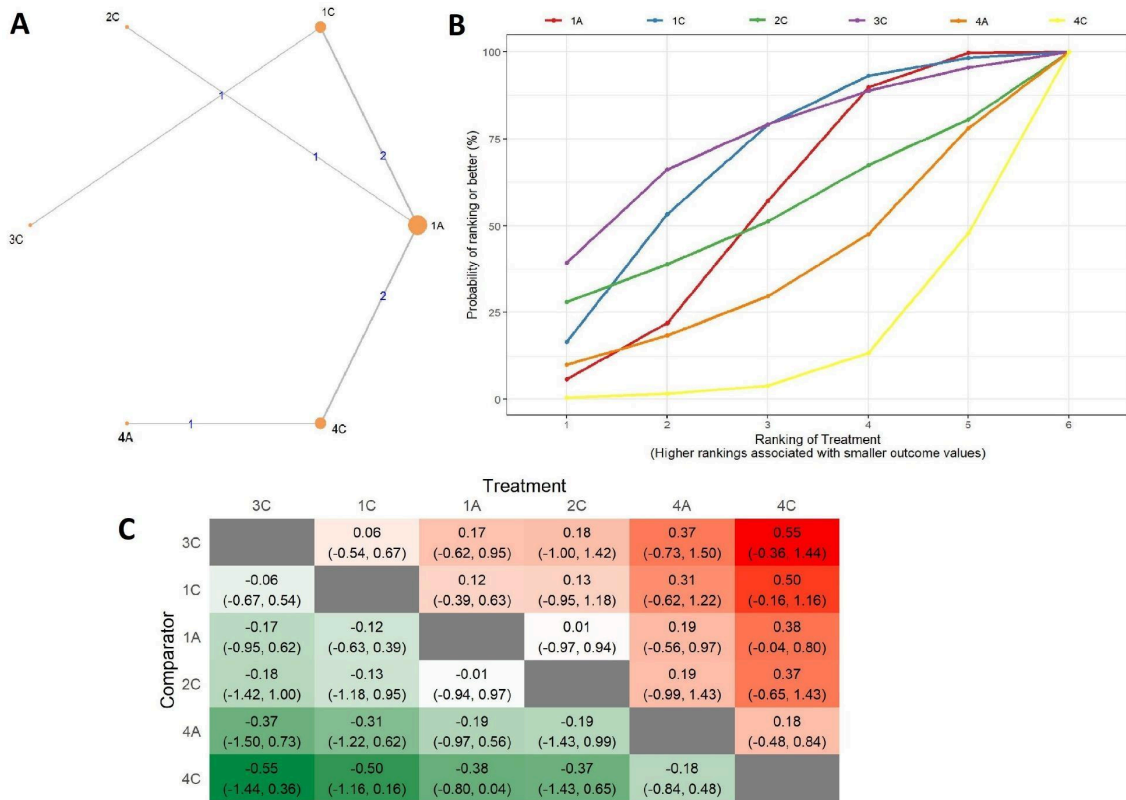


Figure 19. *A*) 1-year bleeding index (BI) network diagram. The nodes indicate the investigated protocols, and the thickness of the edges are proportional to the number of studies included.; *B*) 1-year BI SUCRA curve. The x axis shows the number of possible rankings matching the number of protocols analyzed. The y axis indicates the probability in % to reach a given rank or higher.; *C*) 1-year BI league plot showing mean differences and credible intervals in mm between the protocols shown at the top and left side of the table. Protocols are in order from best to worst starting at the top-left corner. Values above and below the grey grids show the same differences in opposite direction. No significant differences are observable (53).

8.1.8. Risk of Bias and Quality of Evidence

Results of the study- and domain-level RoB showed no risk carried by most studies, however, some studies raised some concerns, mainly due to missing outcome data, possible selection of data and randomization process. The certainty of evidence was often moderate to low due to imprecision, heterogeneity, and incoherence.

8.2. Study II.: Peri-implant hard and soft tissue outcomes with anatomic vs non-anatomic healing abutments on immediate implants – Meta-analysis

8.2.1. Study Search and Selection

Twenty articles were included, reporting on 17 distinct studies (**Figure 20**), 12 of which provided data for quantitative analysis. Study characteristics can be found in **Appendix Table 3** (26,30,82,86,121–136).

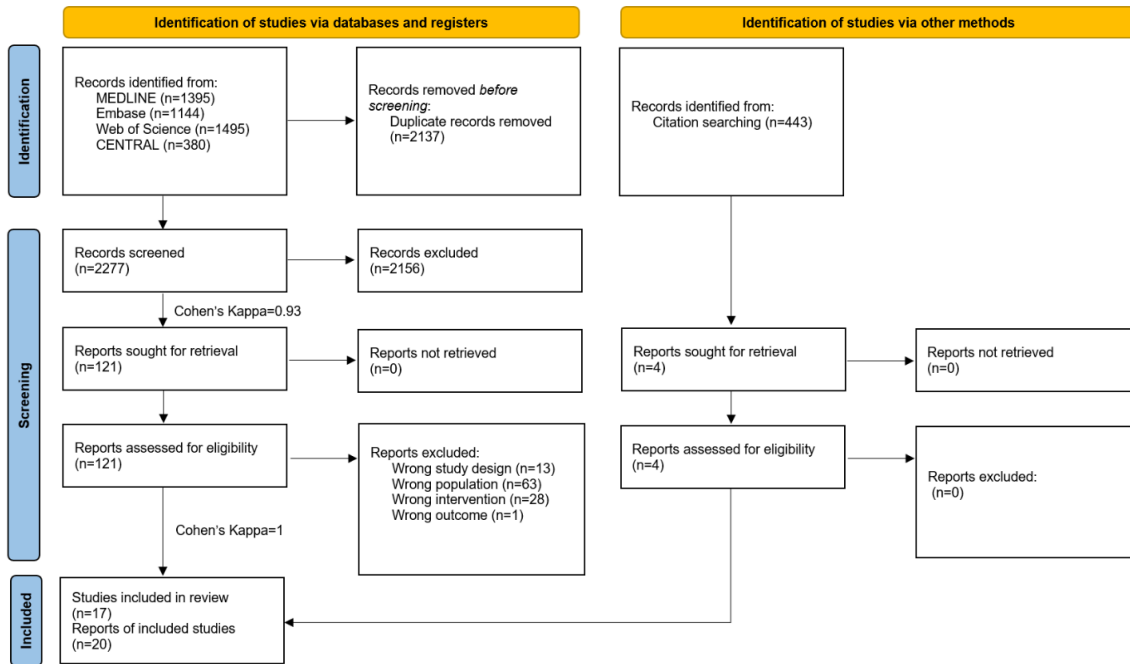


Figure 20. PRISMA 2020 flowchart of the selection process for the second study (52,137).

8.2.2. *Implant Survival (IS)*

All interventions achieved above 99% mean IS over one year (**Figure 21**) (30,82,86,122,126,128–133).

A

Heterogeneity: $I^2 = 0.0\%$ [0.0%; 89.6%], $\tau^2 = 0$, $p = 1.0000$ | | | | | | |
0.7 0.75 0.8 0.85 0.9 0.95 1

B

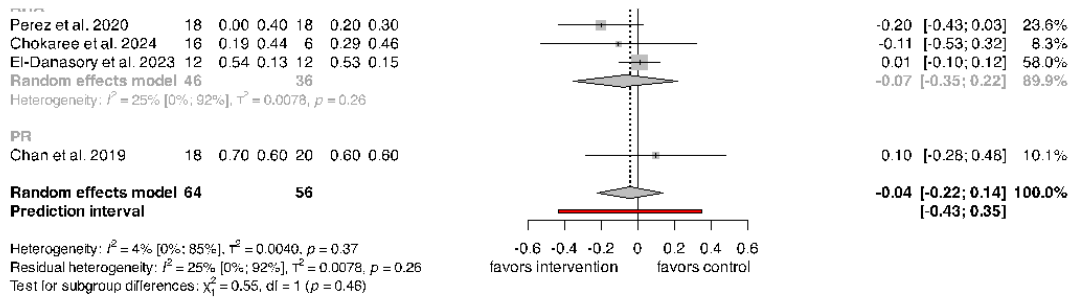
C

Figure 21. Forest plot showing proportional analysis with 95% confidence intervals of implant survival rates when applying **A)** anatomic healing abutments (AHA), **B)** provisional restorations (PR), and **C)** cylindrical healing abutments (CHA)(137).

8.2.3. Marginal Bone Loss (MBL)

Interproximal MBLs were investigated between 3-6 and 12-16 months of follow-up, comparing mean differences of interventions AHA and PR as subgroups to the CHA control group (26,126,128–132). No statistically significant differences were found (Figure 22).

A



B

Figure 22. Forest plot showing mean differences and 95% confidence intervals in mm in interproximal marginal bone losses when applying anatomic healing abutments (AHA) or provisional restorations (PR), compared to cylindrical healing abutments (CHA), at **A)** 3-6 months follow-up and **B)** 12-16 months follow-up. Subgroup analysis was performed for AHA and PR (137).

8.2.4. Pink Esthetic Score (PES)

The application of either AHA or PR resulted in statistically significantly higher PES than CHA at 1-year follow-up, based on the comparison of 340 implants in 7 studies

(30,82,86,128,131–133). MD was 2.31 (95% CI: 0.70; 3.93), favoring AHA and PR (Figure 23). The differences were statistically significant and clinically relevant.

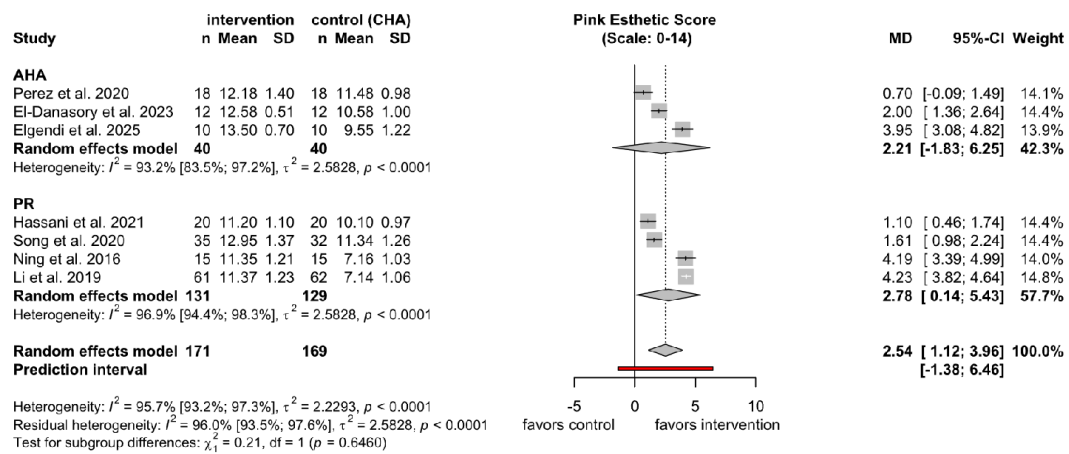


Figure 23. Forest plot showing mean differences and 95% confidence intervals in pink esthetic scores when applying anatomic healing abutments (AHA) or provisional restorations (PR) compared to cylindrical healing abutments (CHA). Subgroup analysis was performed for AHA and PR (137).

Data were not available for long-term quantitative analysis, but Arora et al. found in their retrospective cohort study with a mean 3-year follow-up that immediate provisionalization provides a mean PES of 11.1 ± 2.08 , compared to 10.3 ± 2.23 with CHA (124). The overall difference was not statistically significant; however, the distal papilla was significantly better in the PR group (mean PES: 1.7) than in the CHA group (mean PES: 1.25)(124).

8.2.5. Patient Satisfaction – Visual Analogue Scale (VAS)

Three studies with 260 implants were analyzed for 1-year satisfaction measured with VAS (range: 0-10), comparing only PR to CHA. The difference was not statistically significant (Figure 24)(82,129,133).

No data was available for the AHA group at one year. However, Elgendi et al. reported significantly higher satisfaction for the AHA group (9.8 ± 0.22) at 18 months compared to CHA (9.27 ± 0.24)(30).

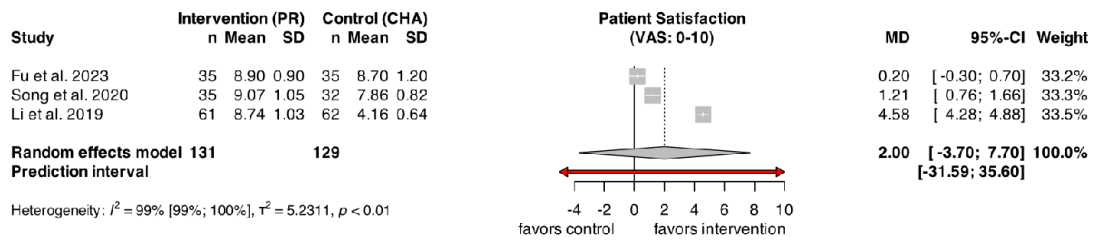


Figure 24. Forest plot showing mean differences and 95% confidence intervals in patient satisfaction measured with visual analog scales (VAS) following the application of anatomic healing abutments (AHA) or provisional restorations (PR) compared to cylindrical healing abutments (CHA)(137).

8.2.6. Changes in Horizontal Ridge Width and Buccal Contour

Three studies measured changes in horizontal ridge width (RW) on gypsum casts of the jaw and one study measured this outcome on intraoral digital scans, which could not be pooled for quantitative analysis due to heterogeneity (**Table 3**)(26,121,123,135).

Table 3. Mean±Standard Deviation (Standard Error in parentheses) differences in horizontal ridge width of the implanted sites with different treatments compared to the same site before extraction or the contralateral site with natural dentition (137).

Study	Implant position	Time Period	Measurement Level (from marginal zenith)	CHA [mm]	CHA + bone graft [mm]	AHA [mm]	AHA + bone graft [mm]	PR [mm]	PR + bone graft [mm]
Amato, 2018	anterior maxilla or mandible	6 months	1 mm	2.07 (0.13)	0.82 (0.13)	-	-	0.48 (0.10)	0.27 (0.08)
			3 mm	2.07 (0.13)	0.90 (0.13)	-	-	0.63 (0.10)	0.30 (0.08)
			5 mm	1.99 (0.12)	0.43 (0.12)	-	-	0.59 (0.10)	0.34 (0.07)
Amato, 2022	6/7 maxilla or mandible	6 months	1 mm	2.53 (0.138)	-	0.25 (0.225)	-	1.11 (0.179)	-
			3 mm	2.16 (0.144)	-	0.30 (0.225)	-	1.23 (0.179)	-
			5 mm	1.56 (0.144)	-	0.19 (0.225)	-	1.12 (0.179)	-
Chokaree, 2024	anterior maxilla or mandible	6 months	0-5 mm	-	0.607±0.421	-	0.3557±0.227	-	-
	molar maxilla or mandible			-	-	-	0.755±0.572	-	-
Tarnow, 2014	anterior maxilla	13 months–4 years	1 mm	0.8	0.4	-	-	0.8	0.4
			3 mm	1.1	0.3	-	-	0.7	0.1
			5 mm	1	0.3	-	-	0.6	0

AHA=anatomic healing abutment, CHA=cylindrical healing abutment, PR=provisional restoration

Amato 2022 applied 3 diameters (5 mm, 6 mm, and 7.5 mm) of CHA for molar extraction sites, the widest of which was included in **Table 3** for visualization (121). In all studies, the PR/AHA group showed better bone preservation than the CHA group. Only Amato 2022 compared CHA, AHA and PR in the same study, where AHA was found to be the most effective (121).

Another two studies found that immediate provisionalization slightly preserves buccal bone thickness (BBT) and buccal contours as measured by CBCT (125,126,134,136). At the level of the implant neck, Chan and Wang et al. measured a reduction in BBT of 0.6 ± 0.7 mm (PR) and 0.6 ± 0.5 mm (CHA) at the 4-month follow-up (126,136). At six months, Su et al. measured a respective BBT of 0.904 ± 0.68 mm (PR) and 0.878 ± 0.73 mm (CHA), accounting for a mean difference in BBT of 0.026 mm (134). The difference in full buccal hard and soft tissue thickness was 0.2 mm at six months, with statistically significant differences above the platform level (134). Reduction in buccal volume was $13.618\pm16.256\%$ (AHA) vs $26.631\pm20.788\%$ (CHA) according to Chokaree et al., which was not statistically significant due to the wide range of variation, but Wang et al. found a significant difference in the volumetric analysis of the buccal mucosa at the 1-year follow-up between PR (11.9% loss) and CHA (17.4% loss)(26,136).

Only one RCT could measure mid-buccal MBL (125,126). At the 12-month follow-up, Chan et al. reported a mid-buccal MBL of 0.3 ± 0.4 mm (PR) vs 0.7 ± 0.6 mm (CHA), which increased to 1.89 ± 1.02 mm (PR) vs 1.88 ± 0.61 mm (CHA) in a mean 30-month follow-up report by Bushahri et al. (125,126). Chan et al. also reported 1-year mid-facial mucosa changes, finding a recession of 0.1 ± 0.9 mm (PR) vs 0.1 ± 0.7 mm (CHA)(126). However, both Chokaree et al. and Perez et al. investigating AHA vs CHA found a vertical soft tissue gain in the CHA group (26,132). Chokaree et al. found a recession of 0.6083 ± 0.857 mm in the AHA group and a gain of 0.048 ± 0.6411 mm at six months (26). At one year, Perez et al. found a recession of 0.2 ± 0.4 mm in the AHA group, but 0.1 ± 0.5 mm overgrowth in the CHA group which were statistically significant differences (132).

8.2.7. Risk of Bias and Quality of Evidence

Most RCTs were deemed low risk, whereas some retrospective cohort studies carried moderate to serious risk, primarily due to confounding, patient selection and missing

outcome data. The certainty of evidence was high in most cases, but moderate for PES due to inconsistency and low for VAS due to study risk of bias and imprecision.

8.3. Study III.: Accuracy of digital impression methods for capturing the peri-implant emergence profile – Systematic review

8.3.1. Study Search and Selection

From 874 articles found by the systematic search, 24 were deemed eligible for inclusion, of which seven articles were available for quantitative meta-analysis (**Figure 25**). Characteristics of the included studies may be found in **Appendix Table 4** (1,35,37–39,47–49,74–77,138–149).

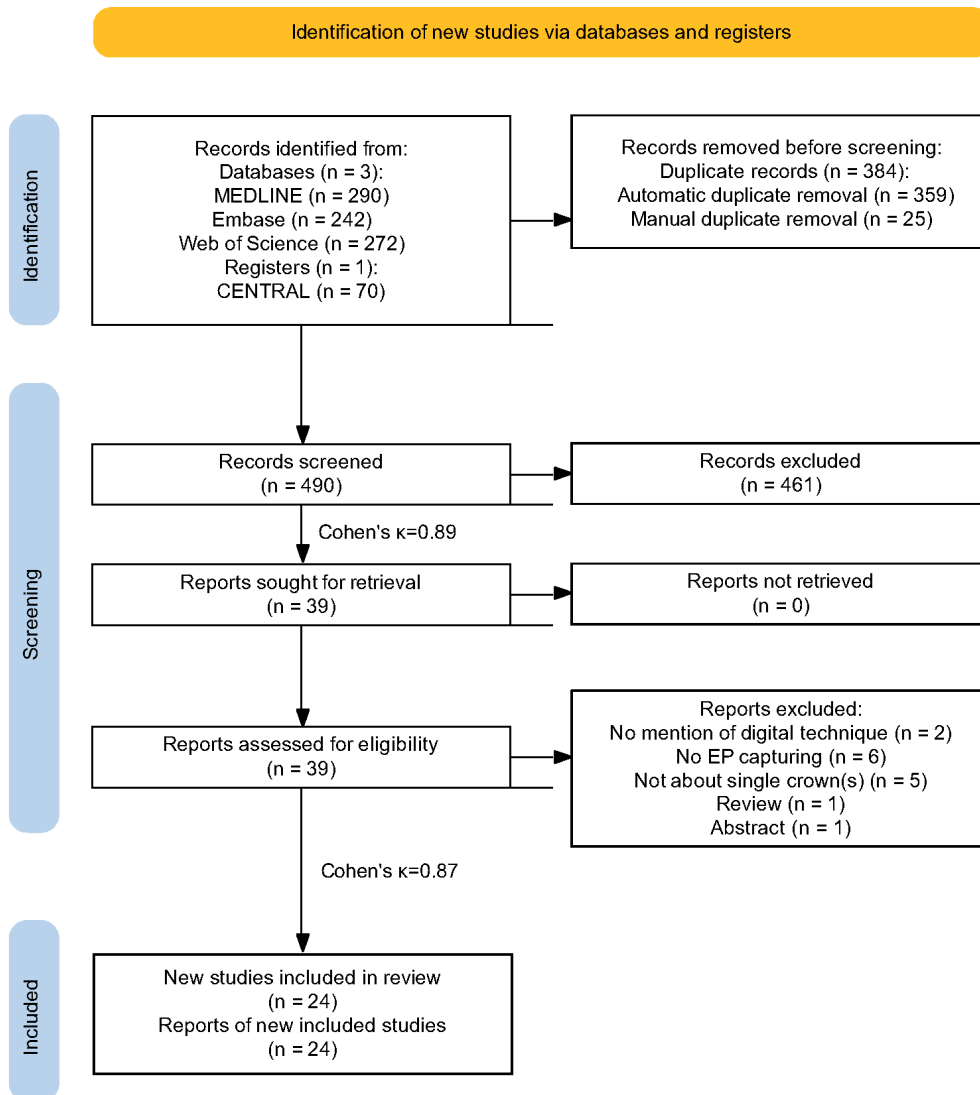


Figure 25. PRISMA 2020 Flowchart of the selection process for the third study (50,52).

8.3.2. Three-dimensional Emergence Profile Discrepancy

Three articles (n=34) reported mean soft tissue deviations by root mean square (RMS) on immediate EP collapse (49,74,141). Mean difference between direct scanning vs indirect scanning or conventional method was 0.27 mm (95% CI: -0.04 mm; 0.59 mm), which was not statistically significant (**Figure 26**).

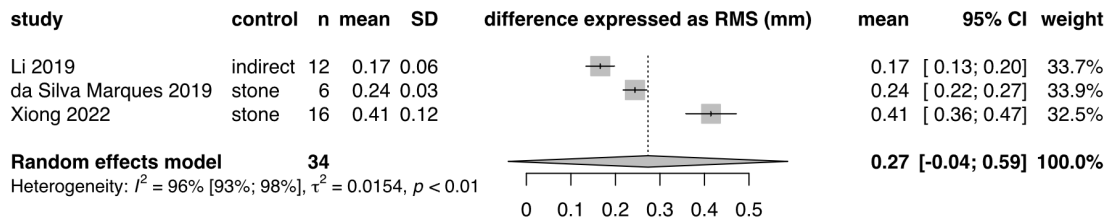


Figure 26. Forest plot showing mean differences with 95% CI in mm comparing the root mean square (RMS) change in the inner surface of the emergence profile of immediate direct emergence profile (EP) scanning vs indirect EP scanning or conventional EP replication. Differences were not statistically significant (50).

Two articles (n=21) reported a percentage of soft tissue deviations on EP collapse after 5 minutes of PR removal (47,77). Mean difference of the inner surface area of the EP in direct and indirect scanning vs conventional impression was 6.02% (95% CI: -2.96%; 15.00%), which was not statistically significant (**Figure 27**).

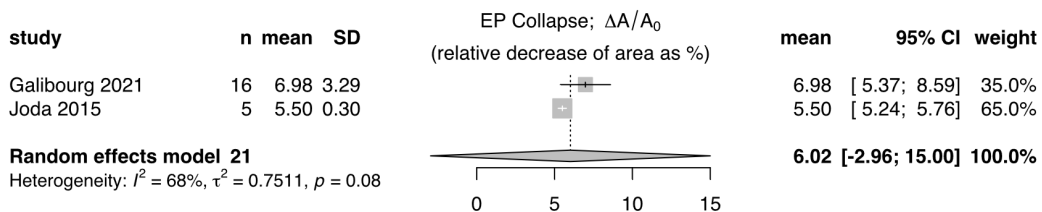


Figure 27. Forest plot showing mean differences with 95% CI comparing the % change in the inner surface area of the emergence profile (EP) of immediate direct EP scanning

vs indirect EP scanning or conventional EP replication. Differences were not statistically significant (50).

8.3.3. Height of the Mucosal Margin

Three articles (n=44) were included in the evaluation of gingival margin height (GMH) comparing direct vs indirect scanning or conventional cast (74–76). The decrease in the GMH was 0.09 mm (95% CI: -0.02 mm; 0.20 mm), which was not significant (**Figure 28**).

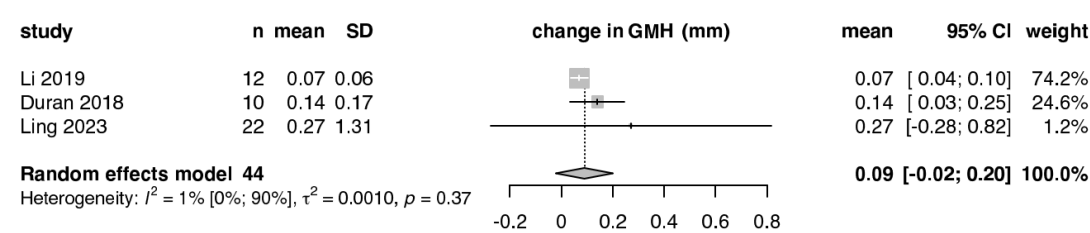


Figure 28. Forest plot showing mean differences with 95% CI comparing the change in the height of the mucosal margin of immediate direct emergence profile (EP) scanning vs indirect EP scanning or conventional EP replication. Differences were not statistically significant (50).

8.3.4. Risk of Bias and Quality of Evidence

The only RCT included in this review was performed by Ling et al., but there was no information on the allocation concealment, which raised some concerns regarding the randomization process (76). All other authors who performed comparative clinical trials reported moderate concerns regarding confounding factors, such as the mucosal phenotype of the patient. Case series and case reports all showed high risk of bias, mainly due to the missing patient demography and health-related information, as well as clinical parameters following the restorative procedure.

9. DISCUSSION

9.1. Summary of Findings, International Comparisons (including all studies)

This thesis synthesizes evidence from three systematic reviews addressing key stages of single implant rehabilitation: 1) the timing of implant placement and loading (53), 2) the application of anatomic healing components for emergence profile conditioning (137), and 3) the accuracy of digital impression methods in capturing the emergence profile for definitive rehabilitation (50). Together, these analyses highlight that treatment success is determined not by a single intervention but by coordinated management of peri-implant tissues.

The network meta-analysis on implant placement and loading demonstrated that immediate implant placement combined with immediate provisionalization (protocol 1A) consistently ranked among the most favorable protocols for esthetic outcomes, aligning with the prior International Team for Implantology (ITI) 7th Consensus Statement from 2023 (16,18,53,150). The null hypothesis was thus rejected.

In the systematic review the 2023 consensus was partially based on, Zhou et al. validated IPLPs based on cumulated implant survival rates, by which they found protocols 4A and 1C to be scientifically and clinically valid treatment options (16). Our cumulated IS rates were generally lower than previous systematic reviews, especially for protocol 1A. As most failures occurred in the first year, we only calculated short-term IS. Immediate implantation tended to have higher failure rates and needed stricter conditions to be met for success (150). For protocol 1A, compared to our IS rate of 91%, Zhou et al. calculated a cumulative IS rate of 97.5% (range: 69.2-100%), weighing different lengths of follow-up, whereas Pommer et al. obtained an IS of 99.6% at 3-5 years (95% CI: 98.5-100%) (13,16). These differences can be explained by the fact that Zhou et al. and Pommer et al. considered different study types and follow-up ranges, whereas our proportional meta-analysis was based on RCTs with only short-term follow-up, increasing our evidence level for short-term applicability (13,16). In addition, current publications with longer follow-up, which were included by previous reviews, have lower implant failure rates, whereas studies with high failure rates in shorter follow-up periods are yet to publish long-term results (98,108,110,117,119). For instance, Block et al. reported four implant failures for

protocol 1A, the highest of all studies, which was the main reason for the low cumulative survival rate of said protocol in our analysis; although, the difference was not considered significant within the study (98). Despite these limitations, the IS of protocol 1A was still acceptable. Furthermore, a most recent systematic review by Gallucci et al. found 98.01% (92–100%) survival rates at a mean 32.9 months (12–120 months) follow up for protocol 1A, demonstrating its long-term survivability, however they also emphasized the importance of careful case selection to achieve this (20). Based on their review, all protocols aside from type 1B, 2B, 3B were deemed scientifically and clinically well documented (20).

Recently, MBL has also gained importance in evaluating protocol validity. In our study, 4B ranked first, followed by protocols 4A, then 1A (53). Protocol 1C ranked only as one of the last protocols before 3C and 4C, suggesting that immediate loading may be a more favorable treatment in terms of MBL, assuming that the implant survives, though no significant differences were observed. Notably, however, when evaluating MBL, nearly all studies set the baseline to the timing of implant placement, in which case the true effect of the timing of implant placement on post-extraction healing cannot be examined in protocols that proceed beyond immediate implantation, as changes between the time of tooth extraction and implantation, are not accounted for. Only Lu et al. and Zhou et al. set the baseline at the time of tooth extraction, which should be the proper method for detecting true differences among different timepoints of implantation (84,97).

Medium- to long-term follow-up showed promisingly low MBLs as well. Gjølvoold et al. even showed bone growth at 5 years compared with at 1 year in both protocols 4A and 4C (109,110).

Only few studies reported on mid-facial MBL or buccal bone thickness (BBT), both measurable on CBCTs only. No analysis was possible due to the low number of rather heterogeneously measured data, despite the undeniable importance of the buccal tissues. Liu et al. and Slagter et al. both compared protocols 1C-3C, yet a quantitative analysis was not feasible from two studies (83,118). Liu found that the BBT reduction was around 0.6 mm (1C) and 0.56 mm (3C), and Slagter reported approximately 0.04 mm (1C) and 0.07 mm (3C); however, within-study differences between compared protocols were minimal (83,118). Inter-study differences may therefore be attributed to study

designs, materials, and methods. Slagter included patients with buccal bone defect sizes of ≥ 5 mm and used autogenous bone and soft tissue grafts in both protocols, whereas Liu reported no information on buccal defect sizes and applied only guided bone regeneration for intervention 3C (83,118). There was no information on phenotype, abutment design, and if there was veneering in the subgingival region, which could have affected results.

Two reports were available for 1-year mid-facial MBL for protocol 1C, where Liu et al. reported a mean MBL of around 1.74 mm and Chan et al. reported only 0.7 mm (83,102). Great differences were observed, with Chan only achieving an MBL similar to the 1-year report of Liu at their 30-month follow-up (1.88 mm)(83,102). This may be explained by the fact that Chan applied allogenic bone grafting, whereas Liu used no grafts at all.

As thin BBT, fast bundle bone resorption, and soft tissue recession are major concerns in implant treatment in the anterior maxilla, it is advisable to standardize and perform such measurements in further studies to obtain evidence that aids clinical decision-making (15,17,151–154).

Similar protocols were investigated for soft tissue recession (STR), but achieved different rankings at mesial, mid-facial, and distal sites. Most data were available for mid-facial recession, where the rankings were 2C, 1A, 4B, 1C, and 3C in descending order. Immediate implantation is often associated with higher mid-facial bone loss, which explains increased STR (155,156). Interestingly, 1A ranked first at distal papilla, but showed greater recession at the mesial papilla, in which it ranked last. This could have been the effect of the position and gingival level of the failing tooth, the quality and quantity of interproximal bone in both vertical and horizontal dimensions towards the neighboring teeth, and 3D implant positioning, as well as oral hygiene, but we had no data to analyze the effect these variables (2,157,158). STR can worsen esthetics, satisfaction, and can indicate MBL underneath, the analysis of which would require data on the same measuring points from the same studies (159,160).

PPD change also indicates bone loss. A deep PPD that is bleeding or purulent could be a sign of peri-implantitis (159,160). As pockets deeper than 4 mm were not reported, we analyzed PPD change instead of PPD. 3A ranked first with a mean difference of >1 mm from the following protocols 4C, 1C, 3C, 2C, and 1A, which showed small differences

from each other, and only 1A was significantly worse than 3A, but had no clinical relevance due to wide CrI. Increased probing depth in 1A may be due to post-extraction healing, which again highlights the importance of investigating changes following tooth extraction as well as after implantation (155,156).

Bleeding is a definite indicator of inflammation, either peri-implantitis if bone loss is present or peri-implant mucositis if present alone (160). In the analysis of BI, there were no statistically significant differences between protocols. Though both PPDe and BI were compared, the examined populations were not the same, and these parameters may only be evaluated as indicators of peri-implantitis when investigated together (159,160). Peri-implant inflammation cannot be attributed to timing protocols alone, as it is greatly associated with individual oral hygiene, measurable with plaque indices, missing from most reports and not available for analysis (159).

Esthetics and patient satisfaction are key indicators of success in the anterior region. For both PES and WES, protocol 1A ranked first with a statistically significant advantage, especially over late placement. Immediate implantation and loading allow patients to preserve their original and natural soft tissue profile, resulting in significantly higher PES and WES (2,103,161). Higher patient satisfaction was also found with protocol 1A. Though mean differences were not statistically significant, the SUCRA values show an extremely high probability for 1A (84.85%) to rank best, with 33.04% advantage over the second protocol (51.81%). Both esthetics and immediate rehabilitation may contribute to the higher satisfaction observed in this study and the literature as well (161).

Our second study evaluated anatomically shaped healing abutments and provisional restorations with a meta-analysis, where we demonstrated their significant esthetic advantage over conventional cylindrical healing abutments, as well as horizontal tissue preservation and papilla formation (137). The null hypothesis was rejected.

Cumulated one-year IS rates were above 99% for all interventions, unaffected by the method of healing. Only the PR group had implant failures, which aligns with the lower implant survival rate of protocol 1A (immediate implantation with immediate loading). Five out of 291 implants failed, of which 2 restorations were in occlusion with the antagonistic jaw (122), and 3 were taken out of static and dynamic occlusion (126,130); however, these restorations could still have been susceptible to increased loading during

feeding (29,162). All studies applied minimal invasive extraction, a minimum insertion torque of 30 Ncm, and most studies also applied particulate bone grafts in the jumping gaps, but only 7 studies reported on the application of surgical guides to ensure correct implant positioning (26,121–123,128,134). Immediate implants can only be immediately provisionalized under strict criteria, with careful consideration of factors influencing IS, such as the type and 3D position of the implant, bone quality and quantity, presence of periapical or periodontal inflammation, phenotype, primary implant stability and grafting, as well as possible parafunctional movements (2,8,150,163). It is also crucial for immediately placed implants to be relieved of loading, therefore, AHAs, which are shorter than PRs may be more advantageous for successful implant-bone integration and survival (2,162). There were no implant failures at all in the AHA and CHA groups. However, there were only 3 randomized studies with overall 40 implants investigating AHAs, so further studies with long-term follow-up are needed to understand their true effects (30,128,132). So far, no comparative clinical studies have reported long-term results, but according to a retrospective case series by Akin et al. of 115 immediate posterior single implant cases with AHAs, the survival rate up to 8 years was 98.26%, with 3 cases of early implant failures (164).

Interproximal marginal bone losses were similar in all groups, with mean differences between the AHA or PR and CHA groups being close to the null effect in both 3-6-month and 12-16-month follow-ups, only slightly favoring the intervention group. Sensitivity analyses excluding posterior implant sites and focusing only on anterior sites yielded no different results. This suggests that the different healing abutment shapes do not significantly affect interproximal bone loss in either anterior or posterior sites in the short term. However, these short-term changes may also be attributed to post-extraction and post-implantation bone remodeling; true hard tissue changes can only be objectively assessed after long-term follow-up (165,166).

Once again, only few studies applied CBCT analysis for mid-buccal bone loss and buccal bone thickness. One study with long-term follow-up showed considerable mid-buccal vertical bone loss at one year (PR: 0.3 mm, CHA: 0.7 mm) which equalized after 2.5 years (PR: 1.89 mm, CHA: 1.88 mm). However, the PR group showed 0.21

mm less buccal bone resorption at 2.5 years (125). Further long-term investigations with CBCT analysis are required to investigate these outcomes.

Chan et al., who found buccal MBLs of 0.3 mm for PR and 0.7 mm for CHA, found only minimal, 0.1 mm recession in both groups (126). Perez et al. found a recession of 0.2 mm in the AHA group, yet even reported a gain of 0.1 mm soft tissue for the CHA group (132). This aligns with the results of Chokaree et al., with slight mid-buccal mucosal gain in the CHA group (0.048 mm) compared to the slight recession in the AHA group (0.608) (26). Souza et al. showed that flatter abutment angulation leads to more MBL, which may also contribute to soft tissue recession and may explain how anatomic abutments—being naturally wider than conventional cylindrical abutments—could potentially prevent upward tissue growth (167). The abutment emergence angulation should not exceed 30° to decrease MBL and risk of periimplantitis (165,168). Although the abutment material could not be investigated, it may also affect vertical and horizontal soft-tissue dimensions and inflammatory parameters (169). Therefore, the right choice of implant diameter, abutment material, height and angulation of abutment widening should be carefully considered for optimal outcomes (165,167–171).

A few studies investigated horizontal bucco-palatal ridge width changes and buccal full tissue thickness at various heights along the implant length. Unfortunately, the low number of heterogeneous studies did not allow mathematical synthesis; however, individual studies all found that the application of AHA or PR preserved horizontal tissue dimensions better than CHA.

In a study by Su et al., when the full buccal hard- and soft-tissue thickness was measured on CBCT, the advantages of PR were statistically significant above platform level (134). Although the differences decreased apically, and hard tissue changes were not significant, the PR group always resulted in more bone and mucosa preservation. This suggests that the correct formation and maintenance of the supracrestal complex could be beneficial for horizontal hard and soft tissue dimensions.

Three studies measured changes in full bucco-palatal ridge width (RW) changes compared to the pre-extraction RW at the same site (121,123) or to the contralateral tooth (135) on gypsum casts. As these studies measure the full bucco-palatal thickness, differences in the buccal and palatal sites cannot be interpreted separately; however, as

post-extraction bone resorption rates are usually higher buccally, it would be informative to find out which site each procedure affects more (14,17).

Amato 2018 and Tarnow et al. compared PR to CHA in the anterior jaws (123,135). Amato 2018 found that reduction in RW in the PR group (0.2-0.7 mm) was only ½ to ⅓ of that of the CHA group (0.4-2.1 mm) after 6 months (123). At 1- to 2-year follow-up, the differences were smaller, but still in favor of PR (135). Inter-study differences were due to the varying choices of reference sites, surgical and prosthodontic methodologies, as well as follow-up times. It was also found that within the same type of restoration, grafting the jumping gap offered better RW preservation up to four years of follow-up, with both cases showing about half as much resorption in the grafted sites as non-grafted sites (123,135)(31,45). This aligns with the literature and the 7th ITI Consensus Statement recommending bone grafting with IIP (2,150). However, in Amato 2018, the non-grafted PR group showed even less resorption than the grafted CHA group, which also demonstrates the potential positive effect of customized PR (123). The tissue-preserving effect was most pronounced near the implant neck, consistent with the findings of Su et al. (123,134). The alveolar bone and mucosa have a mutual effect on each other; therefore, the preservation or loss of either could affect the other equally. To achieve the best clinical outcome, one should aim to preserve both hard- and soft-tissues synergistically, applying both bone- and soft-tissue grafting as well as individualized restorations to promote optimal healing.

Amato 2022 investigated three diameters (5 mm, 6 mm, and 7.5 mm) of CHA, as well as AHA and PR in first or second molar extraction sockets in their RCT, without any bone grafts to avoid confounding (121). On average, molar teeth are 7-10 mm in diameter; therefore, a larger diameter implant and abutment may provide better socket sealing and better prevent the resorption of surrounding tissues, which explains why the widest CHA of 7.5 mm, fitting best in the extraction socket, resulted in the lowest bone resorption (1.56-2.53 mm) among the CHA groups (121,172). Nonetheless, this still failed to reach the preserving effect of the PR (1.11-1.23 mm) and AHA (0.19-0.30 mm) groups, where the EP is custom-made, thus providing even better socket sealing and tissue support (121). The AHA group significantly outperformed the PR group in this study, possibly due to the loading effects discussed earlier; i.e., AHA could allow for

better, more undisturbed healing of hard tissues, which requires further investigation (29,121).

Wang et al. was the only study to examine the buccal mucosa separately (136). They reported a significant difference in volume between the PR and CHA groups at one year, where the volume loss was 17.4% in the CHA group but only 11.9% in the PR group. The region of interest for this measurement was a rectangular area located 2-6 mm apical to the mucosal margin. The depth of post-extraction implant insertion was 3 mm below the mucosal margin. Even when accounting for the 0.1 mm midfacial mucosal recession observed up to the time of measurement, this indicates that the measured area extended from 1 mm coronally to 3 mm apically to the implant platform, reaching the bony structure as well. This suggests that the effect of the PR might affect not only the supracrestal complex but possibly the crestal soft tissues as well. Unfortunately, the 2 mm range at the mucosal margin was not measured, and no separate data were available for the supra- and sub-platform levels, which calls for further investigation, as the supracrestal area that is not supported by crestal bone may be most affected by the implant superstructure (136).

All in all, data from individual studies suggest that AHA and PR might preserve horizontal tissue thickness, primarily the soft tissues, compared to conventional healing abutments, therefore further investigations with a standardized methodology and long-term follow-up are needed for vertical and also for horizontal hard- and soft-tissue changes, where both bone and mucosal changes will be investigated but should be reported as individual outcomes.

If AHA and PR could preserve horizontal tissues, especially soft tissues, they might contribute to higher pink esthetic scores as well, as adequate amounts of vertical and horizontal tissues are crucial for long-term success (162,173). A statistically significant and clinically relevant advantage was found for the PR and AHA groups over the CHA group at the 1-year follow-up, both in the overall effect and for the PR subgroup of the meta-analysis. Among the PR group studies, Li et al. was the only study that did not take the PR out of occlusion (82). However, this did not seem to affect PES, as the results were similar to those of Ning et al. (86). These two studies had larger differences between the PR and CHA groups, primarily due to the low PES in the CHA group, in which dynamic compression technique was applied to individualize EP prior to the final

rehabilitation (82,86). This method of EP formation is quite technique-sensitive and may damage peri-implant tissues if not performed carefully or if there is insufficient vertical and horizontal mucosa available for manipulation, which may explain the lower PES in these cases (7,82,86,162).

The subgroup analysis of the AHA group did not show a significant difference, as only three studies were included (30,128,132). Therefore, further studies are needed to demonstrate the true effect of this intervention. However, the individual results of all studies included in the analysis favored the AHA group and the test for subgroup differences was not significant, therefore, it can be expected that future studies will also show results in favor of the use of anatomically shaped healing abutments (30,128,132). Perez et al. reported that distal papilla scores were significantly better in the AHA group than in the CHA group at 1-year follow-up (132). Arora et al. also found a significant advantage for the PR group in the same parameter, with up to four years of follow-up (124). This is consistent with our network meta-analysis, where IIP with immediate provisionalization ranked first in distal papilla height compared to later placement and loading protocols (53). This effect may be due to the fact that anatomic restorations can better support the interproximal soft tissue and allow vertical regrowth of the papilla, and moreover, due to the direction of the blood supply, the distal papilla may have better blood flow, furthermore, the distal contact point is generally more apical and closer to the marginal bone due to the lower height of the teeth, thus the papilla can more easily fill the sub-contact area (27,157).

The quantitative analysis of overall patient satisfaction included three studies, all of which measured satisfaction levels on visual analog scales (82,129,133). Differences were not statistically significant due to the small number of studies and high heterogeneity. No other patient-reported outcome measures were available for analysis, but including parameters that address multiple aspects of patient satisfaction should be considered, given the increasing focus on individualized, patient-centered care.

With the potential to preserve horizontal tissue thickness and the esthetic advantages, both AHA and PR may be recommended for single immediate restorations, but posterior implants may benefit more from the decreased occlusal loading of AHA. Long-term follow-up is also needed to determine the further potential of such restorations.

In order to maintain the anatomically formed emergence profile (EP), it is crucial to apply the most accurate impression method to replicate the shape of the AHA or PR to the final restoration. Besides the conventional impression methods, current digital workflows still apply direct EP scanning as standard care. Our systematic review on digital impression methods revealed that soft-tissue collapse immediately following removal of the interim prosthesis remains a potential source of inaccuracy (50). Yet, due to the high inter-study heterogeneity and wide confidence intervals, our meta-analysis did not show significant differences between impression methods, and we did not reject the null hypothesis.

Several authors have observed that the peri-implant mucosa collapses after PR removal; moreover, the degree of collapse depends on various factors, including 3D implant position, the amount of vertical and horizontal soft tissue, phenotype, and implant diameter (38,47,49,74–77,141).

As reported by Li et al., a discrepancy in peri-implant soft tissue was observed in non-keratinized, less rigid and stable peri-implant mucosa (74,174). This slight dimensional change increased gradually over time and there was a statistically significant discrepancy (range: 0.08-0.18 mm) immediately after the removal of the PR, suggesting some inaccuracy in direct scanning (74).

No significant differences were found for immediate soft tissue collapse measured on the inner surface of the EP between the direct scanning vs indirect scanning or conventional cast (49,74,141). The analysis resulted in a wide confidence interval, and high heterogeneity was observed, which could be attributed to the heterogenous and low sized samples, as well as the differences in the applied materials and methodologies. Li et al. (74) used the virtual model based on the indirect EP scanning, whereas da Silva et al. (141) and Xiong et al. (49) applied digital scans of the conventional casts as control groups.

Three studies were included in the analysis of the GMH without significant differences between direct vs indirect scanning or conventional cast, though Li et al. and Duran et al. both showed significant immediate soft tissue collapse (74–76).

Following conversion of the 5-minute soft tissue collapse values measured by Galibourg et al. and Joda et al. to percentage decrease of EP area, the results of both studies were

coherent, with Galibourg et al. measuring 6.98% and Joda et al. showing 5.5% mean EP collapse (47,77).

Ling et al. compared the EP supported by crowns fabricated with either direct or indirect EP scanning to the original EP supported by the provisional (76). They found a mean volumetric difference of 1.87 mm³ vs 0.75 mm³ labially and 1.66 mm³ vs 0.65 mm³ palatally with direct vs indirect EP scanning, respectively. This would appear to indicate a more significant soft tissue collapse in direct scanning, albeit statistically insignificant changes in both groups (76).

A standard for the clinically acceptable threshold should be decided according to the difference in accuracy of the indirect EP scanning and conventional impression, as both are considered clinically accepted impression methods; however, performance of this analysis was not possible due to the lack of data.

9.2. Strengths

9.2.1. Study I.: Comparison of implant placement and loading protocols for single anterior maxillary implants – Network meta-analysis

To the authors' knowledge, this was the only NMA reviewing IPLPs, analyzing several protocols (1A, 1C, 2A, 2C, 3A, 3C, 4A, 4B, 4C), including only RCTs with samples across America, Asia, and Europe based on data from English and Chinese language databases. This study focused not only on implant survival and MBLs but also on soft tissue parameters, esthetics, and patient satisfaction.

9.2.2. Study II.: Peri-implant hard and soft tissue outcomes with anatomic vs non-anatomic healing abutments on immediate implants – Meta-analysis

This is the only systematic review with a meta-analysis to have investigated both immediate provisionalization and anatomically shaped healing abutments compared with conventional cylindrical healing abutments. Only two-armed studies published after the year 2000 were used, and most included studies followed strict selection criteria and surgical protocols.

9.2.3. Study III.: Accuracy of digital impression methods for capturing the peri-implant emergence profile – Systematic review

The strengths of this meta-analysis and systematic review are the pre-established and published methodologies, and the low-to-moderate risk of bias shown in the included studies; moreover, to the author's knowledge, this study is the first quantitative and qualitative analysis on this topic.

9.3. Limitations

9.3.1. Study I.: Comparison of implant placement and loading protocols for single anterior maxillary implants – Network meta-analysis

Although a few RCTs with long-term (3 to 5 years) follow-up were included, only 1- and 2-year follow-ups had sufficient data available for qualitative analysis. Even for short-term analyses, the strength of evidence and networks was weak due to the low number of studies; therefore, subset analyses were not possible. Parameters such as the final restoration material and retention method, abutment height and connection, flap design, the patient's mucosal phenotype, and the application of either hard or soft tissue grafts were rarely mentioned, all of which could have affected the outcomes. Missing and possibly selected outcome data, imprecision, heterogeneity, and incoherence were also reasons for the reduced strength of the evidence.

9.3.2. Study II.: Peri-implant hard and soft tissue outcomes with anatomic vs non-anatomic healing abutments on immediate implants – Meta-analysis

Due to a lack of studies, especially those with long-term follow-up, not all clinical parameters and confounding factors could be analyzed. These include mucosal phenotype, implant position, guided implantation, healing and prosthetic abutment diameters, restoration material and retention method, digital or conventional workflow, possible sub-gingival veneering, and application of dynamic compression techniques. The authors also had to include retrospective cohort studies, which reduced the level of evidence; however, most studies synthesized in the meta-analyses were RCTs with a low risk of bias.

9.3.3. Study III.: Accuracy of digital impression methods for capturing the peri-implant emergence profile – Systematic review

The included studies allowed only the comparison of the immediate direct scanning of the EP based on the GMH (mm), RMS, and EP collapse with direct scanning of the inner cone of the soft tissue EP after 5 minutes, to either the indirect scanning or conventional cast. A limited number of well-designed studies were available in the literature for the analyses due to high heterogeneity in study characteristics and study types.

10. CONCLUSIONS

Obtaining predictable esthetic outcomes with single implants depends not only on patient anatomy but the careful planning and execution of multiple sequential interventions from surgery to prosthetic rehabilitation, including but not limited to the choice of optimal implant placement and loading time, with the appropriate soft-tissue formation and replication techniques.

Immediate implant placement may be applied when conditions are met, followed by individualized soft tissue formation with an anatomical healing abutment or immediate provisionalization to achieve superior esthetic results. However, there is no clear evidence on which technique is most accurate for replicating the emergence profile in a digital workflow.

11. IMPLICATIONS FOR PRACTICE

Clinicians should always prospectively plan for the complete workflow of implant prosthodontic rehabilitation at the pre-surgical treatment planning phase and choose the optimal treatment based on the given conditions, and also consider the possibility of altering patient anatomy with hard- or soft-tissue grafting when original conditions are not optimal.

Immediate implantation needs to meet strict conditions, but when applicable, and supplemented with anatomical healing abutment (AHA) or provisional restoration (PR), it can maintain the natural soft tissue profile and grant higher esthetic results, thus improve patient satisfaction, therefore its use is recommended especially in the anterior region. The application of AHA over PR could be considered, and if PR is applied, it is recommended to be taken out of occlusion, as overloading may result in early implant failure.

Regarding digital impression methods that include emergence profile (EP) replication, no clear recommendation can be made; however, caution is recommended when applying direct EP scanning, as the peri-implant tissues lose their dimensional stability quickly after the removal of the restoration.

12. IMPLICATIONS FOR RESEARCH

12.1. Methodology and Study Design

More well-designed RCTs with standardized methodology, larger sample sizes, and long-term follow-up are needed to investigate changes in vertical and horizontal hard- and soft tissues, as well as esthetic results and patient-oriented outcomes in implant-prosthodontic rehabilitation.

More homogeneous studies are needed in terms of phenotype, implant diameter and position, surgical technique, hard or soft tissue grafting, buccal bone dimensions, soft tissue parameters, prosthetic material and procedure, and intraoral scanning accuracy in measuring soft tissue volumetric comparators.

12.2. New Areas

Future studies should also focus on chairside time and cost effectiveness, as the aim of research is to find the optimal treatment option in clinical practice (153,154).

The potential of stock, anatomically shaped, coded, multi-purpose healing abutments should also be explored and investigated.

Appropriate IOS protocols, especially those comparing the indirect scanning to the gold standard, should be investigated to confirm that digital impression technologies can be used as an equally viable alternative to the conventional method.

13. IMPLICATIONS FOR POLICY MAKERS

Implant survival should not be the only validation criterion for implant placement and loading protocol validation, but marginal bone loss and patient-oriented outcomes should also be a part of the evaluation.

If conditions are met, applying 1A protocol in the anterior maxillary region could result in higher esthetics (PES, WES) and patient satisfaction than late placement. With recent systematic reviews of the ITI proving high survivability, our review could also contribute to acknowledging the 1A protocol as a scientifically and clinically validated treatment option. Furthermore, the application of non-occluded anatomical healing abutments instead of immediate provisionalization following immediate implantation may further improve survival rates.

14. FUTURE PERSPECTIVES

Future clinical investigations, especially RCTs, should be conducted with at least 5 years follow-up to further confirm the validity of immediate and early implant placement and loading protocols, as well as the viability of anatomic and coded healing abutments to guide clinical protocols.

Furthermore, clinical investigations should be conducted to compare digital EP impression methods, especially indirect EP scanning to find an accurate digital alternative to replace conventional impressions and decide upon a clinical threshold of acceptability for the accuracy of EP replication methods. The accuracy of CAD/CAM-manufactured casts should also be investigated in order to fully replace the conventional workflow with a digital one.

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16.1. Publications Related to the Thesis

Qian, X., Vánkos, B., Kelemen, K., Gede, N., Varga, G., Hegyi, P., et al. (2025). Comparison of implant placement and loading protocols for single anterior maxillary implants: A systematic review and network meta-analysis. JOURNAL OF PROSTHETIC DENTISTRY, 133(3), 677–688. <http://doi.org/10.1016/j.prosdent.2024.05.033>

Qian, X., Vánkos, B., Agócs, G., Kelemen, K., Wenning, A. S., Kispélyi, B., et al. (2026). Individualized healing significantly improves pink esthetics around immediate single implants: A systematic review and meta-analysis. PERIODONTOLOGY 2000. <http://doi.org/10.1111/PRD.70089>

Mikulas, K., Qian, X., Tajti, P., Agocs, G., Gallucci, G. O., Pedrinaci, I., & Hermann, P. (2025). Accuracy of Digital Impression Methods for Capturing the Peri-Implant Emergence Profile: A Systematic Review. CLINICAL ORAL IMPLANTS RESEARCH, 36(8), 930–943. <http://doi.org/10.1111/clr.14441>

16.2. Publications not Related to the Thesis

Heizer Á., Kisgergely M., Szabó B., Sipos Z., Lee J., Qian X., et al. Oral Burden of Sjögren Disease: A Systematic Review and Meta-analysis. J Dent Res. 2026 Jun 26;00220345261450057. doi:[10.1177/00220345261450057](https://doi.org/10.1177/00220345261450057)

Rozgonyi L., Borbély E., Szabó B., Lee J., Qian X., Vág J., et al. Nonpharmacological Interventions in Dental Procedures for Children and Adolescents with Neurodevelopmental Disorders: A Systematic Review and Meta-Analysis. Journal of Evidence-Based Dental Practice. 2026 Sep 1;26(3):102310. doi:[10.1016/j.jebdp.2026.102310](https://doi.org/10.1016/j.jebdp.2026.102310)

Márton, P., Antal, M., Kiss-Dala, S., Agócs, G., Qian, X., Hegyi, P., Varga, G., & Ábrám, E. (2026). Enamel Damage from Tooth-Whitening- A Systematic Review and Meta-analysis. Journal of Dentistry, 106786. <https://doi.org/10.1016/j.jdent.2026.106786>

Vánkos, B. L., Qian, X., Kelemen, K., Szentes, B. L., Agócs, G., Varga, G., Hegyi, P., Hermann, P., & Kispélyi, B. (2026). Accuracy of Digital and Conventional Implant Impressions in Edentulous Jaws: A Systematic Review and Meta-Analysis of In Vitro Studies. Dentistry Journal, 14(5), 304. <https://doi.org/10.3390/dj14050304>

Haba, K. S., Kreuter, P. K., Qian, X., Agocs, G., Banyai, D., Rozsa, N. K., et al. (2026). Salivary Glucose Testing for Diabetes Mellitus: A Systematic Review and

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Li, X., Cai, G., Hernádfői, M. V., Agocs, G., Szilágyi, Á., Párniczky, A., et al. (2026). Chinese herbal medicine in pediatric oncology: Effects on survival and toxicity - a meta-analysis. PHYTOMEDICINE: INTERNATIONAL JOURNAL OF PHYTOTHERAPY AND PHYTOPHARMACOLOGY, 150. <http://doi.org/10.1016/j.phymed.2025.157723>

Cai, G., Szalai, E. Á., Martinekova, P., Li, X., Qian, X., Veres, D. S., et al. (2025). Concomitant virus infection increases mortality and worsens outcome of acute pancreatitis: a systematic review and meta-analysis. PANCREATOLOGY, 25(1), 20–28. <http://doi.org/10.1016/j.pan.2024.12.005>

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Kivovics, P., & Qian, X. (2021). A kínai orvoslás fogorvosi vonatkozásai. Budapest: Gabbiano Print.

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18. APPENDICES

Appendix Table 1. Demographics and basic characteristics of the included primary studies for the first study (53).

Study	Author, year	Country	Sample size	Age (mean [SD])	Non-smoker	Light smoker (<10/day)	Heavy smoker (>10/day)	Follow up (month)	Compared protocols	Measured outcomes
1	Tonetti 2017	multinational	124	52.5 (13.69)	NR	NR	>20 cigarettes or >14mg nicotine per day excluded	12/24/36	1C vs 3C	IS, MBL, PPD
2	Slagter and Meijer 2021	Netherlands	40	46.15 (15.21)	40	excluded	excluded	60	1C vs 3C	IS, MBL, STR, PES, WES, VAS, PPD, BI
2	Slagter 2016	Netherlands	40	46.15 (15.21)	40	excluded	excluded	12	1C vs 3C	IS, MBL, STR, PES, WES, VAS, PPD, BI
2	Slagter 2017	Netherlands	40	46.15 (15.21)	40	excluded	excluded	12	1C vs 3C	IS
3	Slagter 2017	Netherlands	40	40.85 (15.48)	40	excluded	excluded	12	1A vs 1C	IS
3	Slagter 2015	Netherlands	40	40.85 (15.48)	40	excluded	excluded	12	1A vs 1C	IS, MBL, STR, PES, WES,

										VAS, PPD, BI
3	Slagter and Raghoe bar 2021	Netherlands	40	40.85 (15.48)	40	excluded	excluded	60	1A vs 1C	IS, MBL, STR, PES, WES, VAS, PPD, BI
4	Chan 2019	USA, Michigan	40	59.1 (13.7)	40	excluded	excluded	12	1A vs 1C	IS, MBL, STR
4	Bushahr i 2021	USA, Michigan	28	65.7 (8.5)	28	excluded	excluded	30	1A vs 1C	MBL
5	Crespi 2008	Italy	40	47.21	NR	NR	excluded	24	1A vs 1C	IS, MBL
6	Crespi 2018	Italy	60	54.2	NR	NR	excluded	12/24/36/48	1A vs 1C	IS
7	De Rouck 2009	Belgium	49	53.47 (12.46)	NR	NR	excluded	12	1A vs 1C	IS, MBL, STR, VAS, PPD, BI
8	Cardaro poli 2022 I. esthetic	NR	48	55.17 (14.06)	NR	NR	excluded	12	1C vs 4B	IS, MBL
8	Cardaro poli 2022 II. radiogra phic	NR	48	55.17 (14.06)	NR	NR	excluded	12	1C vs 4B	STR, PES
9	Puisys 2022	Lithuania	52	43.59 (11.8)	NR	NR	excluded	12	1A vs 2C	IS, MBL, STR, PES, PPD, BI

10	Palatella 2008	Italy	16	35	NR	NR	excluded	24	1A vs 2A	IS, MBL
11	Block 2009	USA	76	NR	NR	NR	NR	24	1A vs 4A	IS, MBL
12	Gjelvold 2021	Sweden, Malmö	50	40.85 (14.29)	42	NR	NR	60	4A vs 4C	MBL, BI
12	Gjelvold 2017	Sweden, Malmö	50	40.85 (14.29)	42	NR	NR	12	4A vs 4C	IS, MBL, STR, PES, VAS
13	Deigdi 2009	Italy	60	31.5 (11.8)	NR	NR	excluded	12/24/36	4A vs 4C	IS, MBL, BI
14	den Hartog 2016	Netherlands	62	39.25 (14.08)	62	excluded	excluded	60	4A vs 4C	MBL, STR
14	den Hartog 2011	Netherlands	62	39.25 (14.08)	62	excluded	excluded	18	4A vs 4C	IS, MBL, STR, PES, VAS, BI
15	Hall 2007	New Zealand	28	43.25	19	9	excluded	12	4A vs 4C	IS, MBL, STR
15	Hall 2006	New Zealand	28	43.25	NR	NR	excluded	12	4A vs 4C	IS, MBL
16	Liu 2016	China	92	28.85 (6.83)	92	excluded	excluded	12	1C vs 3C	IS, PES, PPD, BI
17	Lu 2018	China	150	35.11 (6.47)	NR	NR	excluded	12	1A vs 3C	IS, MBL, PES
18	Song 2020	China	44	31.45 (2.88)	NR	NR	NR	12	1A vs 1C	IS, MBL, PES, VAS
19	Huang YB 2020	China	78	35.6	78	excluded	excluded	12	1A vs 4C	IS, MBL, PES
20	Niu 2019	China	86	43.12 (2.22)	NR	NR	NR	12	1A vs 4C	IS, MBL, PES, VAS

21	Zhang Z 2017	China	60	31.81 (6.96)	60	excluded	excluded	36	1A vs 4C	MBL, PES, WES
22	Zhou 2019	China	82	32.24 (4.15)	82	excluded	excluded	12	1A vs 4C	IS, MBL, PES, WES, VAS
23	Sui 2017	China	36	34.95	36	excluded	excluded	12	1A vs 4A	IS, MBL, PES
24	Wang CM 2018	China	60	37.61 (3.16)	NR	NR	NR	12	4A vs 4C	IS, MBL, VAS
25	Li 2019	China	184	32.61 (5.41)	184	excluded	excluded	12	1A vs 1C	IS, PES, VAS
26	Ning 2016	China	45	34.07	45	excluded	excluded	12	1A vs 1C	IS, PES, VAS
27	Tan 2014	China	36	37	36	excluded	excluded	12	1A vs 1C	IS, PES
28	Zhen 2017	China	40	36.75 (3.75)	NR	NR	NR	24	1C vs 2C	IS
29	Ni 2019	China	40	31.53 (5.34)	NR	NR	NR	12	1A vs 3A	IS, PES, VAS, PPD
30	Xu 2021	China	90	33.07 (3.59)	NR	NR	NR	12	1A vs 3C	IS, PES, VAS
31	Cheng 2018	China	64	32.55 (2.12)	NR	NR	excluded	12	1A vs 4C	IS
32	Gui 2017	China	100	38.9 (8.77)	100	excluded	excluded	24	1A vs 4C	PES, VAS
33	Huang X 2019	China	86	37.38 (5.26)	NR	NR	NR	12	1A vs 4C	IS, PES, VAS, PPD
34	Zeng 2019	China	80	32.55 (4.42)	80	excluded	excluded	12	1A vs 4C	IS, PES, VAS, BI

35	Zhang P 2022	China	148	36.18 (3.39)	NR	NR	NR	12	1A vs 4C	IS, PES, WES, VAS, BI
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BI=bleeding index; IS=implant survival; MBL=marginal bone loss; PES=pink esthetic score; PPD=periodontal probing depth; STR=soft tissue recession; VAS=visual analog scale; WES=white esthetic score.

Appendix Table 2. Intervention characteristics of the included primary studies for the first study (53).

Study number	Author, year	Intervention	Implant type	Tissue graft	Healing	Prosthetic material	Screwed/ cemented
1	Tonetti 2017	1C	SPI contact; Thommen Medical	bone and membrane	open - non-anatomic	NR	NR
		3C	SPI contact; Thommen Medical	bone and membrane	open - non-anatomic	NR	NR
2	Slagter and Meijer 2016,2017,2021	1C	NobelActive; Nobel Biocare	autogenic and anorganic bone and autogenic epithelialized soft tissue	closed	PFZ	14 screwed and 6 cemented
		3C	NobelActive; Nobel Biocare	autogenic and anorganic bone and autogenic epithelialized soft tissue	closed	PFZ	12 screwed and 8 cemented
3	Slagter and Raghoobar 2015,2017,2021	1A	NobelActive; Nobel Biocare	autogenic and anorganic bone and autogenic epithelialized soft tissue	open - anatomic	PFZ	14 screwed and 6 cemented
		1C	NobelActive; Nobel Biocare	autogenic and anorganic bone and autogenic epithelialized soft tissue	closed	PFZ	12 screwed and 8 cemented
4	Chan and Bushari 2019, 2021	1A	IS II Active; Neobiotech	allogenic bone	open - anatomic	ceramic	cemented
		1C	IS II Active; Neobiotech	allogenic bone	open - non-anatomic	ceramic	cemented

5	Crespi 2008	1A	Outlink; Sweden & Martina	NR	open - anatomic	PFM	cemented
		1C	Outlink; Sweden & Martina	NR	closed	PFM	cemented
6	Crespi 2018	1A	Outlink; Sweden & Martina	NR	open - anatomic	PFZ	cemented
		1C	Outlink; Sweden & Martina	NR	closed	PFZ	cemented
7	De Rouck 2009	1A	NobelReplace; Nobel Biocare	xenogenic bone	open - anatomic	PFM	NR
		1C	NobelReplace; Nobel Biocare	xenogenic bone and mebrane	closed	PFM	NR
8	Cardaropoli 2022 I. and II.	1C	BLT; Straumann Group	xenogenic bone	open - non-anatomic	ceramic	NR
		4B	BLT; Straumann Group	xenogenic bone and mebrane	closed	ceramic	NR
9	Puisys 2022	1A	BLT; Straumann Group	allogenic bone and autogenic connective tissue	open - anatomic	PFZ	screwed
		2C	BLT; Straumann Group	allogenic bone and autogenic connective tissue	closed	PFZ	screwed
10	Palatella 2008	1A	TE; Straumann Group	NR	open - anatomic	7 PFM, 2 ceramic	screwed and cemented

		2A	TE; Straumann Group	NR	open - anatomic	PFM	screwed and cemented
11	Block 2009	1A	Certain; Zimmer Biomet	allogenic bone	open - anatomic	PFM	cemented
		2A	Certain; Zimmer Biomet	allogenic bone	open - anatomic	PFM	cemented
12	Gjelvold 2017,2021	4A	Tapered Internal; BioHorizons	autogenic bone	open - anatomic	PFZ	15 screwed and 10 cemented
		4C	Tapered Internal; BioHorizons	autogenic bone	closed	PFZ	15 screwed and 9 cemented
13	Deigdi 2009	4A	XiVE Plus; Dentsply Sirona	none	open - anatomic	NR	NR
		4C	XiVE Plus; Dentsply Sirona	none	open - non-anatomic	NR	NR
14	den Hartog 2011,2016	4A	NobelReplace; Nobel Biocare	autogenic and xenogenic bone and membrane	open - anatomic	PFZ	12 screwed and 18 cemented
		4C	NobelReplace; Nobel Biocare	autogenic and xenogenic bone and membrane	closed	PFZ	12 screwed and 19 cemented
15	Hall 2006,2007	4A	NR; Southern Implants	bone	open - anatomic	PFM	screwed
		4C	NR; Southern Implants	bone	closed	PFM	screwed

16	Liu 2016	1C	NR; Straumann Group	NR	open - anatomic	PFM	NR
		3C	NR; Straumann Group	GBR	NR	PFM	NR
17	Lu 2018	1A	NR	autogenic or xenogenic bone	open - anatomic	PFM, PFZ	NR
		3C	NR	autogenic or xenogenic bone	open - non-anatomic	PFM, PFZ	NR
18	Song 2020	1A	NR	xenogenic bone and mebrane	open - anatomic	NR	NR
		1C	NR	xenogenic bone and mebrane	open - non-anatomic	NR	NR
19	Huang YB 2020	1A	NR	xenogenic bone and mebrane	open - anatomic	NR	NR
		4C	NR	xenogenic bone and mebrane	closed	NR	NR
20	Niu 2019	1A	NR	NR	open - anatomic	NR	NR
		4C	NR	NR	closed	NR	NR
21	Zhang Z 2017	1A	NR	NR	open - anatomic	NR	NR
		4C	NR	NR	closed	NR	NR
22	Zhou 2019	1A	NR; Osstem Implant	bone and membrane	open - anatomic	ceramic	NR
		4C	NR; Osstem Implant	bone and membrane	closed	ceramic	NR

23	Sui 2017	1A	NR; Straumann Group	xenogenic bone and collagen membrane	open - anatomic	NR	NR
		4A	NR; Straumann Group	xenogenic bone and collagen membrane	open - anatomic	NR	NR
24	Wang CM 2018	4A	NR	NR	open - anatomic	ceramic	NR
		4C	NR	NR	closed	ceramic	NR
25	Li 2019	1A	TSIII; Dio Implant	xenogenic bone	open - anatomic	ceramic	NR
		1C (closed healing)	TSIII; Dio Implant	xenogenic bone	closed	ceramic	NR
		1C (open healing)	TSIII; Dio Implant	xenogenic bone	open - non-anatomic	ceramic	NR
26	Ning 2016	1A	TSIII; Osstem Implant	xenogenic bone and autogenic soft tissue	open - anatomic	PFM	NR
		1C (closed healing)	TSIII; Osstem Implant	xenogenic bone and autogenic soft tissue	closed	PFM	NR
		1C (open healing)	TSIII; Osstem Implant	xenogenic bone and autogenic soft tissue	open - non-anatomic	PFM	NR
27	Tan 2014	1A	NR; Osstem Implant	none	open - anatomic	NR	NR
		1C	NR; Osstem Implant	none	closed	NR	NR
28	Zhen 2017	1C	NR; Anthogyr, Straumann Group	xenogenic bone and membrane, autogenic soft tissue	closed	ceramic	NR

		2C	NR; Anthogyr, Straumann Group	xenogenic bone and membrane, autogenic soft tissue	closed	ceramic	NR
29	Ni 2019	1A	NR; Ankylos, Dentsply Sirona	xenogenic bone	open - anatomic	NR	NR
		3A	NR; Ankylos, Dentsply Sirona	xenogenic bone	open - anatomic	NR	NR
30	Xu 2021	1A	NR	bone and membrane	open - anatomic	NR	NR
		3C	NR	bone and membrane	closed	NR	NR
31	Cheng 2018	1A	NR	NR	open - anatomic	NR	NR
		4C	NR	NR	NR	NR	NR
32	Gui 2017	1A	XiVE; Dentsply Sirona	xenogenic bone and membrane	open - anatomic	NR	NR
		4C	XiVE; Dentsply Sirona	xenogenic bone and membrane	closed	NR	NR
33	Huang X 2019	1A	NR; BEGO	xenogenic bone and membrane	open - anatomic	NR	NR
		4C	NR; Straumann Group	xenogenic bone and membrane	open - anatomic	NR	NR
34	Zeng 2019	1A	NR; Straumann Group	NR	open - anatomic	NR	NR
		4C	NR; Straumann Group	NR	closed	NR	NR

35	Zhang P 2022	1A	NR; Osstem Implant	xenogenic bone and membrane	open - anatomic	ceramic	NR
		4C	NR; Osstem Implant	xenogenic bone and membrane	closed	ceramic	NR

GBR=guided bone regeneration; PFM=porcelain fused to metal; PFZ=porcelain fused to zirconia; NR=not reported.

Appendix Table 3. Characteristics of the included primary studies for the second study.

Study number (+/- inclusion in meta-analysis)	Author, year	Study design	Region of interest	Sample size	Surgical protocol					Intervention / Healing protocol			Prosthetic protocol	
					Implant type	Guide	Implant position	Insertion torque (Ncm)	Graft	PR/AHA/CHA	HA size (mm)	PR occlusion	Material	Screw/cement retained
1. -	Amato, 2018	retrospective follow-up of RCT	anterior maxilla or mandible	20	Biomet 3i tapered internal or external hex	yes	NR	>=50	none	PR	-	no	NR	screw
				<50				CHA		NR	-			
				34				>=50	50-50 mixture of autogenous and bovine graft (0.5-1.0mm Endobon, Biomet)	PR	-	no		
				13				<50	CHA	NR	-			
2. -	Amato, 2022	RCT	6/7 maxilla or mandible	33	Biomet 3i tapered	yes	4mm subgingival, 2mm subcrestal	>=50	none, only collagen sponge	PR	-	no	NR	screw
				32				AHA		custom	-			
				67				CHA		5	-			
				64						6	-			
				71						7.5	-			
3. +	Amato, 2023	retrospective follow-up of RCT	4/5 maxilla or mandible	40	Biomet 3i tapered internal or external hex	yes	4-5mm subgingival	>=50	50-50 mixture of autogenous and anorganic bovine graft (Endobon, Biomet)	PR	-	yes	PFM of full Zr	screw
				33						PR	-	no		
				53						CHA	5	-		
4. -	Arora, 2018	retrospective cohort	anterior maxilla	20	Astratech OsseoSpeed, Dentsply Sirona	no	NR	>=30	deproteinised bovine bone particles (Bio-Oss)	PR	-	no	Ti or Zr base with PFM or Zr crown	cement
				20						CHA	5	-		

5. +	Chan, 2019	RCT	anterior maxilla	20	IS II active, Neobiotech	no	3mm subgingival	>=30	cancellous particulate allograft (Puros®, Zimmer Biomet)	PR	-	no	ceramic, Ti-base, Zr abutment	cement
	Wang, 2020			CHA						socket-size	-			
				PR						-	no			
				CHA						socket-size	-			
		PR	-	no										
		CHA	socket-size	-										
Busharhi, 2021	retrospective follow-up of RCT	16	12											
6. +	Chokaree, 2024	RCT	maxilla or mandible	16	CMI IS-III Active, Neobiotech Co.	yes	1mm subcrestal	>=30	jumping gap >=2 mm filled with bone grafting material	AHA	custom	-	ceramic, Ti-base, Zr abutment	screw
				6						CHA	NR	-		
7. +	El-Danasy, 2023	RCT	anterior maxilla	12	Oxy implant K1, Biomec SRL	yes	NR	NR	jumping gap >2mm grafted with bovine xenograft (MedPark S1 Dental)	AHA	custom	-	full Zr on Ti-base	screw
				12						CHA	socket-size	-		
8. +	Fu, 2023	RCT	anterior maxilla	35	Seven, MIS	no	NR	NR	jumping gap filled with freeze-dried bone allograft (OraGraft, LifeNet Health)	PR	-	no	NR	screw
				35						CHA	NR	-		
9. +	Grandi, 2015	RCT multicenter	maxilla or mandible	35	JD Evolution, J Dental Care	no	1mm subcrestal, slightly palatal	>=45	jumping gap with anorganic bovine bone granules BioOss; collagen fleece over graft if needed,	PR	-	no	PFM	screw/ cement
				35						CHA	NR	-		

									Medicipio C Collagen Fleece					
10. +	Hassani, 2021	retrospective cohort	anterior maxilla	20	Superline, Dentium	no	NR	NR	jumping gap >2mm filled with biphasic calcium phosphate, Osteon II, Genoss	PR	-	no	PFZ	screw/ cement
				20						CHA	NR	-		
11. +	Li, 2019	RCT	anterior maxilla	61	TSIII, DIO	no	palatal	>=35	Bio-oss, Geistlich	PR	-	yes	ceramic, custom abutment	NR
				62						CHA	NR	-		
12. +	Ning, 2016	RCT	anterior maxilla	15	TSIII, DIO	no	palatal	>=35	Bio-oss, Geistlich and VIP-VT flap	PR	-	no	ceramic, custom abutment	NR
				15						CHA	NR	-		
13. +	Perez, 2020	RCT	anterior maxilla or mandible	18	BLT, Straumann AG	no	crestal	NR	alloplastic bone substitute (GUIDOR easy-graft CRYSTAL, Sunstar Suisse SA) and resorbable membrane (Evolution, Osteobiol-Tecno ss)	AHA	custom	-	NR	NR
				18						CHA	NR	-		
14. +	Song, 2020	retrospective cohort	anterior maxilla	32	ITI soft tissue horizontal implant, Straumann AG	no	palatal, 1-3mm subcrestal	>=35	artificial bone (Engineering Research Centre in Biomaterials, Sichuan University) in gaps >2mm at	PR	-	no	NR	NR

									2-3mm above the bottom of the alveolus, Bio-Oss in gaps >1mm					
				35				<35	guided bone regeneration	CHA	NR	-		
15. -	Su, 2021	retrospective cohort	anterior maxilla	40	NobelActive, Nobel Biocare	yes	NR	>=35	deproteinized bovine particles (Bio-Oss, Geistlich Pharma AG), collagen membrane (Bio-Gide, Geistlich Pharma)	PR	-	no	NR	NR
			40						CHA	NR	-			
16. -	Tarnow, 2014	retrospective cohort	anterior maxilla	17	Tapered non-platform-switched internal-connection implants	no	palatal, 3-4 mm subgingival	>=35	none	PR	-	no	PFM of full ceramic	screw/cement
	5			CHA						NR	-			
	17			small-particle bone allograft					PR	-	no			
	10								CHA	NR	-			
	Chu, 2015			17					none	PR	-	no		
				5						CHA	NR	-		
				17					small-particle bone allograft	PR	-	no		
				10						CHA	NR	-		
17. +	Elgendi, 2025	RCT	posterior maxilla	10	ROOTT, TRATE AG.	yes	interseptal bone, 3mm below neighboring teeth CEJ	>=35	bone xenograft (Bioteck Bio-Gen Granules, Belgium)	AHA	custom	-	PFZ	screw
				10					bone xenograft (Bioteck	CHA	NR	-	PFZ	screw

									Bio-Gen Granules, Belgium), collagen sponge					
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Studies marked with (+) in the “Study number” column provided data for quantitative meta-analysis, those marked with (-) did not.

AHA=anatomic healing abutment, CHA=cylindrical healing abutment, HA=healing abutment, NR=not reported, PFM=porcelain-fused-to-metal restoration, PFZ=porcelain-fused-to-zirconium-dioxide restoration, PR=provisional restoration, RCT=randomized controlled trial, Ti=titanium, Zr=zirconium-dioxide

Appendix Table 4. Characteristics of the included primary studies for the third study (50).

Author, Year	Study type	Sample size	Implant position and type	Impression technique		Intraoral scanner type	Cast type	Prosthetic restoration	Esthetic outcome	Main findings
				Conventional	Digital					
Agnini 2023	case report	1	21, NR	-	provisional in-situ + scanbody + indirect	NR	NR	screw-retained zirconia crown	-	new technique for EP replication
Canullo 2018	comparative case report	2	11, PRAMA	customized impression coping	provisional in-situ + scanbody + indirect	Carestream, CS3600	stone (case1); digital (case2)	zirconia abutment + cemented lithium disilicate crown	PES: analog 8, digital 9	3-year success for both analog and digital pathway
Crockett 2019	dental technique	1	22, NR	-	provisional in-situ + scanbody + indirect	3Shape, TRIOS	NR	NR	-	new technique for EP replication
da Silva Marques 2019	cross-over pilot study	6	maxillary esthetic zone, NR	customized impression coping	direct EP scan	3Shape, TRIOS	stone vs digital	NR	-	EP from immediate direct scanning showed significant differences
Dada 2021	case report	1	21, Straumann	-	provisional in-situ + indirect with repositionable analogue	3Shape, TRIOS	3D-printed	zirconia abutment + ceramic veneering	-	new technique with repositionable analogue

										for EP replication
Dhingra 2020	dental technique	1	21, Straumann	-	provisional in-situ + direct + scanbody + indirect	3Shape, TRIOS3	digital	full-contour lithium disilicate crown	-	new technique for EP replication
Doliveux 2020	dental technique	1	12, Straumann	-	provisional in-situ + scanbody + indirect	3Shape, TRIOS	3D-printed	NR	-	new technique for EP gingival mask fabrication on 3D-printed cast
Duran 2018	cross-over study	10	maxillary esthetic zone, Biohorizons	provisional served as impression coping	direct EP scan	Cerec Omnicam	stone vs digital	NR	-	EP from immediate direct scanning showed significant differences
Galibourg 2021	cross-sectional study	16	maxillary esthetic zone, NR	-	direct EP scan at 0 s, 30 s, 2 m, 5 m	Planmeca	-	-	-	significant EP collapse after 30 seconds compared to immediate direct EP scan
Joda 2014	case report	1	22, Straumann	-	customized scanbody with	iTero	NR	zirconia abutment +	PES: 9	new technique for mucosal

					conventional customization technique			ceramic veneering		margin replication, but submucosal part of EP can't be captured
Joda 2015	cross-sectional study	5	maxillary esthetic zone, Straumann	-	direct EP scan at 0 s, 5 m, 10 m	iTero	-	-	-	slight EP change after 5 min, more significant after 10 min compared to immediate direct EP scan
Lee 2016	case report	1	36, NR	-	provisional in-situ then continued indirect scanning extraoral + scanbody	3Shape, TRIOS Color Pod	digital	customized titanium abutment + zirconia crown	-	new technique for EP replication
Li 2019	cross-sectional study	12	maxillary esthetic zone, NR	-	[provisional in-situ + indirect] vs [direct EP scan at 0 s, 30 s, 1 m, 2 m, 3 m, 4 m, 6 m, 8 m, 10 m, 20 m]	3Shape, TRIOS Color Pod	-	-	-	slight EP change at immediate direct EP scan that increased gradually compared to indirect EP scan

Lin 2013	dental technique	4	14,13,23, 24, Straumann	diagnostic impression with provisional in-situ	scanbody	iTero	milled polyurethane	-	-	new technique for EP gingival mask fabrication on milled cast
Ling 2023	randomized controlled trial	22	Maxillary, esthetic zone, Straumann, Nobel Biocare	-	[direct EP scan] vs [indirect EP scan] + provisional in-situ + scanbody	3Shape, TRIOS3	3D-printed	customized titanium abutment + zirconia crown with direct vs indirect pathway	PES: direct 7.89 ± 1.52 , indirect 8.09 ± 2.27	Indirect scanning accurately replicates soft tissue profiles, while there is a collapse with the direct technique
Liu 2017	case report	3	11, 21, 22, NR	-	provisional in-situ + scanbody + indirect	3Shape, TRIOS	3D-printed	-	-	new technique for EP replication
Mesquida 2024	case report	1	11, Nobel Biocare	-	provisional in-situ + scanbody + indirect	3Shape, TRIOS3	digital	NR	NR	new technique for EP replication
Mino 2019	case report	1	47, Straumann	-	provisional in-situ + scanbody + indirect	3Shape, TRIOS2	digital	customized titanium abutment + zirconia crown	-	new technique for EP replication

Monaco 2016	case report	1	11, Straumann	-	provisional in-situ + scanbody + indirect	3M ESPE	3D-printed	zirconia abutment + ceramic veneering	-	new technique for EP replication
Monaco 2019	dental technique	NR	esthetic zone	-	[direct EP scan] vs [provisional in-situ + scanbody + indirect]	NR	-	-	-	direct scanning requirements : no soft tissue collapse within 1 min, short, wide, and conical EP shape; proposed protocol for direct and indirect multiscan techniques
Tanaka 2023	case report	1	13, Straumann	-	provisional in-situ + scanbody + indirect	3Shape, TRIOS3	digital	titanium-base + monolithic zirconia crown	-	fully digital technique with no need for a physical cast
Xiong 2022	cross-over study	16	maxillary esthetic zone, NR	provisional served as impression coping	[provisional in-situ + indirect] vs [immediate direct EP scan]	3Shape, TRIOS	stone vs digital	-	-	accurate EP replication with indirect multiscan technique; rapid EP collapse with

										immediate direct EP scan
Yilmaz 2020	case report	1	46, Neoss	-	stock anatomic healing abutment with connectable scanbody	3Shape, TRIOS	digital	customized titanium abutment + zirconia crown	-	new combined healing abutment-scanbody implant system
Zimmermann 2022	case report	1	14, S.I.N.	partial arch impression with provisional in-situ	provisional in-situ + direct + scanbody + indirect with provisional in the conventional impression	3Shape, TRIOS 3	digital	lithium disilicate crown	-	new technique for EP replication

EP=emergence profile, NR=not reported

Appendix Document 1. Publication related to Study I.



SYSTEMATIC REVIEW

Comparison of implant placement and loading protocols for single anterior maxillary implants: A systematic review and network meta-analysis



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ABSTRACT

Statement of problem. With increasing esthetic needs, patients prefer missing anterior teeth to be restored as soon as possible, but how the timing of implantation and prosthetic loading influences peri-implant tissue and the esthetic results remains unclear.

Purpose. The purpose of this systematic review and network meta-analysis of randomized controlled trials was to investigate and rank the hard-tissue and soft-tissue outcomes, esthetics, and patient satisfaction of single maxillary implant placement and loading protocols.

Material and methods. A systematic search was conducted to identify studies with at least a 1-year follow-up that compared different implant placement and loading protocols and reported on survival, marginal bone loss (MBL), soft tissue, and esthetics. A random effects model and a Bayesian approach were applied to compare protocols by using mean differences (MD) with 95% credible intervals (CrI) and surface under the cumulative ranking curve (SUCRA) values.

Results. A total of 43 articles were included, with a follow-up of 1 to 5 years. All protocols had high survival rates and no significant differences for 1-year or 2-year MBL. Immediate placement with immediate loading ranked first in pink and white esthetic scores and satisfaction and was statistically significantly better than immediate placement with delayed loading or late placement protocols in pink esthetic scores, where its advantage over late placement with late loading was also clinically relevant [MD: -1.74, CrI: -2.34 to -1.15].

Conclusions. Immediate implantation with immediate loading showed a considerable esthetic advantage over later rehabilitation, whereas only a slight difference in MBL resulted from different protocols. (*J Prosthet Dent* 2025;133:677-688)

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Clinical Implications

Immediate implant placement and loading performed best in pink and white esthetics and patient satisfaction and also ranked well in other aspects, whereas delayed treatments often ranked last. Immediate implant placement and loading is highly recommended when the clinical criteria are fulfilled.

Dental rehabilitation in the esthetic region is always challenging, especially when placing single maxillary anterior implant-supported crowns. Thin buccal bone and rapid bone resorption complicate correct implant positioning, prosthetic design, and supportive therapy, the basis of long-term success.¹⁻⁴ Given patient demands for excellent esthetics and short rehabilitation times, individual treatment plans must be based on the latest scientific and clinical evidence to ensure optimal outcomes. The timing of implant-prosthetic rehabilitation may affect the amount of bone resorption and could also be crucial for soft tissue changes.⁵⁻⁸ According to the 2018 Consensus report of the International Team for Implantology (ITI), the timing of implantation and loading should always be considered together and decided upon tooth extraction. Twelve implant placement and loading protocols (IPLPs) have been defined (Table 1).⁹

Although authors have emphasized that immediate implantation may preserve alveolar bone and the soft tissue contour compared with delayed implantation, mid-facial gingival recession commonly occurs, especially in patients with thin mucosal phenotypes.^{8,10} However, few authors have discussed the effect of early treatment protocols, even though they may integrate the benefits of immediate and delayed protocols.^{3,5} The authors are unaware of a comprehensive review that analyzed and ranked all IPLPs according to their effects on both hard and soft tissue parameters in the anterior maxilla.

Table 1. Implant placement and loading protocols. Numbers refer to timing of implant placement and letters to that of prosthetic loading.⁹

Protocol 1A:	Immediate implantation + immediate restoration
Protocol 1B:	Immediate implantation + early loading
Protocol 1C:	Immediate implantation + conventional loading
Protocol 2A:	Early implantation with soft tissue healing + immediate restoration
Protocol 2B:	Early implantation with soft tissue healing + early loading
Protocol 2C:	Early implantation with soft tissue healing + conventional loading
Protocol 3A:	Early implantation with partial bone healing + immediate restoration
Protocol 3B:	Early implantation with partial bone healing + early loading
Protocol 3C:	Early implantation with partial bone healing + conventional loading
Protocol 4A:	Late implantation + immediate restoration
Protocol 4B:	Late implantation + early loading
Protocol 4C:	Late implantation + conventional loading

The aim of this systematic review and network meta-analysis was to compare the survival, marginal bone loss, pink and white esthetics, satisfaction, and soft-tissue outcomes of all 12 types of IPLPs for single maxillary anterior implants and to rank these protocols based on randomized controlled trials (RCTs). The null hypothesis assumed that all IPLPs have similar performances with no significant differences in any aspect investigated.

MATERIAL AND METHODS

This review followed the Cochrane Handbook and was reported according to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines (Supplemental Table 1, available online).¹¹⁻¹³ The protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO) (registration number CRD42022364995).

The population was healthy adults requiring a single tooth replacement with implantation in the anterior maxilla (until the second premolars). The intervention and comparison were participants receiving treatment according to different IPLPs. The outcomes were implant survival, marginal bone loss, soft tissue changes, esthetics, and satisfaction at a minimum of a 1-year follow-up. Studies were excluded if they did not comply with this framework or included participants with acute periapical or periodontal infection, parafunctional movements, or multiple adjacent implants.

A systematic search was conducted in 7 electronic databases: MEDLINE (PubMed), Embase, Cochrane CENTRAL, Web of Science, China National Knowledge Infrastructure (CNKI), Wanfang Data, and Chinese Scientific Journal Database (VIP database) in October 2022 and last updated in January 2024. A date filter was applied for publications since January 2000. The search keys applied for the systematic search can be found in Supplemental Table 2 (available online).

Two authors (X.Q., B.V.) independently screened the search results by title, abstract, and full text; collected data in a spreadsheet (Excel; Microsoft Corp) by extracting the first author, year of publication, study population, interventions, and outcomes; and assessed risk of bias (RoB) using the Cochrane RoB 2 tool.¹¹ Disagreements were resolved by a third author (K.K.). The certainty of evidence was determined using the Confidence in Network Meta-Analysis (CINeMA) web application.^{14,15}

Pairwise and network meta-analyses (NMAs) were conducted using random-effects models with Bayesian methods. The synthesis of each outcome began with creating a network plot to determine whether the network was fully connected. Consistency checks were excluded by the visual inspection of plots. Mean differences (MDs) with 95% credible intervals (CrIs) were calculated for continuous

data. Network estimates (pooled estimates of direct and indirect data) for each intervention were ranked relative to each other. Interventions were ranked according to their posterior likelihood by calculating the surface under the cumulative ranking (SUCRA) curve values. Cumulative probabilities for each treatment were expressed as single values ranging from 0% to 100%. The higher the percentage or the SUCRA score, the more likely the intervention would be the best or one of the best. All the NMAs were consistent. All computations were performed using statistical software packages (R v4.1.1 and BUGSnet v1.1.0; R Foundation).

The proportion with a 95% confidence interval (CI) was used for the measurement of the effect size for cumulating implant survival rates. As considerable between-study heterogeneity was assumed in all cases, effect sizes were pooled with a random-effects model. Between-study heterogeneity was described by the Higgins and Thompson I^2 statistics.¹⁶ All statistical analyses were performed with the meta (v6.2.1) package for basic meta-analysis calculations and plots and the dmetar (v0.0.9000) package for additional influential analysis calculations and plots in R (v4.1.2; R Foundation).^{17–19} The inverse variance method was used to pool proportions. A Hartung-Knapp adjustment was applied for CIs.^{20,21} The Clopper-Pearson method was used for the CI of proportion calculation of individual studies.²²

For a cell count of 0, the individual study proportion with 95% CI was calculated by adding 0.01 as a continuity correction.

RESULTS

Forty-three articles were selected (Fig. 1). The characteristics of each study are included in Supplemental Tables 3 and 4 (available online).^{23–65}

The results of study-level and domain-level RoB are shown in Supplemental Figure 1–8 (available online). Most studies carried no risk, whereas some studies raised some concerns, mainly because of missing outcome data, possible selection of data, and the randomization process. The certainty of evidence was often moderate to low due to imprecision, heterogeneity, and incoherence (Supplemental Tables 5–10, available online).

Thirty-three studies were analyzed for 1-year implant survival (IS), but an NMA was not feasible because of the low number of implant failures; thus, for this outcome only, cumulated IS rates with 95% CI were calculated for each protocol by using a proportional meta-analysis.^{23,25–32,35–41,45,46,48–62,64,65} Survival rates were 1A (N=762) =91% (CI: 86%, 94%), 1C (N=477) =96% (CI: 92%, 98%), 2C (N=45) =100% (CI: 100%, 100%), 3C (N=168) =100% (CI: 100%, 100%), 4A (N=178) =96%

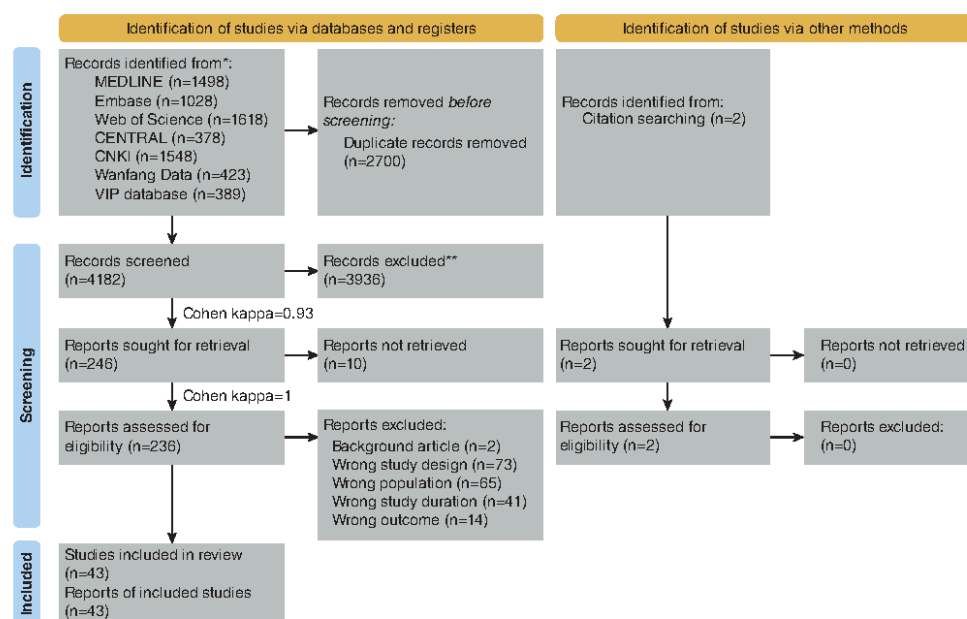


Figure 1. Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 flowchart of study selection process.

(CI: 93%, 98%), and 4C (N=517) =98% (CI: 94%, 99%) (Supplemental Figs. 9–14, available online).

Eighteen studies (N=1055)^{25,27,30–32,35–37,39–41,49,52,55–57,59,63,65} were analyzed for 1-year marginal bone losses (MBLs) by comparing 7 protocols (Supplemental Figs. 15, 16, available online). The SUCRA values for each protocol in descending order were 4B=88.16%, 4A=71.5%, 1A=62.26%, 2C=39.95%, 1C=37.56%, 4C=25.36%, and 3C=25.18% (Fig. 2). Five studies (N=209) were synthesized for 2-year MBLs by comparing 5 protocols.^{23,27,29,31,38} The SUCRA values were 2A=67.26%, 1C=58.49%, 1A=58.14%, 4A=44.31%, and 4C=21.79% (Fig. 3). No statistically or clinically significant differences were reported among protocols at 1 or 2 years.

Separate data of 1-year mid-facial, mesial, and distal soft tissue recession (STR) were available for quantitative synthesis (Fig. 4, Supplemental Figs. 17–19, available

online). Six studies (N=262) were synthesized for mid-facial STR by comparing 5 protocols.^{26,27,30,32,35–37,39–41}

SUCRA values were 2C=73.2%, 1A=63.64%, 4B=50.45%, 1C=37.64%, and 3C=25.07%. The same 5 studies (N=212) were synthesized for mesial and distal STR, by comparing 4 protocols. For mesial STR, SUCRA values were 4B=63.05%, 1C=55.21%, 3C=44.91%, and 1A=36.83%. SUCRA values for distal STR were 1A=56.85%, 4B=53.08%, 3C=50.17%, and 1C=39.91%. No statistically or clinically significant differences were reported among protocols.

Twenty-two studies (N=1665) were analyzed for 1-year pink esthetic score (PES), by comparing 8 protocols (Supplemental Fig. 20, available online).^{26,32,35,39–41,47–58,60–62,65} SUCRA values were 1A=89.61%, 2C=76.71%, 3A=64.77%, 1C=52.21%, 4B=47.58%, 4A=34.4%, 4C=23.67%, and 3C=11.05%.

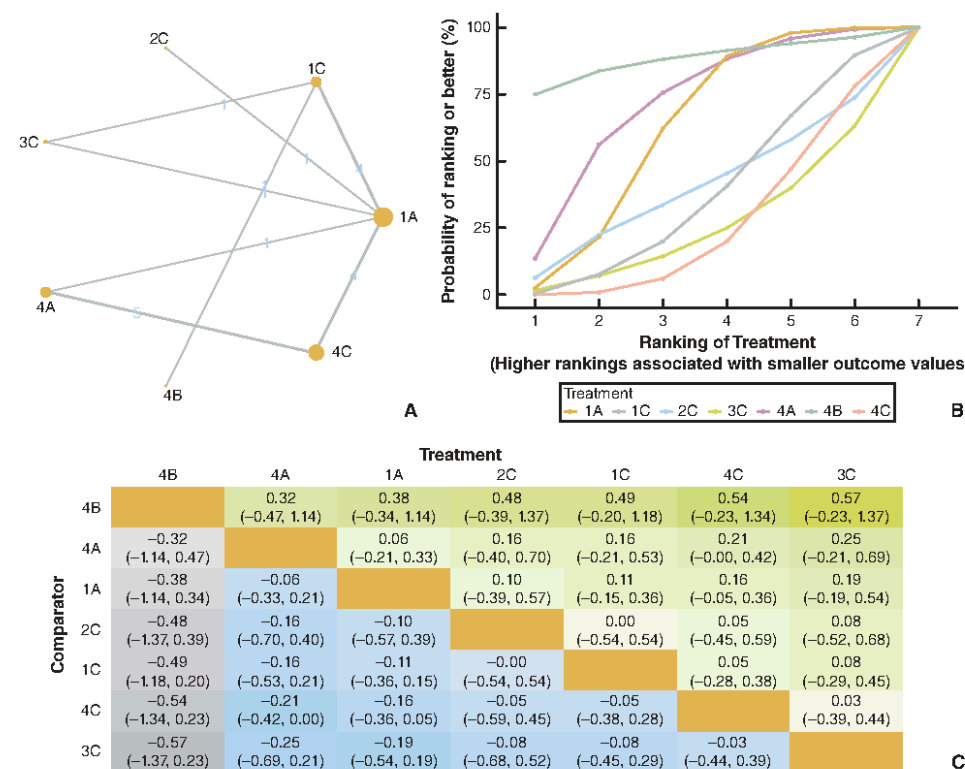


Figure 2. A, 1-year marginal bone loss (MBL) network diagram. Nodes indicate investigated protocols, and edge thickness refers proportionally to number of studies included. B, 1-year MBL SUCRA curves. X axis shows number of possible rankings matching number of protocols analyzed. Y axis indicates probability (%) to reach given rank or higher. C, 1-year MBL league plot showing mean differences and credible intervals in mm between protocols ordered from best to worst starting at top-left corner. Values above and below gray grids show same differences in opposite direction. No significant differences observed.

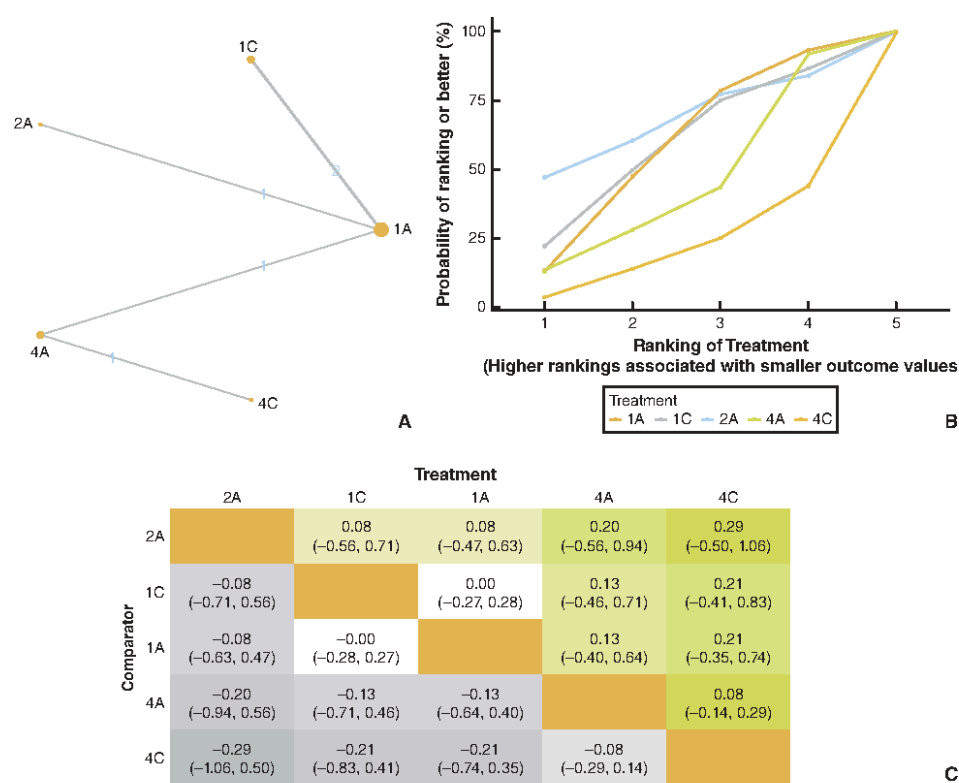


Figure 3. A, Two-year marginal bone loss (MBL) network diagram. Nodes indicate investigated protocols, and edge thickness refers proportionally to number of studies included. B, 2-year MBL SUCRA curve. X axis shows number of possible rankings matching number of protocols analyzed. Y axis indicates probability (%) to reach given rank or higher. C, 2-year MBL league plot showing mean differences and credible intervals in mm between protocols ordered from best to worst starting at top-left corner. Values above and below gray grids show same differences in opposite direction. No significant differences observed.

Differences among protocols 1A-1C [MD: -1.11, CrI: -1.91 to -0.25], 1A-4A [MD: -1.53, CrI: -2.65 to -0.32], 1A-4C [MD: -1.74, CrI: -2.34 to -1.15], and 1A-3C [MD: -2.17, CrI: -3.37 to -0.93] were statistically significant (the CrI does not contain the null effect). The clinical significance threshold was 1; thus, only the difference in protocols 1A-4C was clinically relevant considering the whole CrI (Fig. 5).

Four studies (N=310) were analyzed for 1-year white esthetic score (WES), by comparing 4 protocols (Supplemental Fig. 21, available online).^{40,41,62,65} The difference between 1A-4C [MD: -1.41, CrI: -2.66 to -0.15] was statistically significant but not clinically relevant (Supplemental Fig. 22, available online).

Thirteen studies (N=982) were analyzed for 1-year satisfaction measured with a visual analog scale (VAS),

comparing 6 protocols (Supplemental Fig. 23, available online).^{32,35,40,41,47,48,50,53,55,56,60,61,65} SUCRA values were 1A=84.85%, 3C=51.81%, 4A=48.74%, 1C=40.59%, 4C=37.27%, and 3A=36.75%. Though protocol 1A was much more likely to be ranked first, no statistically significant differences were found among the protocols (Fig. 6).

Seven studies (N=462) were analyzed for 1-year change in peri-implant probing depth (PPDc), comparing 6 protocols (Supplemental Figs. 24, 25, available online).^{39-41,45,48,51,53} Another 7 studies (N=517) were analyzed for 1-year bleeding index (BI), comparing 6 protocols (Supplemental Figs. 26, 27, available online).^{30,32,39,40,51,61,62}

Some studies used cone beam computed tomography (CBCT) to measure buccal bone thickness (BBT) and mid-facial MBL, the results of which are shown in Table 2. Quantitative analyses of these outcomes were

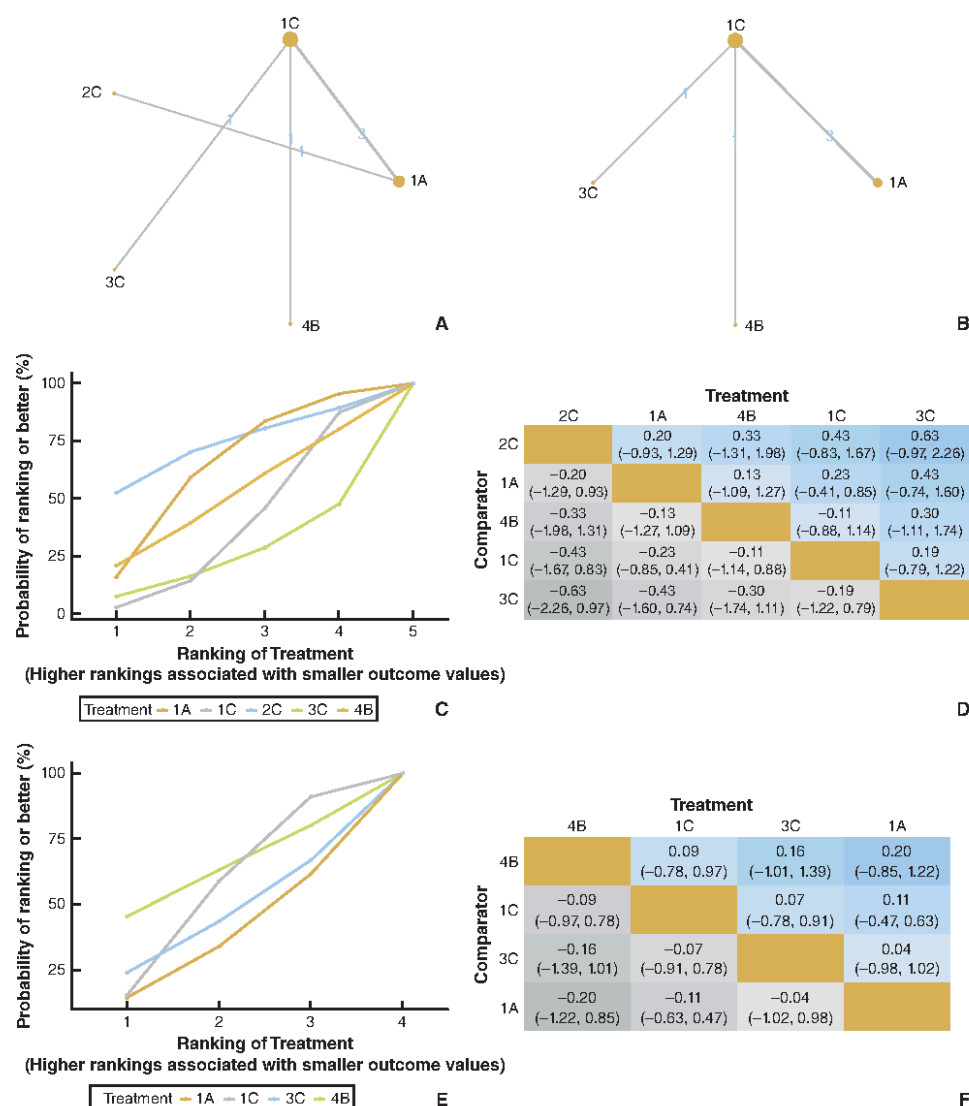


Figure 4. A, One-year mid-facial soft tissue recession (STR) network diagram. Nodes indicate investigated protocols, and edge thickness refers proportionally to number of studies included. B, 1-year mesial and distal STR network diagram. C, 1-year mid-facial STR SUCRA curve. X axis shows number of possible rankings matching number of protocols analyzed. Y axis indicates probability (%) to reach given rank or higher. D, 1-year mid-facial STR league plot showing mean differences and credible intervals in mm between protocols ordered from best to worst starting at top-left corner. Values above and below gray grids show same differences in opposite direction. No significant differences observed. E, 1-year mesial STR SUCRA curve. F, 1-year mesial STR league plot. No significant differences observed. G, 1-year distal STR SUCRA curve. H) 1-year distal STR league plot. No significant differences observed.

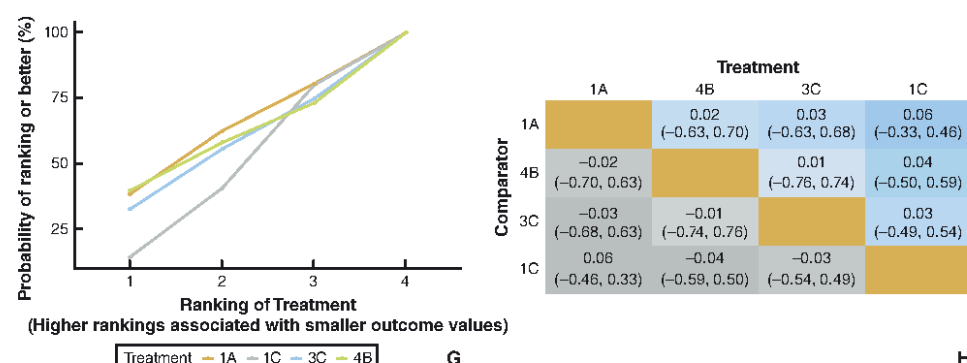


Figure 4. (continued)

not possible. Four studies reported on the BBT of various protocols,^{24,27,43,51} whereas buccal MBL was only measured by Chan and Bushari et al^{24,27} and Liu et al.⁵¹

Four studies with 3-year follow-up compared protocols 1C-3C, 1A-1C, 1A-4C, and 4A-4C.^{28,31,45,63} Only Crespi et al²⁸ reported 4-year results, comparing 1A-1C. The longest reported follow-up was 5 years in 4 studies, comparing 1C-3C, 1A-1C, and 4A-4C.^{33,34,42,44}

Tonetti et al⁴⁵ (1C protocol), Zhang et al⁶³ (1A), Gjølvdal et al³⁴ (4C), and den Hartog et al³³ (4A) each reported 1 implant failure, whereas others found no failure at 3 to 5 years of follow-up, resulting in high medium-to-long-term survival rates. Low (≤ 1 mm) MBL was measured in all studies.^{33,34,42,44} Gjølvdal et al^{34,35} even reported lower 5-year MBLs (4A=0.50 $\pm$ 0.73, 4C=0.54 $\pm$ 0.65) than at 1 year (4A=0.57 $\pm$ 0.52, 4C=0.69 $\pm$ 0.57).

DISCUSSION

The authors are unaware of a previous NMA to rank IPLPs. Survival rates were above 96% for all included protocols except for protocol 1A (91%), the reason for which remains to be investigated. However, protocol 1A generally ranked high in other aspects, with significant advantage in esthetics, especially over protocol 4C. Thus, the null hypothesis that all IPLPs have similar performances with no significant differences in any aspect investigated was rejected.

The cumulated IS rates were found to be generally lower than in previous systematic reviews, especially for protocol 1A. As most failures occurred in the first year, only short-term IS was analyzed.⁶⁶ The 1A protocol requires careful patient selection and is technique-sensitive, influenced by several surgical and prosthetic factors such as pre-extraction gingival levels, phenotype, intact bone walls with ≥ 1 mm buccal bone, and correct implant 3D positioning with >2 mm jumping gap filled with biomaterial.^{10,67} Zhou et al³

calculated a cumulative IS rate of 97.5% (range: 69.2 to 100%), whereas Pommer et al⁵ obtained an IS of 99.6% at 3 to 5 years (95% CI: 98.5 to 100%). These differences can be explained by Zhou et al³ and Pommer et al⁵ considering different study types and follow-up ranges, whereas, in the present study, RCTs with short-term follow-up were analyzed.

Although most studies measured interproximal MBLs, data were not reported separately for mesial and distal sites; thus, only mean interproximal MBLs could be analyzed at the 1-year and 2-year follow-up. Different studies were included for the 1-year and 2-year analyses, which could cause incoherence in the rankings; therefore, no tendencies could be derived for longer-term MBL. Interestingly, protocol 4B performed the best at 1 year, but only based on 1 analysis by Cardaropoli et al,²⁵ where 0.17 mm bone growth was measured compared with the 0.31 bone loss in protocol 1C. Bone grafting was applied in both interventions; however, the implant was placed at the crestal level for 4B but subcrestally for 1C to compensate for postextraction healing.

Zhou et al³ stated 4A and 1C to be scientifically and clinically valid treatment options based on IS. Recently, MBL has gained importance in evaluating protocol validity. In the present study, 4B was followed by protocols 4A, then 1A. Protocol 1C only ranked as one of the last protocols before 3C and 4C, showing that immediate loading may be a more favorable treatment regarding MBL, though no significant differences were observed. Nearly all studies took the timing of implant placement as baseline, in which case, the true effect of placement timing on postextraction healing cannot be examined in protocols later than immediate implantation. Only Lu et al⁵² and Zhou et al⁶⁵ set the baseline at the time of tooth extraction, which should be the most appropriate method of detecting true differences among the protocols. Medium- to long-term follow-up showed promising MBLs. Gjølvdal et al^{34,35} showed bone growth at 5 years compared with at 1 year in both protocols 4A and 4C.

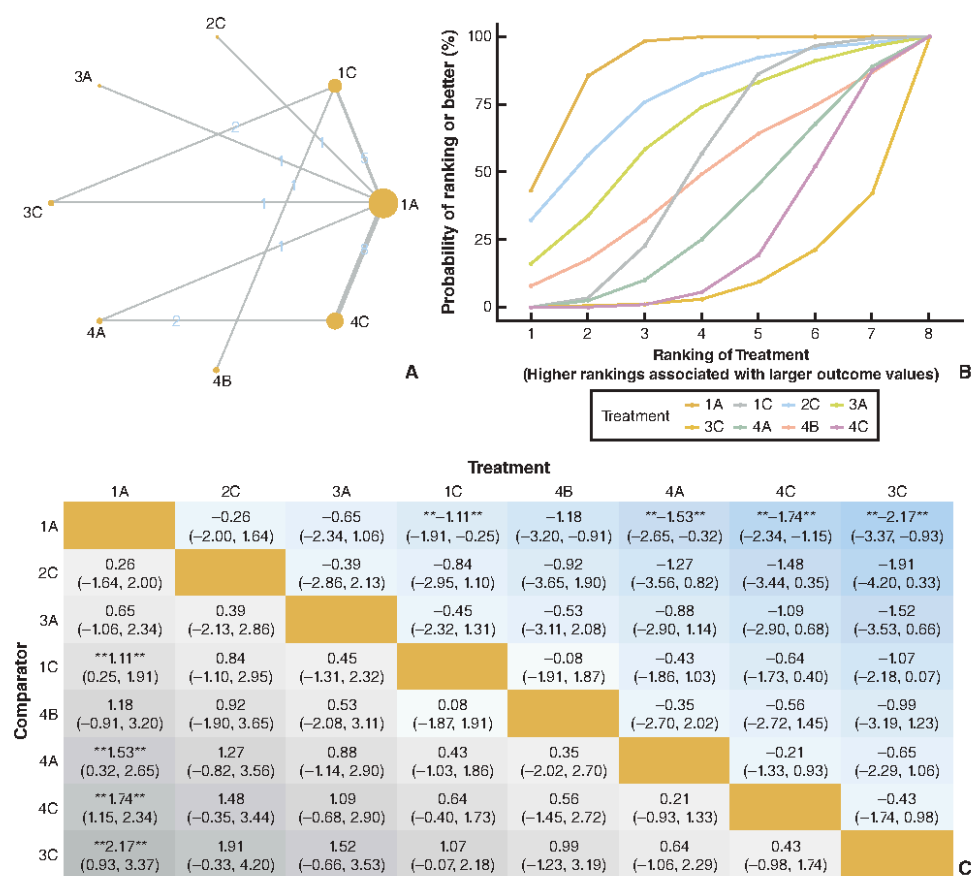


Figure 5. A, One-year pink esthetic score (PES) network diagram. Nodes indicate investigated protocols, and edge thickness refers proportionally to number of studies included. B, 1-year PES SUCRA curve. X axis shows number of possible rankings matching number of protocols analyzed. Y axis indicates probability (%) to reach given rank or higher. C, 1-year PES league plot showing mean differences and credible intervals in mm between protocols ordered from best to worst starting at top-left corner. Values above and below gray grids show same differences in opposite direction. Double asterisks indicate statistically significant differences.

Few studies have reported on mid-facial MBL or BBT, both measurable only on CBCT scans. Slagter et al⁴³ only evaluated the top 5-mm section from the implant platform. Liu et al⁵¹ measured BBT at 1 mm apical to the platform, at mid-implant level, and at 1 mm coronal to the apex of the implant, and also measured mid-facial MBL. Chan et al²⁷ also measured mid-facial MBL as well as BBT at 0, 2, 4, 6, and 8 mm above platform level. No analysis was possible because of the low number of rather heterogeneously measured data.

Both Liu et al⁵¹ and Slagter et al⁴³ compared protocols 1C and 3C. Liu et al⁵¹ reported that the BBT reduction was

around 0.6 mm (1C) and 0.56 mm (3C), and Slagter et al⁴³ reported approximately 0.04 mm (1C) and 0.07 mm (3C); however, the within study differences between compared protocols were minimal. Interstudy differences may therefore be attributed to study designs, materials, and methods. Slagter et al⁴³ included patients with buccal bone defect sizes of ≥ 5 mm and used autogenous bone and soft tissue grafts in both protocols, whereas Liu et al⁵¹ reported no information on buccal defect sizes and applied only guided bone regeneration for intervention 3C. There was no information on phenotype, abutment design, and whether there was veneering in the subgingival region.

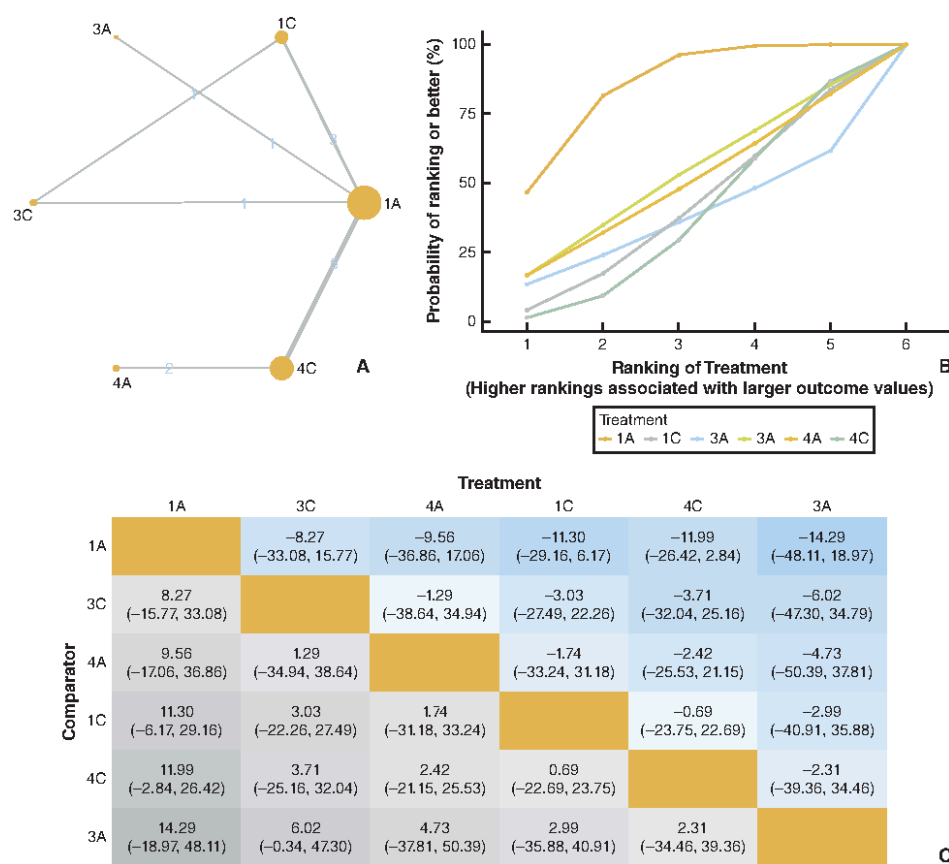


Figure 6. A, One-year visual analog scale (VAS) network diagram. Nodes indicate investigated protocols, and edge thickness refers proportionally to number of studies included. B, 1-year VAS SUCRA curve. X axis shows number of possible rankings matching number of protocols analyzed. Y axis indicates probability (%) to reach given rank or higher. C, 1-year VAS league plot showing mean differences and credible intervals in mm between protocols ordered from best to worst starting at top-left corner. Values above and below gray grids show same differences in opposite direction. No significant differences observed.

Table 2. Buccal marginal bone loss (MBL) and buccal bone thickness (BBT) (mean $\pm$ standard deviation) at first two time points reported for 1A, 1C, and 3C protocols^{24,27,43,51}

Study	Measurement	Time of Measurement	Measured Dimensions (mm)		
			1A	1C	3C
Chan 2019, Bushahri 2021	BBT (platform level)	4 months	2.3 $\pm$ 1.4	2.5 $\pm$ 1.2	-
		30 months	1.83 $\pm$ 1.04	2.04 $\pm$ 0.92	-
	Buccal MBL	12 months	0.3 $\pm$ 0.4	0.7 $\pm$ 0.6	-
		30 months	1.89 $\pm$ 1.02	1.88 $\pm$ 0.61	-
Liu 2016	BBT (1 mm apical to the platform)	0 month	-	1.33 $\pm$ 0.32	1.27 $\pm$ 0.25
		12 months	-	0.73 $\pm$ 0.38	0.71 $\pm$ 0.34
	Buccal MBL	0 month	-	-0.44 $\pm$ 0.31	-0.42 $\pm$ 0.50
		12 months	-	1.30 $\pm$ 0.50	-0.31 $\pm$ 0.42
Slagter 2017 (<5 mm defect)	BBT (1 mm apical to the platform)	1 month	2.05 $\pm$ 0.80	1.39 $\pm$ 0.94	-
		12 months	1.94 $\pm$ 0.79	1.37 $\pm$ 0.78	-
Slagter 2017 (>5 mm defect)	BBT (1 mm apical to the platform)	1 month	-	1.29 $\pm$ 0.60	0.88 $\pm$ 0.57
		12 months	-	1.25 $\pm$ 0.53	0.81 $\pm$ 0.46

Two reports were available for 1-year mid-facial MBL for protocol 1C, where Liu et al⁵¹ reported a mean MBL of around 1.74 mm, and Chan et al²⁷ reported only 0.7 mm. Large differences were observed, with Chan et al²⁷ only achieving an MBL similar to that of the 1-year report of Liu et al⁵¹ at their 30-month follow-up (1.88 mm). The differences may be explained by the fact that Chan et al²⁷ performed allogenic bone grafting, whereas Liu et al⁵¹ used no grafting.

As thin buccal bone, fast bundle bone resorption, and soft tissue recession are major concerns in implant treatment in the anterior maxilla, it is advisable to standardize and perform such measurements in further studies to obtain evidence that aids in clinical decision-making.^{14,68,69}

The protocols were similar regarding STR but achieved different rankings at mesial, mid-facial, and distal sites. Most data were available for mid-facial recession, where the rankings were 2C, 1A, 4B, 1C, and 3C in descending order. Immediate implantation has often been associated with higher mid-facial bone loss, which explains increased STR.^{70,71} Interestingly, 1A ranked first at the distal papilla but showed greater recession at the mesial papilla where it ranked last. The difference could have been the effect of the position and gingival level of the failing tooth, the quality and quantity of interproximal bone in both vertical and horizontal dimensions toward the neighboring teeth, and 3D implant positioning, as well as oral hygiene, but no data were available to analyze the effect these variables.^{10,72–74} STR can worsen esthetics, satisfaction, and can indicate MBL underneath, the analysis of which would require data on the same measuring points from the same studies.^{75,76}

PPD change also indicates bone loss and a deep PPD that is bleeding or purulent could be a sign of peri-implantitis.^{75,76} As pockets deeper than 4 mm were not reported, PPD change was analyzed instead of PPD. The 3A protocol ranked first with a mean difference of >1 mm from the following protocols 4C, 1C, 3C, 2C, and 1A, which showed small differences from each other; only 1A was significantly worse than 3A but had no clinical relevance because of wide CI. Increased probing depth in 1A may have been associated with postextraction healing.^{70,71}

Bleeding is a definitive indicator of inflammation, either peri-implantitis if bone loss is present or peri-implant mucositis if no bone loss is present.⁷⁶ In the analysis of BI, there were no statistically significant differences among the protocols. Though both PPDc and BI were compared, the examined populations were not the same, and these parameters may only be evaluated as indicators of peri-implantitis when investigated together.^{75,76} Peri-implant inflammation cannot be attributed to timing protocols alone, as it is greatly associated with individual oral hygiene, measurable with plaque indices, missing from most reports, and not available for analysis.⁷⁵

Esthetics and patient satisfaction are key indicators of success in the anterior region. For both PES and WES, protocol 1A ranked first with a statistically significant advantage, especially over late placement. Immediate implantation and loading allowed patients to preserve their original and natural soft tissue profile, resulting in significantly higher PES and WES.^{10,28,77} Higher patient satisfaction was also found with protocol 1A. Though mean differences were not statistically significant, the SUCRA values showed an extremely high probability for 1A (84.85%) to rank best, with 33.04% advantage over the second protocol (51.81%). Both esthetics and immediate rehabilitation may contribute to the higher satisfaction observed in the present study and in the literature.⁷⁷

The authors are unaware of a previous NMA reviewing IPLPs, analyzing several protocols (1A, 1C, 2A, 2C, 3A, 3C, 4A, 4B, 4C), including only RCTs with samples across America, Asia, and Europe based on data from English and Chinese language databases. This study focused not only on implant survival and MBLs but also on soft tissue parameters, esthetics, and patient satisfaction.

Although a few RCTs with long-term (3 to 5 years) follow-up were included, only 1-year and 2-year follow-ups had sufficient data available for qualitative analysis. Even for short-term analyses, the strength of evidence and networks was weak because of the low number of studies, and therefore subset analyses were not possible. Parameters such as the definitive restoration material and retention method, abutment height and connection, flap design, mucosal phenotype of the patient, and application of either hard or soft tissue grafts were rarely mentioned, all of which could have affected the outcomes. Missing and possibly selected outcome data, imprecision, heterogeneity, and incoherence were also reasons for the reduced strength of the evidence.

If conditions are met, applying 1A protocol in the anterior maxillary region could result in improved esthetics (PES, WES) and patient satisfaction. With recent systematic reviews of the ITI proving high survivability, this review could also contribute to acknowledging the 1A protocol as a scientifically and clinically validated treatment option.^{3,67,78,79}

Well-designed RCTs with standardized methodology, larger sample sizes, and long-term follow-up focusing on patient phenotype, implant placement position, hard or soft tissue grafting, buccal bone dimensions, and soft tissue parameters are needed for stronger clinical recommendations.

CONCLUSIONS

Based on the findings of this systematic review and network meta-analysis, the following conclusions were drawn:

1. Immediate implant placement with immediate loading (1A) shows a considerable advantage in

terms of esthetics and promising benefits in patient satisfaction over later rehabilitation, whereas minor differences were monitored on MBLs around anterior maxillary single implants treated with different protocols.

- Further studies are needed to determine the long-term effects of different implant placement and loading protocols.

APPENDIX A. SUPPORTING INFORMATION

Supplemental data associated with this article can be found in the online version at doi:10.1016/j.prosdent.2024.05.033.

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Appendix Document 2. Publication related to Study II.



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REVIEW ARTICLE
Peri-Implant Diseases

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Individualized healing significantly improves pink esthetics around immediate single implants: A systematic review and meta-analysis

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Abstract

Aim: This systematic review and meta-analysis aimed to compare soft and hard tissue outcomes of applying anatomic healing abutments (AHA) and provisional restorations (PR) versus cylindrical healing abutments (CHA) on immediately placed single implants.

Materials and Methods: Four databases (PubMed, Embase, Cochrane, and Web of Science) were searched on September 8, 2025, for two-armed studies comparing AHA/PR to CHA on immediate single-tooth implants. Outcomes included implant survival (IS), marginal bone loss (MBL), pink esthetic score (PES), patient satisfaction, as well as buccal bone and mucosal changes. Random-effects meta-analyses were performed.

Results: Twenty studies were included; 12 contributed to quantitative synthesis, showing no difference in IS (over 99% in all groups), MBL, or patient satisfaction. Pooled analysis of seven studies (340 implants) showed higher PES with AHA and PR than CHA group at 1 year (MD: 2.54; 95% CI: 1.12–3.96). Descriptive evidence suggested a trend toward improved horizontal tissue preservation with individualized healing.

Conclusion: Within the limitations of this study, PR significantly improved PES without compromising IS or MBL. Their use may be beneficial, especially in the esthetic region, but further studies are needed to investigate their cost-effectiveness and long-term effect, especially on horizontal tissue changes.

Clinical Implications: Anatomically shaped healing abutments and provisional restorations provide higher pink esthetics around immediately placed single implants, which is especially relevant for restorations in the anterior region.

German O. Gallucci and Krisztina Mikulás have contributed equally and share last authorship.

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KEYWORDS

dental esthetics, dental implant-abutment design, immediate dental implant loading, meta-analysis, single-tooth dental implants

1 | INTRODUCTION

The integrity of the peri-implant supracrestal complex is crucial for the long-term survival and success of implant-supported restoration, as it protects the implant and bone against mechanical and microbial invasion.¹⁻⁵ The correct formation of the supracrestal complex ensures biological and functional integrity of the peri-implant tissues, facilitates effective plaque control, and is also essential for achieving natural esthetics, meeting the increasing patient demands, which can be especially challenging when rehabilitating single-tooth gaps.^{1,6-11}

Immediate implant placement (IIP) shortens treatment time, reduces the number of surgeries, and may minimize post-extraction alveolar ridge reduction, bundle bone resorption, and soft-tissue collapse during the remodeling phase, which mainly occurs in the first year following surgery.^{3,4,6,12-14} The treatment time may be further shortened with non-submerged healing, as sulcular and junctional epithelium can form around the healing abutment, together with implant-bone integration.^{4,6,9,12,15-17}

The conventionally applied cylindrical-shaped prefabricated healing abutments (CHA) create a uniform, unnatural cylindrical emergence profile (EP) not matching the extraction socket.¹⁸ Instead, custom restorations matching the individual anatomy of the replaced tooth may be fabricated to be delivered with IIP. Anatomic healing abutments (AHA) passively seal the extraction socket without replacing the clinical crown, whereas provisional restorations (PR) are functional restorations exerting immediate functional load on the peri-implant bone and soft tissues, although this may increase the risk of implant failure due to overloading if occlusal forces are not well distributed.^{4,5,18-23} Despite their differences in biomechanic effect mechanisms, both components share the objective of maintaining the original tissue contours during early healing, which may stabilize the blood clot, support the peri-implant mucosa, and reduce post-extraction bone resorption to preserve more cortical bundle bone.^{4,18,20-22} However, AHAs and PRs are also more costly and labor-intensive to fabricate compared with stock CHAs,^{20,21,24} and the question remains unanswered whether the clinical parameters, especially potential bone preservation are significantly better to make it worth the additional effort to obtain anatomically shaped restorations that can be delivered together with IIP, and whether AHA and PR have similar results as they have not been investigated together, which highlights the need for a comprehensive review.

Therefore, this systematic review and meta-analysis aimed to compare implant survival, hard and soft-tissue parameters, esthetics, and patient satisfaction resulting from the use of AHA and PR versus CHA on immediately placed single implants, based on the currently available literature. The null hypothesis is that the application of PR and AHA does not result in a difference compared with applying CHAs.

2 | MATERIALS AND METHODS

The Cochrane Handbook and the PRISMA 2020 guidelines were followed in conducting and reporting this systematic review and meta-analysis (Table S1).^{25,26} The protocol was prospectively registered in the PROSPERO database (CRD42023458206) and was fully adhered to.

The study applied the Population (P), Intervention (I), Comparison (C), Outcomes (O) framework to investigate (P) healthy adults who underwent a non-adjacent single-tooth replacement with immediate implantation in either jaw and received (I1) an AHA or (I2) immediate provisionalization (PR) compared with (C) a non-anatomic, cylindrical stock healing abutment (CHA), to compare their effect on (O) implant survival (IS), marginal bone loss (MBL), pink esthetic score (PES), and patient satisfaction with visual analog scale (VAS). Studies were excluded if they did not match our question framework or included subjects with multiple adjacent implants, periodontal infection, or parafunctional movements.

A systematic search was conducted in four electronic databases (MEDLINE [PubMed], Embase, Cochrane CENTRAL, Web of Science) on July 18, 2023, and was last updated on September 8, 2025. A date filter was applied for publications since January 1, 2000. The search keys applied for the systematic search can be found in Table S2. No additional gray literature was searched.

Two independent authors (XQ and BV) screened the search results by title, abstract, and then full text.^{27,28} Citation chasing was performed on the articles included via initial full-text selection to obtain further potentially eligible studies.²⁹ Data were collected from eligible articles in a specific Excel template, extracting first author, year of publication, study population, interventions, and the outcomes. Risk of bias was assessed using the Risk of Bias 2 (RoB-2) tool for randomized controlled trials (RCTs) and Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool for non-randomized cohort studies to account for their different possible sources of bias, with additional examination of possible funding bias. Any disagreements between the independent reviewers were resolved by a third party (KK). The certainty of evidence was determined with the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach using the GRADEpro web application.³⁰

2.1 | Effect measures and data synthesis

The meta-analysis was conducted in R (v.4.4.1) with the *meta* package (v.7.0.0). Random-effects models were applied for data synthesis to account for anticipated clinical and methodological heterogeneity (e.g., application of AHA vs PR, implant location, grafting and surgical protocols, implant systems, prosthetic workflows, follow-up duration, and study

design) among the included studies.³¹⁻³³ For binary outcomes (IS), the proportion of events in each intervention group was pooled using the *metaprop* function, then proportions were back-transformed for interpretation. Continuity corrections (0.5) were applied to studies with zero events, using the "if0all" method for binary data. For continuous outcomes (MBL, PES, and VAS), mean differences (MDs) were calculated and pooled with the *metacont* function. Ninety-five percent confidence intervals (95% CI) were calculated for all estimates. Heterogeneity across studies was assessed using the I-squared statistic.³⁴ Tau-squared was calculated using the restricted maximum-likelihood estimator, and prediction intervals were presented where appropriate.³⁵ Subset or subgroup analyses were performed for specific interventions (e.g., types of healing restorations used) and follow-up durations (e.g., 3–6 months, 12–16 months) wherever possible. Sensitivity analyses excluding posterior implant sites were performed to evaluate the robustness of the pooled estimates as subgroup analysis was not possible in this case due to the low number of studies investigating posterior sites. The Hartung-Knapp adjustment was applied to enhance the robustness of the random-effects estimates.³⁶ Results were displayed in forest plots. Funnel plots were created to investigate publication bias.

3 | RESULTS

Twenty articles were included, reporting on 17 distinct studies (Figure 1), 12 of which provided data for quantitative analysis. Study characteristics can be found in Table 1.^{20,24,37-54}

3.1 | Implant survival (IS)

All interventions achieved ≥99% mean IS over 1 year (Figures 2 and S1).^{24,38,42,44-51}

3.2 | Marginal bone loss (MBL)

Interproximal MBLs investigated between 3–6 and 12–16 months of follow-up showed no statistically significant differences (Figures 3 and S2).^{20,42,44-47,50} Sensitivity analysis excluding posterior sites did not change the direction, magnitude, or statistical significance of the effect estimates at 3–6 and 12–16 months (Figure S2B,E).

3.3 | Pink esthetics score (PES)

The application of either AHA or PR resulted in statistically significantly higher PES (MD: 2.54, CI: 1.12; 3.96) than CHA at 1-year follow-up, which showed clinical relevance (Figures 4 and S3A–C).^{24,44,47-51} Sensitivity analysis excluding posterior sites did not change the direction, magnitude, or statistical significance of the effect estimates (Figure S3B).

Data were not available for long-term quantitative analysis, but Arora et al. found 11.1 ± 2.08 (PR) vs 10.3 ± 2.23 (CHA) mean PES in their retrospective cohort study with a mean 3-year follow-up, which was not statistically significant.⁴⁰ However, the distal papilla was significantly better in the PR group (1.7) than the CHA group (1.25).⁴⁰

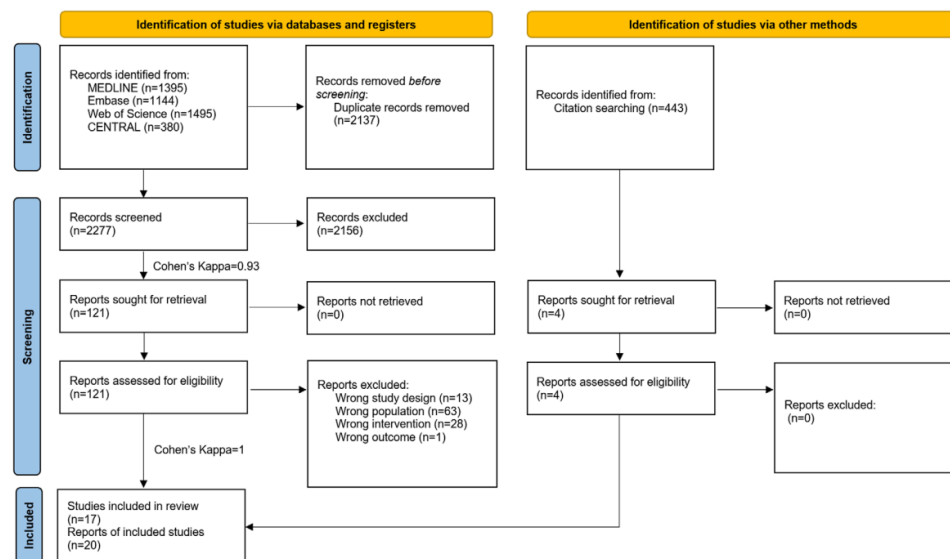


FIGURE 1 PRISMA 2020 flowchart of the selection process.

TABLE 1 Characteristics of the included studies.

Study number (±inclusion in meta-analysis)	Author, year	Study design	Region of interest	Follow-up duration from implantation (month)	Compared protocols	Sample size
1. -	Amato, 2018	Retrospective follow-up of RCT	Anterior maxilla or mandible	1,3,6	PR vs. CHA	20
						13
					PR vs. CHA (grafted)	34
						13
2. -	Amato, 2022	RCT	6/7 maxilla or mandible	2,4,6	PR vs. AHA vs. 5/6/7.5 mm CHA	33
						32
						67
						64
						71
3. +	Amato, 2023	Retrospective follow-up of RCT	4/5 maxilla or mandible	Mean 2.5 years (1–5 y)	PR (occluded) vs. CHA	40
					PR (non-occluded) vs. CHA	33
					PR vs. CHA	53
4. -	Arora, 2018	Retrospective cohort	Anterior maxilla	Mean 3y (12+ month)	PR vs. CHA (grafted)	20
						20
5. +	Chan, 2019	RCT	Anterior maxilla	1,4,12	PR vs. CHA (grafted)	20
						20
	Wang, 2020					20
						20
	Busharhi, 2021	Retrospective follow-up of RCT		30		16
						12
6. +	Chokaree, 2024	RCT	Maxilla or mandible	4,6	AHA vs. CHA (grafted)	16 6
7. +	El-Danasory, 2023	RCT	Anterior maxilla	6,12	AHA vs. CHA (grafted)	12
						12
8. +	Fu, 2023	RCT	Anterior maxilla	3,6,9,12	PR vs. CHA (grafted)	35
						35
9. +	Grandi, 2015	RCT multicenter	Maxilla or mandible	16	PR vs. CHA (grafted)	35
						35
10. +	Hassani, 2021	Retrospective cohort	Anterior maxilla	12	PR vs. CHA (grafted)	20
						20

Surgical protocol					Intervention protocol			Prosthetic protocol	
Implant and connection type	Surgical guide	Implant position	Insertion torque (Ncm)	Graft	PR/AHA/CHA	HA size (mm)	PR occlusion	Material	Screw/cement retained
Biomet 3i tapered, internal or external hex	Yes	NR	≥50	None	PR	-	No	NR	Screw
			<50		CHA	NR	-		
			≥50	50-50 mixture of autogenous and bovine graft (0.5-1.0mm Endobon, Biomet)	PR	-	No		
			<50		CHA	NR	-		
Biomet 3i tapered, internal or external hex	Yes	4mm subgingival, 2mm subcrestal	≥50	None, only collagen sponge	PR	-	No		
			≥35		AHA	Custom	-		
					CHA	5	-		
						6	-		
Biomet 3i tapered, internal or external hex	Yes	4-5 mm subgingival	≥50	50-50 mixture of autogenous and anorganic bovine graft (Endobon, Biomet)	PR	-	Yes	PFM or full Zr	Screw
					PR	-	No		
					CHA	5	-		
Astratech OsseoSpeed, Dentsply Sirona, internal connection	No	NR	≥30	Deproteinized bovine bone particles (Bio-Oss)	PR	-	No	Ti or Zr base with PFM or Zr crown	Cement
					CHA	5	-		
IS II active, Neobiotech, internal connection	No	3mm subgingival	≥30	Cancellous particulate allograft (Puros®, Zimmer Biomet).	PR	-	No	Ceramic, Ti-base, Zr abutment	Cement
					CHA	Socket-size	-		
					PR	-	No		
					CHA	Socket-size	-		
CMI IS-III Active, Neobiotech Co., internal connection	Yes	1mm subcrestal	≥30	Jumping gap ≥2mm filled with bone grafting material	AHA	Custom	-	Ceramic, Ti-base, Zr abutment	Screw
					CHA	NR	-		
Oxy Implant K1, Biomec SRL, internal connection	Yes	NR	NR	Jumping gap >2mm grafted with bovine xenograft (MedPark S1 Dental)	AHA	Custom	-	Full Zr on Ti-base	Screw
					CHA	Socket-size	-		
Seven, MIS, internal connection	No	NR	NR	Jumping gap filled with freeze-dried bone allograft (OraGraft, LifeNet Health)	PR	-	No	NR	Screw
					CHA	NR	-		
JD Evolution, J Dental Care, internal connection	No	1mm subcrestal, slightly palatal	≥45	Jumping gap with anorganic bovine bone granules Bio-Oss; collagen fleece over graft if needed, Medicipio C Collagen Fleece	PR	-	No	PFM	Screw/cement
					CHA	NR	-		
Superline, Dentium, internal connection	No	NR	NR	Jumping gap >2mm filled with biphasic calcium phosphate, Osteon II, Genoss	PR	-	No	PFZ	Screw/cement
					CHA	NR	-		

(Continues)

TABLE 1 (Continued)

Study number (±inclusion in meta-analysis)	Author, year	Study design	Region of interest	Follow-up duration from implantation (month)	Compared protocols	Sample size
11. +	Li, 2019	RCT	Anterior maxilla	3,9,15	PR vs. CHA (grafted)	61 62
12. +	Ning, 2016	RCT	Anterior maxilla	3,9,15	PR vs. CHA (grafted)	15 15
13. +	Perez, 2020	RCT	Anterior maxilla or mandible	4,12	AHA vs. CHA (grafted)	18 18
14. +	Song, 2020	Retrospective cohort	Anterior maxilla	3,12	PR vs. CHA (grafted)	32 35
15. -	Su, 2021	Retrospective cohort	Anterior maxilla	3,6	PR vs. CHA (grafted)	40 40
16. -	Tarnow, 2014	Retrospective cohort	Anterior maxilla	13 months to 4 years	PR vs. CHA PR vs. CHA (grafted)	17 5 17 10
	Chu, 2015				PR vs. CHA PR vs. CHA (grafted)	17 5 17 10
17. +	Elgendi, 2025	RCT	Posterior maxilla	6,12,18	AHA vs. CHA (grafted)	10 10

Note: Studies marked with (+) in the "Study number" column provided data for quantitative meta-analysis, those marked with (-) did not.

Abbreviations: HA, healing abutment; NR, not reported; PFM, porcelain-fused-to-metal restoration; PFZ, porcelain-fused-to-zirconium-dioxide restoration; PR, provisional restoration; RCT, randomized controlled trial; Ti, titanium; Zr, zirconium-dioxide.

3.4 | Patient satisfaction—Visual analogue scale (VAS)

Three studies with 260 implants were analyzed for 1-year satisfaction measured with VAS (range: 0–10), comparing only PR to

CHA. The difference was not statistically significant (Figures 5 and S4).^{45,48,51}

No data were available for the AHA group at 1 year. However, Elgendi et al. reported significantly higher satisfaction for the AHA group (9.8 ± 0.22) at 18 months compared with CHA (9.27 ± 0.24).²⁴

Surgical protocol					Intervention protocol			Prosthetic protocol	
Implant and connection type	Surgical guide	Implant position	Insertion torque (Ncm)	Graft	PR/AHA/CHA	HA size (mm)	PR occlusion	Material	Screw/cement retained
TSIII, DIO, internal connection	No	Palatal	≥35	Bio-oss, Geistlich	PR CHA	- NR	Yes -	Ceramic, custom abutment	NR
TSIII, DIO, internal connection	No	Palatal	≥35	Bio-oss, Geistlich and VIP-VT flap	PR CHA	- NR	No -	Ceramic, custom abutment	NR
BLT, Straumann AG, internal connection	No	Crestal	NR	Alloplastic bone substitute (GUIDOR easy-graft CRYSTAL, Sunstar Suisse SA) and resorbable membrane (Evolution, Osteobiol-Tecnoss)	AHA CHA	Custom NR	- -	NR	NR
ITI soft-tissue horizontal implant, Straumann AG, internal connection	No	Palatal, 1-3 mm subcrestal	≥35	Artificial bone (Engineering Research Centre in Biomaterials, Sichuan University) in gaps >2 mm at 2-3 mm above the bottom of the alveolus, Bio-Oss in gaps >1 mm	PR	-	No	NR	NR
			<35	Guided bone regeneration	CHA	NR	-		
NobelActive, Nobel Biocare, internal connection	Yes	NR	≥35	Deproteinized bovine particles (Bio-Oss, Geistlich Pharma AG), collagen membrane (Bio-Gide, Geistlich Pharma)	PR CHA	- NR	No -	NR	NR
Tapered non-platform-switched internal-connection implants	No	Palatal, 3-4 mm subgingival	≥35	None	PR CHA	- NR	No -	PFM of full ceramic	Screw/cement
				Small-particle bone allograft	PR CHA	- NR	No -		
				None	PR CHA	- NR	No -		
				Small-particle bone allograft	PR CHA	- NR	No -		
ROOTT, TRATE AG., internal connection	Yes	Interseptal bone, 3 mm below neighboring teeth CEJ	≥35	Bone xenograft (Bioteck Bio-Gen Granules, Belgium)	AHA	Custom	-	PFZ	Screw
				Bone xenograft (Bioteck Bio-Gen Granules, Belgium), collagen sponge	CHA	NR	-	PFZ	Screw

3.5 | Changes in horizontal ridge width and buccal contour

Three studies measured changes in horizontal ridge width (RW) on gypsum casts of the jaw and one study measured this outcome on intraoral

digital scans, which could not be pooled for quantitative analysis due to heterogeneity (Table 2).^{20,37,39,53} Amato³⁷ applied three diameters (5 mm, 6 mm, and 7.5 mm) of CHA for molar extraction sites, the widest of which was included in the table for visualization. In all studies, the PR/AHA group showed better bone preservation than the CHA group.

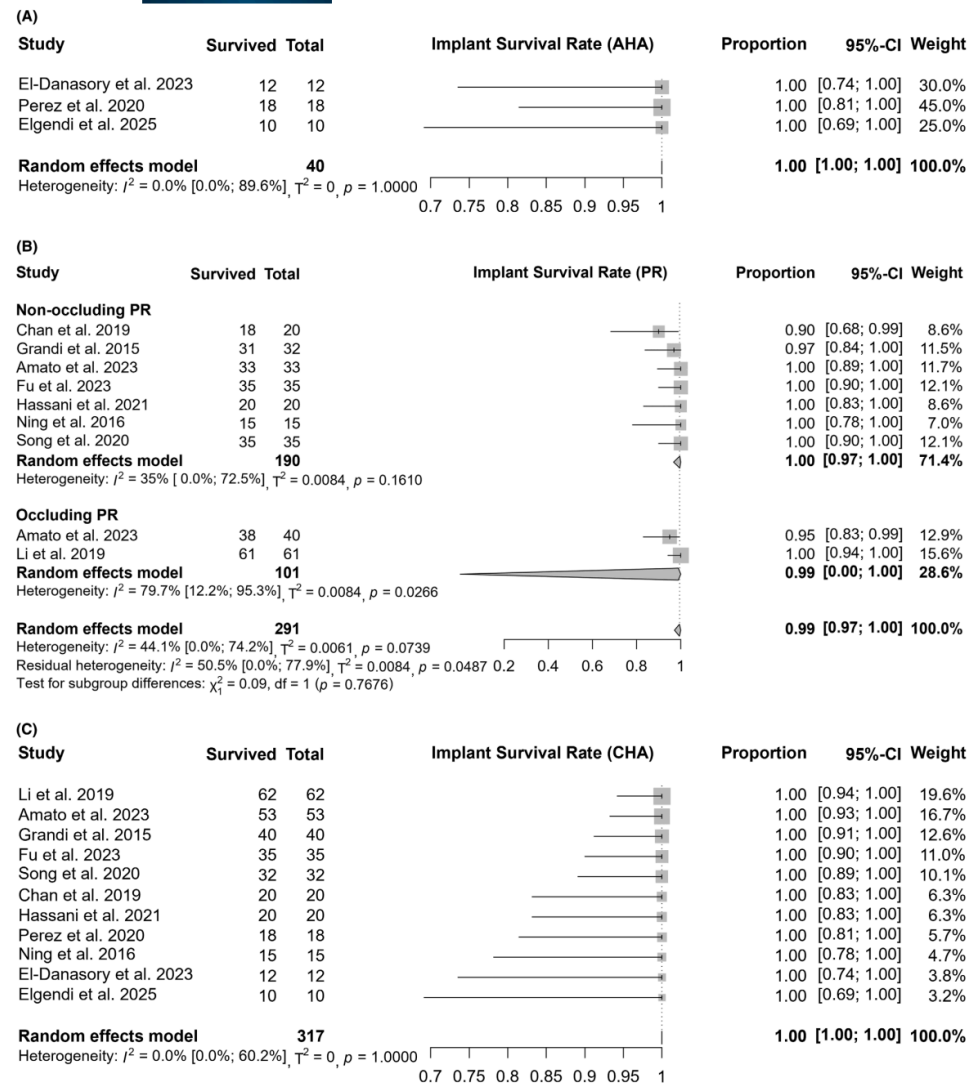


FIGURE 2 Forest plot showing proportional analysis of implant survival rates when applying (A) anatomic healing abutments (AHA), (B) provisional restorations (PR), and (C) cylindrical healing abutments (CHA).

Only Amato³⁷ compared CHA, AHA, and PR in the same study, where AHA was found to be the most effective.

Another two studies found that immediate provisionalization slightly preserves buccal bone thickness (BBT) and buccal contours as measured by CBCT.^{41,42,52,54} At the level of the implant neck,

Chan and Wang et al. measured a reduction in BBT of 0.6 ± 0.7 mm (PR) and 0.6 ± 0.5 mm (CHA) at the 4-month follow-up.^{42,54} At 6 months, Su et al. measured a respective BBT of 0.904 ± 0.68 mm (PR) and 0.878 ± 0.73 mm (CHA), accounting for a mean difference in BBT of 0.026 mm.⁵² The difference in full buccal hard and soft-tissue

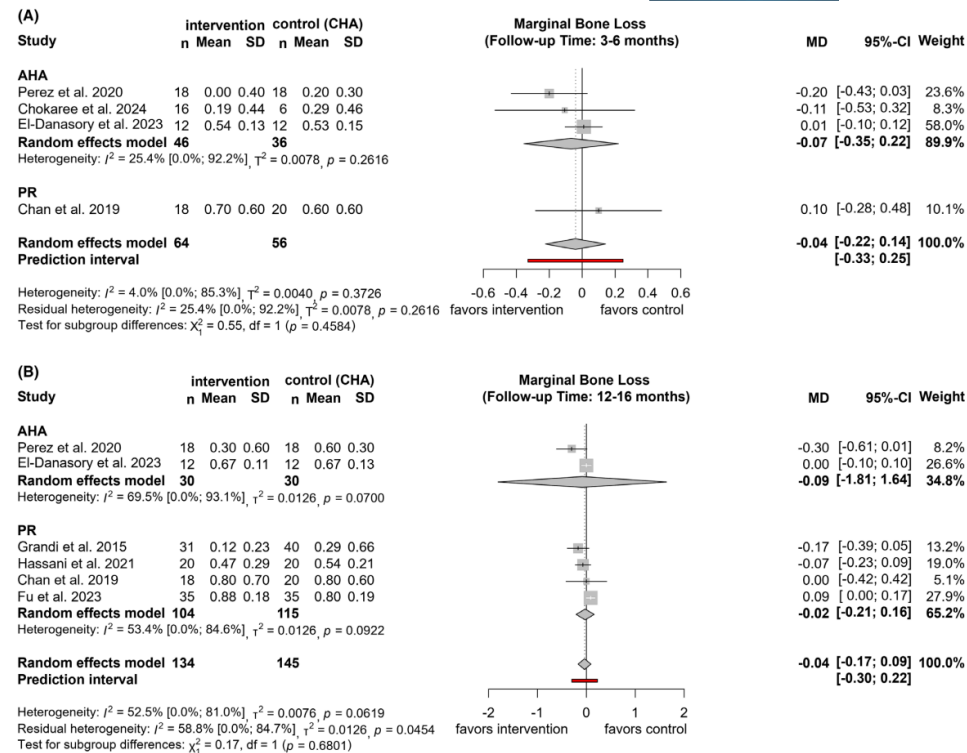


FIGURE 3 Forest plot showing mean differences in mm in interproximal marginal bone losses when applying anatomic healing abutments (AHA) or provisional restorations (PR), compared with cylindrical healing abutments (CHA), at (A) 3–6 month follow-up and (B) 12–16 month follow-up. Subgroup analysis was performed for AHA and PR.

thickness was 0.2 mm at 6 months, with statistically significant differences above the platform level.⁵² Reduction in buccal volume was $13.618 \pm 16.256\%$ (AHA) vs $26.631 \pm 20.788\%$ (CHA) according to Chokaree et al., which was not statistically significant due to the wide range of variation, but Wang et al. found a significant difference in the volumetric analysis of the buccal mucosa at the 1-year follow-up between PR (11.9% loss) and CHA (17.4% loss).^{20,54}

Only one RCT could measure mid-buccal MBL.^{41,42} At the 12-month follow-up, Chan et al. reported a mid-buccal MBL of 0.3 ± 0.4 mm (PR) vs 0.7 ± 0.6 mm (CHA), which increased to 1.89 ± 1.02 mm (PR) vs 1.88 ± 0.61 mm (CHA) in a mean 30-month follow-up report by Bushahri et al.^{41,42} Chan et al. also reported 1-year mid-facial mucosa changes, finding a recession of 0.1 ± 0.9 mm (PR) vs 0.1 ± 0.7 mm (CHA).⁴² However, both Chokaree et al. and Perez et al. investigating AHA vs CHA found a vertical soft-tissue gain in the CHA group.^{20,50} Chokaree et al. found a recession of 0.6083 ± 0.857 mm in the AHA group and a gain of 0.048 ± 0.6411 mm at 6 months.²⁰ At 1 year, Perez et al. found a

recession of 0.2 ± 0.4 mm in the AHA group, but 0.1 ± 0.5 mm overgrowth in the CHA group which were statistically significant differences.⁵⁰

3.6 | Risk of bias and certainty of evidence

Most RCTs were low risk, whereas some retrospective cohort studies carried moderate to serious risk of bias, primarily due to confounding, patient selection, and missing outcome data (Figures S5–S8). The certainty of evidence was high in most cases, but moderate for PES due to inconsistency and low for VAS due to study risk of bias and imprecision (Table S3). Additional analysis of funding bias revealed three studies, by Grandi et al.,⁴⁶ Chan et al.,^{41,42,54} and Perez et al.,⁵⁰ where the authors received funding, such as grants, honoraria, implants or prosthetic parts from commercial institutions.^{41,42,46,50,54} Grandi et al. stated the funding institutions had no role in study design and publication of the results.⁴⁶ Chan et al.

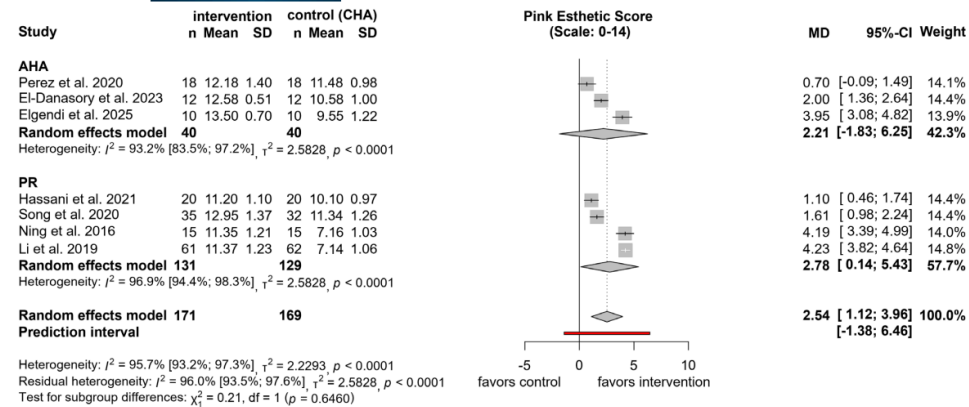


FIGURE 4 Forest plot showing mean differences in pink esthetic scores when applying anatomic healing abutments (AHA) or provisional restorations (PR) compared with cylindrical healing abutments (CHA). Subgroup analysis was performed for AHA and PR.

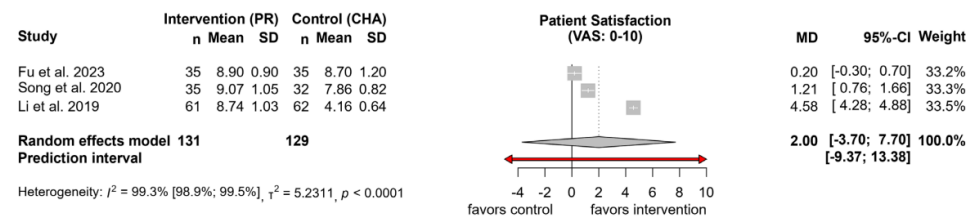


FIGURE 5 Forest plot showing mean differences in patient satisfaction measured with visual analog scales (VAS) following the application of anatomic healing abutments (AHA) or provisional restorations (PR) compared with cylindrical healing abutments (CHA).

TABLE 2 Mean $\pm$ standard deviation (standard error in parentheses) differences in horizontal ridge width of the implanted sites with different treatments compared with the same site before extraction or the contralateral site with natural dentition.

Study	Implant position	Time Period	Measurement Level (from marginal zenith)	CHA [mm]	CHA + bone graft [mm]	AHA [mm]	AHA + bone graft [mm]	PR [mm]	PR + bone graft [mm]
Amato, 2018	Anterior maxilla or mandible	6 months	1mm	2.07 (0.13)	0.82 (0.13)	–	–	0.48 (0.10)	0.27 (0.08)
			3mm	2.07 (0.13)	0.90 (0.13)	–	–	0.63 (0.10)	0.30 (0.08)
			5mm	1.99 (0.12)	0.43 (0.12)	–	–	0.59 (0.10)	0.34 (0.07)
Amato, 2022	6/7 maxilla or mandible	6 months	1mm	2.53 (0.138)	–	0.25 (0.225)	–	1.11 (0.179)	–
			3mm	2.16 (0.144)	–	0.30 (0.225)	–	1.23 (0.179)	–
			5mm	1.56 (0.144)	–	0.19 (0.225)	–	1.12 (0.179)	–
Chokaree, 2024	Anterior maxilla or mandible	6 months	0–5mm	–	0.607 ± 0.421	–	0.3557 ± 0.227	–	–
	Molar maxilla or mandible			–	–	–	0.755 ± 0.572	–	–
Tarnow, 2014	Anterior maxilla	13 months–4 years	1mm	0.8	0.4	–	–	0.8	0.4
			3mm	1.1	0.3	–	–	0.7	0.1
			5mm	1	0.3	–	–	0.6	0

Abbreviations: AHA, anatomic healing abutment; CHA, cylindrical healing abutment; PR, provisional restoration.

published three articles from the same study but stated conflict of interest only in the first publication.^{41,42,54}

4 | DISCUSSION

This is the first meta-analysis to investigate the effect of both anatomic healing abutments and provisional restorations compared with conventional healing abutments on single immediate implants. Short-term results showed no significant differences in marginal bone loss, only a descriptive trend in buccal bone thickness preservation; however, pink esthetic scores were significantly better with anatomic healing, particularly with provisional restoration; therefore, the null hypothesis was rejected.

4.1 | Implant survival

Our cumulated 1-year IS rates were above 99% for all interventions, unaffected by the method of healing. Only the PR group had implant failures, 5 out of 291, of which two restorations were in occlusion with the antagonistic jaw,³⁸ and three were taken out of static and dynamic occlusion^{42,46}; however, these restorations could still have been susceptible to increased loading during feeding.^{5,55} All studies applied minimal invasive extraction, a minimum insertion torque of 30 Ncm, and most studies also applied particulate bone grafts in the jumping gaps, but only seven studies reported on the application of surgical guides to ensure correct implant positioning.^{20,37–39,44,52} IIP can only be immediately provisionalized under strict criteria, with careful consideration of factors influencing IS, such as the type and 3D position of the implant, bone quality and quantity, presence of periapical or periodontal inflammation, phenotype, primary implant stability and grafting, as well as possible parafunctional movements.^{4,6,9,16} It is also crucial for immediately placed implants to be relieved of loading; therefore, shorter AHAs might be more advantageous for successful implant-bone integration and survival, which warrants further investigation.^{5,6} There were no implant failures at all in the AHA and CHA groups. However, there were only three randomized studies with overall 40 implants investigating AHAs. Further studies with long-term follow-up are needed to understand their true effects. So far, no comparative clinical studies have reported long-term results, but according to a retrospective case series by Akin et al. of 115 immediate posterior single implant cases with AHAs, the survival rate up to 8 years was 98.26%, with 3 cases of early implant failures.⁵⁶

4.2 | Hard tissue parameters

Interproximal marginal bone losses were similar in all groups, with mean differences between the AHA/PR and CHA groups being close to the null effect in both 3–6-month and 12–16-month follow-ups, only slightly favoring the intervention group. Sensitivity analyses excluding posterior implant sites and focusing only on anterior sites

yielded no different results. This suggests that the different healing abutment shapes do not significantly affect interproximal bone loss in the short term. However, the lack of data on long-term follow-up limits the interpretation of the effect on bone levels, these short-term changes may also be attributed to post-extraction and post-implantation bone remodeling; true hard tissue changes can only be objectively assessed after long-term follow-up.

Only few studies applied CBCT analysis for mid-buccal bone loss and buccal bone thickness. One study with long-term follow-up showed considerable mid-buccal vertical bone loss at 1 year (PR: 0.3 mm, CHA: 0.7 mm) which equalized after 2.5 years (PR: 1.89 mm, CHA: 1.88 mm); however, the PR group showed 0.21 mm less buccal bone resorption at 2.5 years.⁴³ Further long-term investigations with CBCT analysis are required to investigate these outcomes.

4.3 | Soft-tissue parameters

Chan et al., who found buccal MBLs of 0.3 mm for PR and 0.7 mm for CHA, found only minimal 0.1 mm recession in both groups.⁴² Perez et al. found a recession of 0.2 mm in the AHA group, yet a gain of 0.1 mm soft tissue was reported for the CHA group.⁵⁰ This aligns with the results of Chokaree et al., with slight mid-buccal mucosal gain in the CHA group (0.048 mm) compared with the slight recession in the AHA group (0.608 mm).²⁰ Souza et al. showed that flatter abutment angulation leads to more MBL, which may also contribute to soft-tissue recession and may explain how anatomic abutments—being naturally wider than conventional cylindrical abutments—could potentially prevent upward tissue growth.⁵⁷ The abutment emergence angulation should not exceed 30° to decrease MBL and risk of periodontitis.^{58,59} Though abutment material could not be investigated, it may also affect vertical and horizontal soft-tissue dimensions and inflammatory parameters.¹⁹ Therefore, the right choice of implant diameter, abutment material, height and angulation of abutment widening should be carefully considered for optimal outcomes.^{8,19,57–60}

A few studies investigated horizontal bucco-palatal ridge width changes and buccal full tissue thickness at various heights along the implant length. Unfortunately, the low number of heterogeneous studies did not allow mathematical synthesis; however, they all found that the application of anatomically individualized restorations preserved horizontal tissue dimensions better than CHA.

In a study by Su et al., when the full buccal hard- and soft-tissue thickness was measured on CBCT, the advantages of PR were statistically significant above platform level.⁵² Although the differences decreased apically, and hard tissue changes were not significant, the PR group consistently resulted in more bone and mucosa preservation, which suggests that the correct formation and maintenance of the supracrestal complex are not only an aesthetic concern, but also crucial for hard and soft-tissue preservation and implant success.

Three studies measured changes in full bucco-palatal RW changes compared with the pre-extraction RW at the same site^{37,39} or to the contralateral tooth⁵³ on gypsum casts. As these studies measured the full bucco-palatal thickness, differences in the buccal and palatal sites

could not be interpreted separately; however, post-extraction bone resorption rates tend to be higher buccally; thus, it would be informative to find out where each procedure has an effect.^{61,62}

Amato³⁹ and Tarrow et al.⁵³ compared PR to CHA in the anterior jaws. Amato⁵³ found that reduction in RW in the PR group (0.2–0.7 mm) was only ½ to ⅓ of that of the CHA group (0.4–2.1 mm) after 6 months. At 1- to 2-year follow-up, the differences were smaller, but still in favor of PR. Inter-study differences were due to the varying choices of reference sites, surgical and prosthodontic methodologies, as well as follow-up times. It was also found that within the same type of restoration, grafting the jumping gap offered better RW preservation up to 4 years of follow-up, with both cases showing about half as much resorption in the grafted sites as non-grafted sites.^{39,53} This aligns with the literature and the 7th Consensus Statement of the International Team for Implantology recommending bone grafting with IIP.^{6,16} However, in Amato,³⁹ the non-grafted PR group showed even less resorption than the grafted CHA group, which also demonstrates the potential positive effect of individualized PR. The tissue-preserving effect was most pronounced near the implant neck, consistent with the findings of Su et al.^{39,52} As the alveolar bone and mucosa are interdependent, the preservation or loss of either could affect the other simultaneously. To achieve the best clinical outcome, one should aim to preserve both hard- and soft tissues synergistically, applying both bone- and soft-tissue grafting as well as individualized restorations to promote optimal healing.

Amato³⁷ investigated three diameters (5 mm, 6 mm, and 7.5 mm) of CHA, as well as AHA and PR in first or second molar extraction sockets in their RCT, without any bone grafts to avoid confounding. On average, molar teeth are 7–10 mm in diameter; therefore, a larger diameter implant and abutment may prevent the resorption of surrounding tissues, which explains why the widest CHA of 7.5 mm, fitting best in the extraction socket, resulted in the lowest bone resorption (1.56–2.53 mm) among the CHA groups.^{37,63} Nonetheless, this still failed to reach the preserving effect of the PR (1.11–1.23 mm) and AHA (0.19–0.30 mm) groups with individualized EP providing more superior socket sealing and tissue support.³⁷ The AHA group significantly outperformed the PR group in this study, possibly due to the loading effects discussed earlier, that is, the AHA group could allow for better, more undisturbed healing of hard tissues; however, further direct comparisons are required.³⁷

Wang et al. was the only study to examine the buccal mucosa separately.⁵⁴ They reported a significant difference in volume between the PR and CHA groups at 1 year, where the volume loss was 17.4% in the CHA group but only 11.9% in the PR group. The region of interest for this measurement was a rectangular area located 2–6 mm apical to the mucosal margin. The depth of post-extraction implant insertion was 3 mm below the mucosal margin. Even when accounting for the 0.1 mm mid-facial mucosal recession observed up to the time of measurement, this indicates that the measured area extended from 1 mm coronally to 3 mm apically to the implant platform, reaching the bony structure as well. This suggests that the effect of the PR may not only affect the supracrestal complex but also the crestal soft tissues. Unfortunately, the 2 mm range at the mucosal margin was not measured, and no separate data were

available for the supra- and sub-platform levels, which calls for further investigation, as the supracrestal area that is not supported by crestal bone may be most affected by the implant superstructure.⁵⁴

All in all, although data from individual studies suggest that AHA and PR might preserve horizontal tissue thickness, quantitative synthesis of these results was not feasible; therefore further investigations with a standardized methodology and long-term follow-up are needed for vertical and also for horizontal hard- and soft-tissue changes, where bone and mucosal changes shall be investigated separately.

4.4 | Esthetics and patient-oriented outcomes

Pink esthetic score is an objective measure of soft-tissue quality and quantity based on the available amount of vertical and horizontal tissues.^{5,64,65} A statistically significant and clinically relevant advantage was found for the intervention groups over the CHA group at the 1-year follow-up, both in the overall effect and for the PR subgroup of the meta-analysis. Sensitivity analyses excluding posterior implant sites and focusing only on anterior sites yielded similar results. However, high heterogeneity was found in the analyses, which should be accounted for. Among the PR group studies, Li et al. was the only study that did not take the PR out of occlusion.⁴⁸ However, this did not seem to affect PES, as the results were similar to those of Ning et al. These two studies had larger differences between the PR and CHA groups, primarily due to the low PES in the CHA group, in which dynamic compression technique was applied to individualize EP prior to the final rehabilitation.^{48,49} This method of EP formation is technique-sensitive and may damage peri-implant tissues if not performed carefully or if there is insufficient vertical and horizontal mucosa available for manipulation, which may explain the lower PES in these cases.^{5,48,49,66}

The subgroup analysis of the AHA group did not show a significant difference due to the limited number of studies with small sample sizes; therefore, further studies are needed to demonstrate the true effect of this intervention. However, the individual results of all studies included in the analysis favored the AHA group; furthermore, the test for subgroup differences did not reveal a significant intergroup difference between the AHA and PR groups; therefore, results of future studies might also show results in favor of the use of anatomically shaped healing abutments.^{44,50}

Perez et al. reported that distal papilla scores were significantly better in the AHA group than in the CHA group at 1-year follow-up.⁵⁰ Arora et al. also found a significant advantage for the PR group in the same parameter, with up to 4 years of follow-up.⁴⁰ This is consistent with a recent network meta-analysis, where IIP with immediate provisionalization ranked first in distal papilla height compared with later placement and loading protocols.⁶⁷ This effect may be due to the fact that anatomic restoration can better support the interproximal soft tissue and allow vertical regrowth of the papilla, and moreover, due to the direction of the blood supply, the distal papilla may have better blood flow; furthermore, the distal contact point is generally more apical and closer to the marginal bone due to the lower height of the teeth, thus the papilla can more easily fill the sub-contact area.^{22,68}

Though PES is a commonly accepted and frequently applied measure of the peri-implant soft-tissue esthetics, it is evaluated clinicians based on parameters which patients may not find important, and clinicians also tend to be more critical in evaluation.^{65,69,70} However, patient-reported outcome measures (PROMs) that could reflect patient needs are often not unified across studies and not based on validated questionnaires, the most common tool of which is the visual analogue scale.^{69,70} However, recent reviews and consensus reports have shown that there is low correlation between clinician and patient evaluation of esthetic results, which warrants further caution when interpreting PES results.⁶⁹⁻⁷²

The quantitative analysis of overall patient satisfaction in this review included three studies, all of which measured satisfaction levels on VAS. Differences were not statistically significant due to the small number of studies and high heterogeneity. It is important that PROMs should be evaluated based on unified measurement methods, such as internationally validated questionnaires.^{69,70} No other patient-reported outcome measures were available for analysis, but the inclusion of parameters focusing on multiple aspects of patient satisfaction should be considered by further studies, given the increasing focus on individualized, patient-centered care.

4.5 | Strengths and limitations

This is the only systematic review with meta-analysis that investigated both immediate provisionalization and anatomically shaped healing abutments against the conventional cylindrical healing abutments. Only two-armed studies published after the year 2000 were used, and most included studies followed strict selection criteria and surgical protocols.

Unfortunately, due to a lack of studies, especially those with long-term follow-up, not all clinical parameters and confounding factors could be analyzed, which contributed to the high heterogeneity in our synthesis results. These include mucosal phenotype, implant location (anterior or posterior) and position, guided implantation, insertion torque, implant system, connection type, healing and prosthetic abutment diameters, restoration material and retention method, digital or conventional workflow, possible subgingival veneering, and application of dynamic compression techniques. The authors also had to include retrospective cohort studies, which reduced the level of evidence, but most studies synthesized in the meta-analyses were RCTs with low risk of bias. Furthermore, the amount of additional financial, temporal, and labor cost of AHA and PR could not be investigated; yet it would be crucial to evaluate cost-effectiveness for implementation in routine clinical practice.

4.6 | Implications for practice and research

Within the limitations of current data, the application of PR or AHA may be recommended to improve esthetics, particularly important in the esthetic region. For best clinical outcome, hard- and soft

tissues should be preserved synergistically, applying both bone and soft-tissue grafting as well as individualized restorations to promote optimal healing.

More well-designed RCTs with large sample sizes and long-term follow-up are needed to investigate changes in vertical and horizontal hard- and soft tissues, as well as esthetic results. The potential of stock, anatomically shaped, coded, multi-purpose healing abutments should also be explored and investigated. Future studies should also focus on determining the chairside time and cost-effectiveness of AHA, PR, and CHA, as the aim of research is to find the optimal treatment option in clinical practice.^{73,74}

5 | CONCLUSION AND CLINICAL APPLICATION

The application of individually shaped transmucosal components, especially provisional restorations on immediate single implants significantly improved pink esthetics compared with prefabricated cylindrical healing abutments in short term without compromising implant survival or marginal bone; therefore, their use may be beneficial in clinical practice.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS APPROVAL AND PATIENT CONSENT STATEMENT

No ethics approval was required for this meta-analysis as all data applied for this study had been published in peer-reviewed journals. No patients were involved in any part of our study.

PROTOCOL REGISTRATION

The protocol was prospectively registered in the PROSPERO International prospective register of systematic reviews (CRD42023458206).

DECLARATION OF GENERATIVE AI IN SCIENTIFIC WRITING

During the preparation of this work, the authors used no AI tools. The authors take full responsibility for the content of the publication.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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Appendix Document 3. Publication related to Study III.

Clinical Oral Implants Research

WILEY

CLINICAL ORAL IMPLANTS RESEARCH

REVIEW ARTICLE

OPEN ACCESS

Accuracy of Digital Impression Methods for Capturing the Peri-Implant Emergence Profile: A Systematic Review

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Keywords: computer-aided design | crowns | dental esthetics | dental impression technique | fixed partial denture | single-tooth dental implant

ABSTRACT

Background: Accurately replicating the emergence profile (EP) of conditioned soft tissue is pivotal for the success of implant-supported restorations. In the field of digital technology, various methods have emerged to capture EP. This review aims to critically assess current digital methodologies for capturing peri-implant EP.

Material and Methods: Prospective interventional or observational clinical studies focusing on digitally mapping the emergence profile (EP) around single implant-supported restorations were included. Systematic reviews, in vitro and animal studies, and those not emphasizing EP capture were excluded. A systematic search across four databases (MEDLINE, CENTRAL, Embase, Web of Science) was conducted on 7th August 2024 based on a previously registered protocol (PROSPERO registration number: CRD42023459484). Risk of bias was assessed with RoB 2, ROBINS-I, and JBI critical appraisal tools. Qualitative and quantitative analyses were carried out.

Results: Twenty-four eligible studies were identified, comprising 5 dental techniques, 12 case reports, 1 randomized controlled study, 2 cross-sectional studies, and 4 cross-over studies. The studies reported semi-digital pathways, direct scanning, indirect scanning, coded-healing abutments, and individualized use of scan bodies. Notably, the direct scanning technique showed considerable soft tissue collapse. Similar results can be achieved with indirect scanning and the conventional method.

Conclusions: Indirect EP scanning appears as the most promising method for capturing peri-implant EP. However, a confirmation of this finding requires a quantitative analysis through randomized clinical trials.

1 | Introduction

In recent decades, implant-supported restorations have evolved into a well-established therapeutic option for restoring a single tooth in the esthetic zone. However, these cases may be esthetically challenging, and success is determined by the presence of a well-contoured prosthesis blending seamlessly with adjacent natural teeth while ensuring the long-term health of both hard

The first two authors contributed equally to this study.

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and soft tissues (Doliveau et al. 2020; Lewis and Klineberg 2011; Montero 2021; Ntounis and Petropoulou 2010; Polack 2002; Wittneben et al. 2013).

Achieving a natural peri-implant emergence profile (EP) during the provisional phase is of paramount importance in the esthetic zone (De Rouck et al. 2009; Morton et al. 2014; Wittneben et al. 2013). Diverse analog and digital techniques have been proposed to establish the most esthetic EP, all while promoting optimal peri-implant soft tissue development and architecture (Dhingra et al. 2020; Wittneben et al. 2016). The use of implant-supported provisional restorations (ISPR) and customized healing abutments can assist in obtaining the desired EP, thereby attaining satisfactory results for the definitive restoration (Breeding and Dixon 1996; Doliveau et al. 2020; Esguerra 2016; Finelle and Lee 2017; Lin et al. 2013; Liu et al. 2017; Liu et al. 2018; Oh et al. 2019; Proussaefs and AlHelal 2018; Yilmaz and Abou-Ayash 2020; Yiqing et al. 2018).

Accurately transferring implant positions plays a pivotal role in attaining long-term success in implant therapy while mitigating the risk of mechanical and biological complications

(Kunavisarut et al. 2002; Sahin et al. 2002; Wang et al. 2002). However, the precise translation of soft tissue information onto the working cast to enable faithful reproduction of this preestablished EP is challenging (Azer 2010; Dhingra et al. 2020; Esguerra 2016; Liu et al. 2017; Monaco et al. 2019; Yilmaz and Abou-Ayash 2020; Yiqing et al. 2018). For capturing soft tissue information, both analog and digital methods are available. **Conventional methods (CM)** include the use of elastomeric impression materials with individualized open-tray impression copings, which, despite having been used for a long time, are associated with disadvantages such as patient discomfort and extended chairside time (Burhardt et al. 2016; Glisic et al. 2019) (Figure 1A–C). Digital methods, which replace CMs with intraoral scans (IOs) are gaining importance for single-unit restorations, with the potential for reducing the aforementioned disadvantages (Lee and Gallucci 2013; Wismeijer et al. 2018).

The **direct digital EP** scanning procedure for a definitive single-unit restoration involves three distinct scans: (1) The initial scan encompassing the ISPR along with the surrounding soft tissue; (2) the direct EP scanning of the peri-implant soft tissue taken immediately after ISPR removal; and (3) a

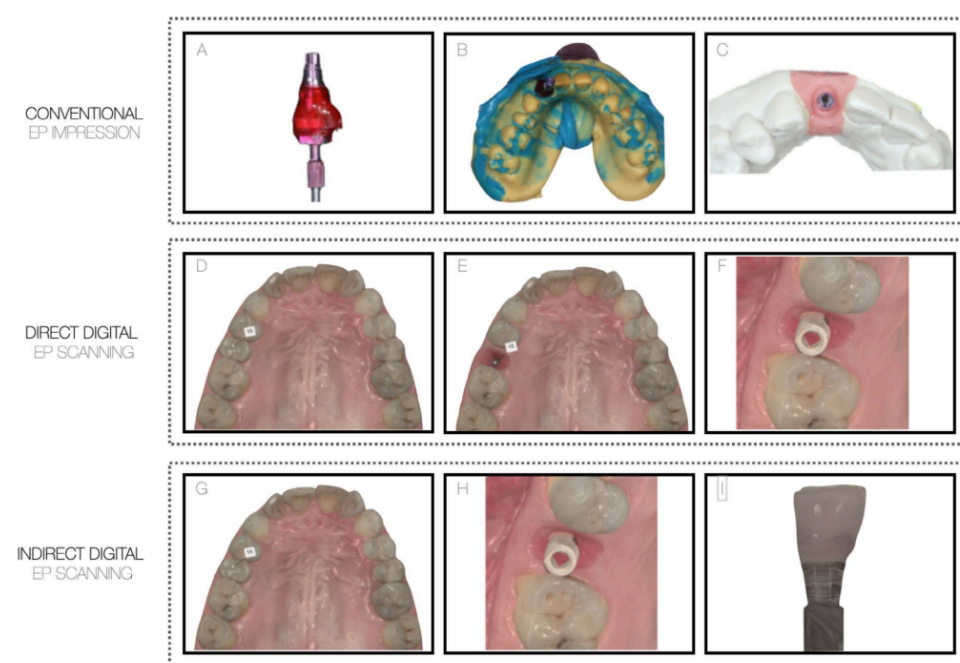


FIGURE 1 | Steps of conventional (A, B, and C), direct digital (D, E, and F), and indirect digital (G, H, I) workflows of peri-implant emergence profile (EP) replication. (A) Customized open-tray impression coping replicating the EP of the provisional restoration (ISPR); (B) Open-tray elastomeric impression with the technical analog attached to the impression coping; (C) Epoxy-resin cast with resilient gingival mask; (D, G) Intraoral full-arch scan with the ISPR in situ, to support the computer-aided design (CAD) phase; (E) Direct EP scan immediately after ISPR removal; the EP of the final restoration will follow the peri-implant soft tissue profile captured at this stage; (F, H) Registering implant position with a scan body; (I) Extraoral indirect EP scan of the ISPR, which will be overlapped with the scan with the ISPR in situ, to obtain the subgingival EP at the CAD phase.

scanbody screwed to the implant, enabling the precise 3D localization of the latter (Monaco et al. 2019) (Figure 1D–F). However, contradictory data exist regarding the digital scanning accuracy of the soft-tissue profile subsequent to the removal of the ISPR. Conflicting findings have emerged from other studies, indicating that ISPR removal can induce a considerable, time-dependent alteration in the submucosal contour due to the rapid peri-implant soft tissue collapse (Duran et al. 2018; Joda 2015; Li et al. 2019). Recently, an **indirect scanning protocol**, which involves an additional extraoral scanning of the ISPR, has been proposed, with the aim of eliminating the inaccuracies of direct scanning (Monaco et al. 2016; Xiong et al. 2022) (Figure 1G–I).

Due to the variability in the potential impact of ISPR removal on the accuracy of peri-implant mucosa replication, the primary objective of this review was to assess the precision of direct and indirect digital impression methods in capturing peri-implant EP compared to the conventional impression around single implant-supported crowns, based on the available evidence.

2 | Material and Methods

This study was conducted based on the Cochrane Handbook (Higgins et al. 2022), and reported following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines (Page et al. 2021). The study was registered in the International Prospective Register of Systematic Reviews (PROSPERO on 10th October 2023 registration number: CRD42023459484, https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=459484).

2.1 | Eligibility Criteria

The aim of this study was to answer the following PICO question: How accurate (outcome—O) are direct and indirect digital impression methods (interventions—I1, I2) for capturing peri-implant emergence profiles in patients with single implant-supported crowns (population—P) compared to the conventional impression (comparator—C)?

Studies matching the following criteria were included: clinical trials, case reports, and case series of patients in need of implant-supported single restorations(s), describing a method used for digital EP replication. Studies not meeting these inclusion criteria were excluded: questionnaires, *in vitro* and animal studies, systematic reviews, and conference abstracts.

2.2 | Search, Selection and Data Collection

A comprehensive search was conducted on August 7, 2024 in MEDLINE, EMBASE, Web of Science, and Cochrane Central Register of Controlled Trials (CENTRAL) to select eligible studies with the following keywords: (dental implant) AND digital AND (impression OR replication OR capturing OR scan*) AND ((emergence profile) OR (soft tissue) OR (peri-implant mucosa)).

Following automatic and manual duplicate removal, two reviewers (KM and XQ) independently selected the articles based on titles, abstracts, and full texts. Disagreements were resolved by discussion between the two reviewers. The following parameters were extracted from eligible articles: first author, year of publication, study type, number of participants, implant type and position, phenotype, impression technique, type of cast, type of intraoral scanner applied, definitive prosthetic restoration, esthetic outcomes, and study results, including main findings and numerical data for measurement results regarding EP discrepancies between different impression methods. Qualitative and quantitative analyses were carried out. The methodology and results of the quantitative analyses can be found in Appendix S1.

No ethical approval was required for this review, as all data had already been published in peer-reviewed journals. The datasets used in this study can be found in the full-text articles included in the review. No patients were involved in the planning, conduct, or interpretation of our study.

3 | Results

After selection, 24 articles were deemed eligible for the analysis, including 5 dental techniques, 12 case reports, 1 pilot randomized controlled study, 2 cross-sectional studies, and 4 cross-over studies, among which 2 were pilot studies (Agnini et al. 2023; Canullo et al. 2018; Crockett et al. 2019; da Silva Marques et al. 2019; Dada et al. 2021; Dhingra et al. 2020; Doliveux et al. 2020; Duran et al. 2018; Galibourg et al. 2021; Joda 2015; Joda et al. 2014; Lee 2016; Li et al. 2019; Lin et al. 2013; Ling et al. 2023; Liu et al. 2017; Mesquida et al. 2024; Mino et al. 2019; Monaco et al. 2016; Monaco et al. 2019; Tanaka et al. 2023; Xiong et al. 2022; Yilmaz and Abou-Ayash 2020; Zimmermann et al. 2022) (Table 1). The selection flowchart is shown in Figure 2. The reasons for excluding retrieved articles at the full-text selection phase are listed in Table S1 (available online).

3.1 | Conventional EP Replication

In four comparative studies, a CM was employed as a control group, contrasted against their respective reported digital methods (Canullo et al. 2018; da Silva Marques et al. 2019; Duran et al. 2018; Xiong et al. 2022). Canullo et al. compared conventional and digital workflows in a case report, using traditional analog impressions with a customized implant impression coping (CIIC) and indirect EP scanning of the provisional crown to create full ceramic single crowns. Both methods resulted in minimal bone loss and esthetic success after 3 years (Canullo et al. 2018). The remaining studies involved scanning stone casts to establish a comparison with the digital models. Da Silva Marques et al. employed a customized stock impression coping, incorporating the impression of the patient's well-designed provisional crown to accurately replicate the EP (da Silva Marques et al. 2019). Duran et al. and Xiong et al. directly used the provisional restoration to take the impression and poured the stone cast immediately (Duran et al. 2018; Xiong et al. 2022). All of these stone casts were scanned to compare them to the digital models *in silico*.

TABLE 1 | Characteristics of the included studies.

Author, year	Study type	Number of patients	Number of implants	Implant type and position	Phenotype	Impression technique		Type of intraoral scanner	Type of cast	Definitive restoration	Esthetic outcomes of definitive restoration	Main findings
						Conventional	Digital					
Agnini et al. 2023	Case report	1	1	2L, NR	NR	—	Provisional in situ + scanbody + indirect	NR	NR	Screw-retained zirconia crown	—	New technique for EP replication
Canullo et al. 2018	Comparative case report	2	2	1L, PRAMA	NR	Customized impression coping	Provisional in situ + scanbody + indirect	Carestream, CS3600	Stone (case1); digital (case2)	Zirconia abutment + cemented lithium disilicate crown	PES: analog 8, digital 9	3-year success for both analog and digital pathway
Crockett et al. 2019	Dental technique	1	1	22, nr	NR	—	Provisional in situ + scanbody + indirect	3Shape, TRIOS	NR	NR	—	New technique for EP replication
da Silva Marques et al. 2019	Cross-over pilot study	6	6	maxillary esthetic zone, NR	NR	Customized impression coping	Direct EP scan	3Shape, TRIOS	Stone vs. digital	NR	—	EP from immediate direct scanning showed significant differences
Dada et al. 2021	Case report	1	1	2L, Straumann	NR	—	Provisional in situ + indirect with repositionable analogue	3Shape, TRIOS	3D-printed	Zirconia abutment + ceramic veneering	—	New technique with repositionable analogue for EP replication
Dhingra et al. 2020	dental technique	1	1	2L, Straumann	NR	—	Provisional in situ + direct + scanbody + indirect	3Shape, TRIOS3	Digital	Full-contour lithium disilicate crown	—	New technique for EP replication
Dolivet et al. 2020	dental technique	1	1	12, Straumann	NR	—	Provisional in situ + scanbody + indirect	3Shape, TRIOS	3D-printed	NR	—	New technique for EP gingival mask fabrication on 3D-printed cast

(Continues)

TABLE 1 | (Continued)

Author, year	Study type	Number of patients	Number of implants	Implant type and position	Phenotype	Impression technique		Type of intraoral scanner	Type of cast	Definitive restoration	Esthetic outcomes of definitive restoration	Main findings
						Conventional	Digital					
Duran et al. 2018	Cross-over study	10	10	Maxillary esthetic zone, Biohorizons	NR	Provisional served as impression coping	Direct EP scan	Cerec Omnicam	Stone vs. digital	NR	—	EP from immediate direct scanning showed significant differences
Gailbourg et al. 2021	Cross-sectional study	16	16	Maxillary esthetic zone, NR	NR	—	Direct EP scan at 0 s, 30 s, 2 m, 5 m	Planmeca	—	—	—	Significant EP collapse after 30 s compared to immediate direct EP scan
Joda et al. 2014	case report	1	1	22, Straumann	NR	—	Customized scanbody with conventional customization technique	iTero	NR	Zirconia abutment + ceramic veneering	PES: 9	New technique for mucosal margin replication, but submucosal part of EP can't be captured
Joda 2015	Cross-sectional study	5	5	Maxillary esthetic zone, Straumann	NR	—	Direct EP scan at 0 s, 5 m, 10 m	iTero	—	—	—	Slight EP change after 5 min, more significant after 10 min compared to immediate direct EP scan
Lee 2016	Case report	1	1	36, NR	NR	—	Provisional in situ then continued indirect scanning extraoral + scanbody	3Shape, TRIOSColor Pod	Digital	Customized titanium abutment + zirconia crown	—	New technique for EP replication

(Continues)

TABLE 1 | (Continued)

Author, year	Study type	Number of patients	Number of implants	Implant type and position	Phenotype	Impression technique			Type of intraoral scanner	Type of cast	Definitive restoration	Esthetic outcomes of definitive restoration	Main findings
						Conventional	Digital						
Li et al. 2019	cross-sectional study	10	12	Maxillary esthetic zone, NR	NR	—	[provisional in situ + indirect] vs. [direct EP scan at 0 s, 30 s, 1 m, 2 m, 3 m, 4 m, 6 m, 8 m, 10 m, 20 m]	3Shape, TRIOSColor Pod	—	—	—	Slight EP change at immediate direct EP scan that increased gradually compared to indirect EP scan	
Lin et al. 2013	Dental technique	1	4	14,13,23,24, Straumann	NR	Diagnostic impression with provisional in situ	Scanbody	iTero	Milled polyurethane	—	—	—	New technique for EP gingival mask fabrication on milled cast
Ling et al. 2023	Randomized controlled trial	15	22	Maxillary, esthetic zone, Nobel Biocare	NR	—	[Direct EP scan] vs. [indirect EP scan] + provisional in situ + scanbody	3Shape, TRIOS3	3D-printed	Customized titanium abutment + zirconia crown with direct vs. indirect pathway	PES: direct 7.89±1.52, indirect 8.09±2.27	Indirect scanning accurately replicates soft tissue profiles, while there is a collapse with the direct technique	
Liu et al. 2017	Case report	1	3	11, 21, 22, NR	NR	—	Provisional in situ + scanbody + indirect	3Shape, TRIOS	3D-printed	—	—	—	New technique for EP replication
Mesquida et al. 2024	Case report	1	1	11, Nobel Biocare	NR	—	Provisional in situ + scanbody + indirect	3Shape, TRIOS3	Digital	NR	NR	NR	New technique for EP replication
Mino et al. 2019	Case report	1	1	47, Straumann	NR	—	Provisional in situ + scanbody + indirect	3Shape, TRIOS2	Digital	Customized titanium abutment + zirconia crown	—	—	New technique for EP replication

(Continues)

TABLE 1 | (Continued)

Author, year	Study type	Number of patients	Number of implants	Implant type and position	Phenotype	Impression technique			Type of intraoral scanner	Type of cast	Definitive restoration	Esthetic outcomes of definitive restoration	Main findings
						Conventional	Digital						
Monaco et al. 2016	Case report	1	1	LL, Straumann	NR	—	Provisional in situ + scanbody + indirect		3M ESPE	3D-printed	Zirconia abutment + ceramic veneering	—	New technique for EP replication
Monaco et al. 2019	Dental technique	—	NR	Esthetic zone	NR	—	[Direct EP scan] vs. [provisional in situ + scanbody + indirect]		NR	—	—	—	Direct scanning requirements; no soft tissue collapse within 1 min, short, wide, and conical EP shape; proposed protocol for direct and indirect multiscan techniques
Tanaka et al. 2023	Case report	1	1	I3, Straumann	NR	—	Provisional in situ + scanbody + indirect		3Shape, TRIOS3	Digital	Titanium-base + monolithic zirconia crown	—	Fully digital technique with no need for a physical cast
Xiong et al. 2022	Cross-over study	16	16	Maxillary esthetic zone, NR	NR	Provisional served as impression coping	[Provisional in situ + indirect] vs. [immediate direct EP scan]		3Shape, TRIOS	Stone vs. digital	—	—	Accurate EP replication with indirect multiscan technique; rapid EP collapse with immediate direct EP scan

(Continues)

TABLE 1 | (Continued)

Author, year	Study type	Number of patients	Number of implants	Implant type and position	Phenotype	Impression technique		Type of intraoral scanner	Type of cast	Definitive restoration	Esthetic outcomes of definitive restoration	Main findings
						Conventional	Digital					
Yilmaz and Abou-Ayash 2020	Case report	1	1	46, Neoss	NR	—	Stock anatomic healing abutment with connectable scanbody	3Shape, TRIOS	Digital	Customized titanium abutment + zirconia crown	—	New combined healing abutment-scanbody implant system
Zimmermann et al. 2022	Case report	1	1	14, S.L.N.	NR	Partial arch impression with provisional in situ	Provisional in situ + direct + scanbody + indirect with provisional in the conventional impression	3Shape, TRIOS 3	Digital	Lithium disilicate crown	—	New technique for EP replication

Abbreviations: EP, emergence profile; NR, not reported; PES, pink esthetic score.

3.2 | Semi-Digital EP Replication

In the semi-digital method, a CM was also applied at some point in the workflow. In some cases, impressions were made digitally, but for esthetical reasons, the crowns were hand-veneered on 3D-printed or milled casts. Meanwhile, Zimmerman et al. took an impression containing the ISPR and scanned this assembly to replicate the submucosal EP contour of the crown (Zimmermann et al. [2022](#)). Lin et al. took an impression with the ISPR in situ, then used this impression as an index for creating a removable, resilient gingival mask on the milled cast (Lin et al. [2013](#)). Doliveux et al. applied a very similar technique but perfected it by 3D printing an ISPR replica for the same purpose, avoiding the need to hold on to the patient's ISPR (Doliveux et al. [2020](#)).

3.3 | Direct EP Scanning

Ten studies reported on direct EP scanning, involving the immediate intraoral scanning of soft tissue following ISPR removal (da Silva Marques et al. [2019](#); Dhingra et al. [2020](#); Duran et al. [2018](#); Galibourg et al. [2021](#); Joda [2015](#); Li et al. [2019](#); Ling et al. [2023](#); Monaco et al. [2019](#); Xiong et al. [2022](#); Zimmermann et al. [2022](#)).

3.3.1 | Soft Tissue Collapses in Direct Scanning

All clinical studies reported significant soft tissue collapses immediately after removing the ISPRs, although to different extents as the degree of collapse depends on various factors such as 3D implant position, the amount of vertical and horizontal soft tissue, phenotype, and implant diameter (da Silva Marques et al. [2019](#); Duran et al. [2018](#); Galibourg et al. [2021](#); Joda [2015](#); Li et al. [2019](#); Ling et al. [2023](#); Xiong et al. [2022](#)).

Li et al. used the virtual model based on the indirect EP scanning, whereas da Silva et al. and Xiong et al. applied digital scans of the conventional casts as control groups. Approximately 244 µm was detected by Da Silva Marques et al. and 415 µm by Xiong et al., while Li et al. reported on a smaller, yet still significant collapse both immediately (approximately 200 µm) and up to 20 min (up to 1 mm) after ISPR removal when compared to the indirect EP scanning (da Silva Marques et al. [2019](#); Li et al. [2019](#); Xiong et al. [2022](#)).

As reported by Li et al., a discrepancy in peri-implant soft tissue was observed in non-keratinized, less rigid and stable peri-implant mucosa (Ivanovski and Lee [2018](#); Li et al. [2019](#)). This slight dimensional change increased gradually over time, and there was a statistically significant discrepancy (range of 0.08 mm to 0.18 mm) immediately after the removal of the ISPR, suggesting some inaccuracy in direct scanning (Li et al. [2019](#)).

Galibourg et al. and Joda compared the soft tissue collapse at different time points (30 s, 2 min, 5 min), (0 s, 5 min, 10 min) to the immediate direct scanning, where further significant soft tissue collapse was also observed as time passed (Galibourg et al. [2021](#); Joda [2015](#)). Duran et al. also reported dimensional changes in peri-implant soft tissues immediately after ISPR removal compared to the conventional cast made with a pick-up impression with the patient's ISPR. These changes occurred primarily at

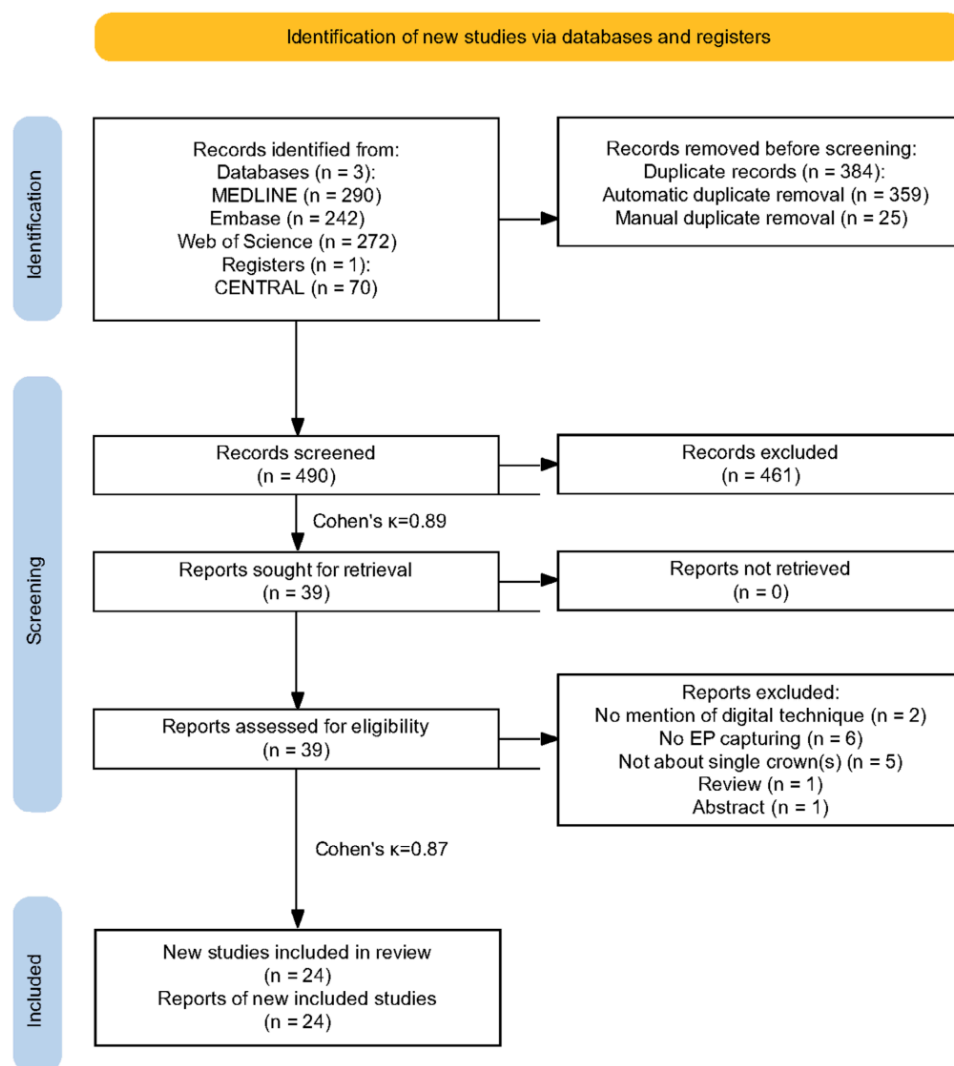


FIGURE 2 | Flowchart of the selection process.

the midlevel gingiva in the buccolingual (BL) dimension, and at both the coronal and midlevel gingiva thirds in the mesiodistal (MD) dimension. The changes ranged from 0.51 mm (coronal) to 1.35 mm (midlevel) (Duran et al. 2018).

Xiong et al. compared the accuracy of intraoral scanning for peri-implant soft-tissue profiling with and without the removal of the ISPR. They stated that the peri-implant mucosa collapsed

by approximately 500 μ m after 20 s of ISPR removal, regardless of the patient's phenotype, thus demonstrating that the ISPR plays a crucial role in preserving peri-implant soft-tissue architecture (Xiong et al. 2022). Li et al. observed that there was a statistically significant, but clinically minimal, displacement of the papilla and mucosal zenith levels, with up to 0.07 mm decrease immediately after ISPR removal, and up to 0.27 mm at 20 min (Li et al. 2019).

Galibourg et al. found that the volume of the EP decreased over time, with an average of 5% at 30 s, 10% at 2 min, and 14% at 5 min compared to the immediate direct scanning (Galibourg et al. 2021). Compared with the same reference, Joda 2015, only reported a 5.5% dimensional deviation at 5 min and a 21.7% deviation after 10 min of ISPR removal (Joda 2015). Following the conversion of the 5-min soft tissue collapse values measured by Galibourg et al. and Joda to percentage decrease of EP area, the results of both studies were coherent (Galibourg et al. 2021; Joda 2015). A standard for the clinically acceptable threshold should be decided according to the difference in accuracy of the indirect EP scanning and CM, as both are considered clinically accepted impression methods; however, the performance of this analysis was not possible due to the lack of data.

Ling et al. conducted a randomized controlled trial comparing the EP supported by definitive crowns fabricated with either direct or indirect EP scanning to the original EP supported by the provisional. They found a mean volumetric difference of 1.87 mm³ vs. 0.75 mm³ labially and 1.66 mm³ vs. 0.65 mm³ palatally with direct vs. indirect EP scanning, respectively. This would appear to indicate a more significant soft tissue collapse in direct scanning, albeit not statistically significant changes in both groups. The thickening of the mucosa was more prominent apically than coronally (Ling et al. 2023).

3.4 | Indirect EP Scanning

Seventeen studies reported on indirect EP scanning methods, which require multiple scans to be made and superimposed to obtain all necessary information for prosthetic fabrication (Agnini et al. 2023; Canullo et al. 2018; Crockett et al. 2019; Dada et al. 2021; Dhingra et al. 2020; Doliveux et al. 2020; Lee 2016; Li et al. 2019; Ling et al. 2023; Liu et al. 2017; Mesquida et al. 2024; Mino et al. 2019; Monaco et al. 2016; Monaco et al. 2019; Tanaka et al. 2023; Xiong et al. 2022; Zimmermann et al. 2022).

Dada et al. did not use a scanbody at all, but made an indirect scan with the ISPR screwed into a repositionable analog to design the final restoration (Dada et al. 2021). Lee et al. made an intraoral scan with the scanbody, then attempted to scan the ISPR in situ, and continued the same scan extraorally as the indirect scan. However, the software did not easily process such information, raising the risk of false data (Lee 2016). Dhingra et al. and Zimmermann et al. meanwhile, not only made the three basic scans mentioned earlier but performed a direct EP scan as well (Dhingra et al. 2020; Zimmermann et al. 2022). In a crossover study, Xiong et al. reported that indirect scanning was able to replicate the EP as accurately as the CM, with the ISPR serving as an impression coping (Xiong et al. 2022). Ling et al. concluded in their randomized controlled trial that while slight deviations occur, the indirect technique allows an acceptable replication of the provisional crown's submucosal contour (Ling et al. 2023). According to a comparative case report of two patients by Canullo et al., the 3-year outcomes of an anterior crown made digitally with indirect scanning are similar to those fabricated with a conventional workflow (Canullo et al. 2018). Zimmermann et al. performed a digital scan of the ISPR in situ and took an elastomeric impression with it. After removing the

ISPR from the mouth, they performed a direct EP scan, then registered the 3D position of the implant with the help of a scanbody. Finally, they performed an indirect EP scanning with the ISPR seated in the elastomeric impression (Zimmermann et al. 2022).

3.5 | Special Scanbodies

Two studies reported on the use of special scanbodies (Joda et al. 2014; Yilmaz and Abou-Ayash 2020). Joda et al. (2014) customized stock scanbodies (Joda et al. 2014). Yilmaz et al. reported on a special implant system that manufactured coded, anatomical, stock healing abutments, to which a special scanbody can be attached, but there were no measurements reported on the accuracy of this technique (Yilmaz and Abou-Ayash 2020).

3.6 | 3D-Printed and Milled Casts

Some studies fabricated the definitive prosthesis using only virtual models (Canullo et al. 2018; da Silva Marques et al. 2019; Dhingra et al. 2020; Duran et al. 2018; Lee 2016; Mino et al. 2019; Tanaka et al. 2023; Yilmaz and Abou-Ayash 2020; Zimmermann et al. 2022), whereas others 3D-printed or milled casts for checking and/or veneering the crowns (Dada et al. 2021; Doliveux et al. 2020; Lin et al. 2013; Ling et al. 2023; Liu et al. 2017; Monaco et al. 2016).

Doliveux et al. and Lin et al. used the provisional crown and an elastomeric impression as an index for creating a resilient gingival mask on the fabricated cast (Doliveux et al. 2020; Lin et al. 2013).

Monaco et al. 2016, Liu et al., and Dada et al. used 3D-printed casts to manufacture veneered crowns on zirconia abutments (Dada et al. 2021; Liu et al. 2017; Monaco et al. 2016). None mentioned any use of resilient gingival masks.

4 | Discussion

Once the desired soft tissue profile has been established, its accurate transfer is critical, but the question is whether the digital methods compete with the gold standard CM (Dhingra et al. 2020).

This is the first systematic review aimed at determining the best method for capturing peri-implant EP, summarizing the most recent evidence. Articles addressing the topic revealed a marked heterogeneity concerning the study types. The main findings by different methods of EP replication are outlined in Table 1.

4.1 | Systematic Review of the Collapse of the Peri-Implant Mucosa

Duran et al. found that a digital impression does not accurately capture the EP immediately after ISPR removal, reporting a 0.51–1.35 mm deviation (Duran et al. 2018). However, they measured the whole cross-sectional mesiodistal or buccolingual distances, including the mucosa on both sides and the space in between, instead of the inner surface dimensional changes, which may explain the larger deviations; therefore, their results cannot

be compared to those of other trials. More rigorous methodologies should be applied in further studies. In comparison, Joda discovered a minor percentage change in the EP after 5 min and a more noticeable change after 10 min when compared to an immediate direct EP scan (Joda 2015; Li et al. 2019). The differences in the findings can be attributed to applying different measurement techniques. Joda used conventional impressions, in which the mucosa could have been compressed, while Li et al. directly scanned the peri-implant mucosa with IOS (Joda 2015; Li et al. 2019).

4.2 | Conventional vs. Digital EP Scanning Methods

Measuring the actual dimensions of the soft tissue *in vivo* can be challenging. Wei et al. evaluated the trueness of intraoral digital impressions by comparing them to the elastomeric impression (Wei et al. 2020). For the soft-tissue scan, Wei et al. reported a trueness level of approximately 80 μm labial to the natural dentition (Wei et al. 2020). Gan et al. reported a trueness level of 130.54 $\pm$ 33.95 μm and a precision level of 55.26 $\pm$ 11.21 μm for palatal soft tissue scans (Gan et al. 2016). Meanwhile, Deferm et al. reported a trueness level of 0.02 $\pm$ 0.07 mm and a precision level of 80 μm (Deferm et al. 2018). While IOS allows direct scanning of the intraoral soft tissue conditions without the need for conventional cast fabrication and the application of desktop or industrial scanners, the accuracy of this method, especially regarding 3D volumetric comparisons, still needs to be investigated (Wittneben et al. 2016).

Da Silva et al. evaluated two impression techniques in 6 patients: CM with CIIC and digital direct EP impression. The study found significant soft tissue differences with IOS use. This could be due to soft tissue collapse without ISPR support. CIIC prevented a 243.89 μm change in peri-implant soft tissue. However, differences were below the 1 mm detectable threshold, and the null hypothesis could not be rejected due to the small sample size (da Silva Marques et al. 2019).

The ISPR can also be used as an impression coping; however, elastomeric impression material must be used in this method as well. Moreover, the cast needs to be poured immediately to recover the ISPR for the patient, and this is only achievable if the technical equipment is in close proximity to the dental office. Xiong et al. found a greater dimensional discrepancy between the direct EP scanning (414.7 $\pm$ 116.0 μm) and conventional impression, as well as between IOS + ISPR (230.6 $\pm$ 85.5 μm) and conventional groups. This was attributed to the silicone gingival mask material used during casting, which might impact peri-implant mucosal accuracy. Inaccuracies during IOS procedures could also contribute to soft-tissue deviation (Xiong et al. 2022). It should be noted that this technique of creating an impression with the ISPR is not practical for everyday use.

4.3 | Indirect EP Scanning

By following the indirect scanning method, a virtual model can be established, which allows for a predictable and definitive restoration in the esthetic area, thereby shortening the

duration of clinical procedures (Agnini et al. 2023; Canullo et al. 2018; Crockett et al. 2019; Doliveux et al. 2020; Lee 2016; Liu et al. 2017; Mesquida et al. 2024; Mino et al. 2019; Monaco et al. 2016; Monaco et al. 2019; Tanaka et al. 2023).

Monaco et al. suggested protocolizing this method; however, this is based on subjective experience, and currently, there is no conclusive evidence to support which technique is suitable and comparable to the gold standard for each phenotype (Monaco et al. 2019). According to Zimmerman et al., the advantage of the indirect technique is to provide a more efficient and rapid workflow to ensure a predictable and successful outcome (Zimmermann et al. 2022). Crockett posits in a dental technique report that the indirect EP scanning technique may be a valid option to capture the peri-implant soft-tissue configuration because the clinician is not under a time limit due to soft tissue collapse (Crockett et al. 2019).

However, the indirect EP scanning is characterized by the need for multiple scan files to be superimposed. One limitation found by Lee et al. was that the scanner's software may struggle to process complex information in the case of larger files, leading to potential inaccuracies (Lee 2016). Dada et al. also reduced the number of scans by eliminating the use of a scanbody and stated that the indirect EP scan with the digital analog is sufficient. However, this may cause inaccuracies in determining the correct implant position in prosthetic planning (Dada et al. 2021).

Ling et al. conducted a randomized controlled trial comparing definitive crowns fabricated based on either direct or indirect EP scanning. Crowns fabricated based on direct scanning could not support the peri-implant mucosa as the ISPRs, causing a significant deviation in the soft-tissue dimensions, with a decrease in vertical and an increase in horizontal aspects. This randomized study evaluates both the accuracy of digital EP replication and the following esthetic results that can be achieved with the prostheses fabricated with the two workflows (Ling et al. 2023).

Moreover, Mesquida et al. described the Boolean operation to merge the indirect EP scan onto the EP mapped around the scanbody, to create the mesh that allows the accurate replication of the definitive restoration based on the indirect EP scanning (Mesquida et al. 2024).

Finally, it should be noted that the accuracy of indirect scanning and the similarity of the definitive restoration's emergence profile to that of the interim restoration are still uncertain due to the low number of rather heterogeneous and low-evidence studies available.

4.4 | Special Scanbodies

Joda et al. customized the scanbody with the conventional customization technique, which only allowed replication of the outer contour and margin of the soft tissue but did not provide data on the actual submucosal EP, as it was not scanned indirectly (Joda et al. 2014).

Also available are coded healing abutments, which allow not only shaping of the EP but also impression-taking without the need

for removing the healing abutment. This shortens the workflow, and after scanning, the data can immediately be transferred for the fabrication of the restoration (Abduo et al. 2017; Attar 2023). These scannable healing abutments also seem promising, but only limited data are available.

4.5 | 3D-Printed and Milled Casts

When fabricating dental prostheses using a hybrid workflow with a digital impression, a physical model is still required for the veneering. Lin et al. used a new technique for removable, resilient EP gingival mask fabrication on milled polyurethane casts with the patient's ISPR (Lin et al. 2013), while Doliveux et al. modified the technique by replacing the ISPR with its 3D-printed replica (Doliveux et al. 2020). These articles presented a new technique for the precise transfer of the EP with the help of a conventional gingival mask, which is an essential step in the semi-digital workflow when implementing the hand build-up technique. Tanaka et al. asserted that the application of multilayered zirconium-dioxide crown materials precludes the need for veneering on a physical cast, and that staining is sufficient in this case even for restoring the esthetic region as well (Tanaka et al. 2023). Previously, monolithic zirconium-dioxide restorations could not compete with veneered zirconia restorations regarding esthetics, and 3D-printed casts were needed in digital pathways as well for hand veneering purposes (De Angelis et al. 2021). However, with the improvement in mechanical and esthetic properties of zirconia crowns, especially regarding multilayered zirconia, it might now be possible for monolithic restorations to achieve results comparable to those of veneered restorations, thus allowing fully digital workflows and decreasing additional workload (Zhang et al. 2022).

4.6 | Strengths and Limitations

The strengths of the present systematic review are the pre-established and published methodologies; moreover, to the author's knowledge, this study is the first review on this topic.

A limited number of well-designed studies were available in the literature for the analyses due to high heterogeneity in study characteristics and study types and the moderate to high risk of bias of most studies. Although the authors attempted to perform the quantitative analyses as planned in the pre-study protocol, the results were not interpretable due to the previously mentioned limitations. However, to ensure transparency and avoid publication bias, we published the materials related to this analysis in the [Supporting Information](#).

The importance of this topic requires many more homogeneous studies in terms of phenotype, implant diameter, depth, distance to neighboring teeth and IOS accuracy, as well as the accuracy of the measurement programs in evaluating soft tissue parameters, and appropriate IOS protocols, especially those comparing the indirect scanning to the gold standard, with larger sample sizes to confirm that digital impression technologies can be used as an equally viable alternative to CM with strong evidence.

5 | Conclusion

Based on the available literature, indirect scanning may be indicated as an optimal digital technique for EP scanning, while direct scanning is less advised due to possible inaccuracies caused by soft tissue collapse when compared to the conventional method. This review suggests that future well-designed randomized clinical trials should be conducted focusing on the discussed parameters for higher level quantitative analyses.

Author Contributions

Krisztina Mikulás: conceptualization, project administration, methodology, formal analysis, writing – original draft, funding acquisition. **Xinyi Qian:** project administration, data curation, formal analysis, visualization, writing – original draft, methodology, funding acquisition. **Péter Tajti:** data curation, writing – original draft. **Gergely Agócs:** formal analysis, writing – original draft, software. **German O. Gallucci:** conceptualization, formal analysis, writing – review and editing, writing – original draft. **Ignacio Pedrinaci:** formal analysis, writing – original draft, writing – review and editing, data curation. **Péter Hermann:** writing – review and editing, supervision.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that supports the findings of this study are available in the Supporting Information of this article.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supplementary materials associated with this article, including the methods and results of the quantitative analyses can be found in the online version at doi: [10.1111/clr.14441](https://doi.org/10.1111/clr.14441) under **Supporting Information**.