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EFFECTS OF BIOMATERIALS AND PROSTHETIC DESIGN ON PERI-IMPLANT HARD AND SOFT TISSUE HEALTH

PhD Thesis

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"If we knew what we were doing, it wouldn’t be called research."

Albert Einstein

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1. LIST OF ABBREVIATIONS

BOP	bleeding on probing
CI	confidence interval
GRADE	grading of recommendations assessment, development, and evaluation
ICC	intracluster correlation coefficient
IPBL	interproximal bone level
KM	keratinized mucosa
KMW	keratinized mucosa width
M	average cluster size
MC	metal-ceramic
MBL	marginal bone loss
MD	mean difference
mPI	modified plaque index
mSBI	modified sulcus bleeding index
MZ	monolithic zirconia
nr	not reported
NRT	non-randomized trial
OAOT	one abutment one time
OR	odds ratio
PCR	plaque control record
PI	plaque index
PICO	population, intervention, comparator, and outcome
PPD	probing pocket depth
PS	platform-switching
RCT	randomized controlled trials
REML	restricted maximum likelihood
RR	risk ratio
SC	single crown
SD	standard deviation

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STA supracrestal tissue attachment

VMT vertical mucosal thickness

2. STUDENT PROFILE

2.1. Vision and mission statement, specific goals

My vision is to improve and provide the best patient care, enhancing the quality of life for patients needing implant rehabilitation.

My mission is to broadly apply the best novel biomaterials and prosthetic designs in clinical practice.

My specific goals include the investigation of monolithic zirconia and metal-ceramic implant-supported single crowns, along with the evaluation of short and long implant-abutment designs.

2.2. Scientometrics

Number of all publications:	6
Cumulative IF:	32.547
Av IF/publication:	5.424
Ranking (Sci Mago):	D1: 2, Q1: 3, Q4: 1
Number of publications related to the subject of the thesis:	2
Cumulative IF:	21.8
Av IF/publication:	10.9
Ranking (Sci Mago):	D1: 2
Number of citations on Google Scholar:	68
Number of citations on MTMT (independent):	42
H-index:	5

The detailed bibliography of the student can be found on page 66.

2.3. Future plans

Understanding dental implantology requires theoretical knowledge and real-life experience in patient care. In the future, I want to focus on advancing my research on implant-supported restorations while also getting hands-on experience in patient care. Working directly with patients will give me valuable insights into their needs and experiences, helping me understand how different materials and techniques impact their health. By combining research results with clinical practice, I aim to make an impact on patient care and outcomes in implant prosthodontics.

3. SUMMARY OF THE PHD

Material and prosthetic design choices for single implant restorations call for an update as novel biomaterials and controverting studies about abutment design have appeared in the field of implant prosthodontics.

We conducted two meta-analyses to give evidence-based suggestions to clinicians in the following questions. These analyses evaluated [1] the potential benefits of using monolithic zirconia single implant crowns in the posterior region compared with the gold standard metal-ceramic crowns, and [2] the effects of using short and long implant-abutments with regard to 'one abutment one time' protocol.

Our results revealed that monolithic zirconia single crowns (SC) showed no significant difference from the gold standard metal-ceramic regarding marginal bone loss (MBL) and other biological parameters; nonetheless, they exhibited significantly less chipping. With a refined statistical methodology, our findings also indicated that longer abutments reduced early MBL.

In conclusion, our findings verified the potential of monolithic zirconia SC. They can be a valid alternative option with less technical complications for restoring dental implants in the posterior region. We also concluded that clinicians should prioritize using long abutments as they tend to reduce early MBL; however, the timing of the abutment insertion may be less relevant.

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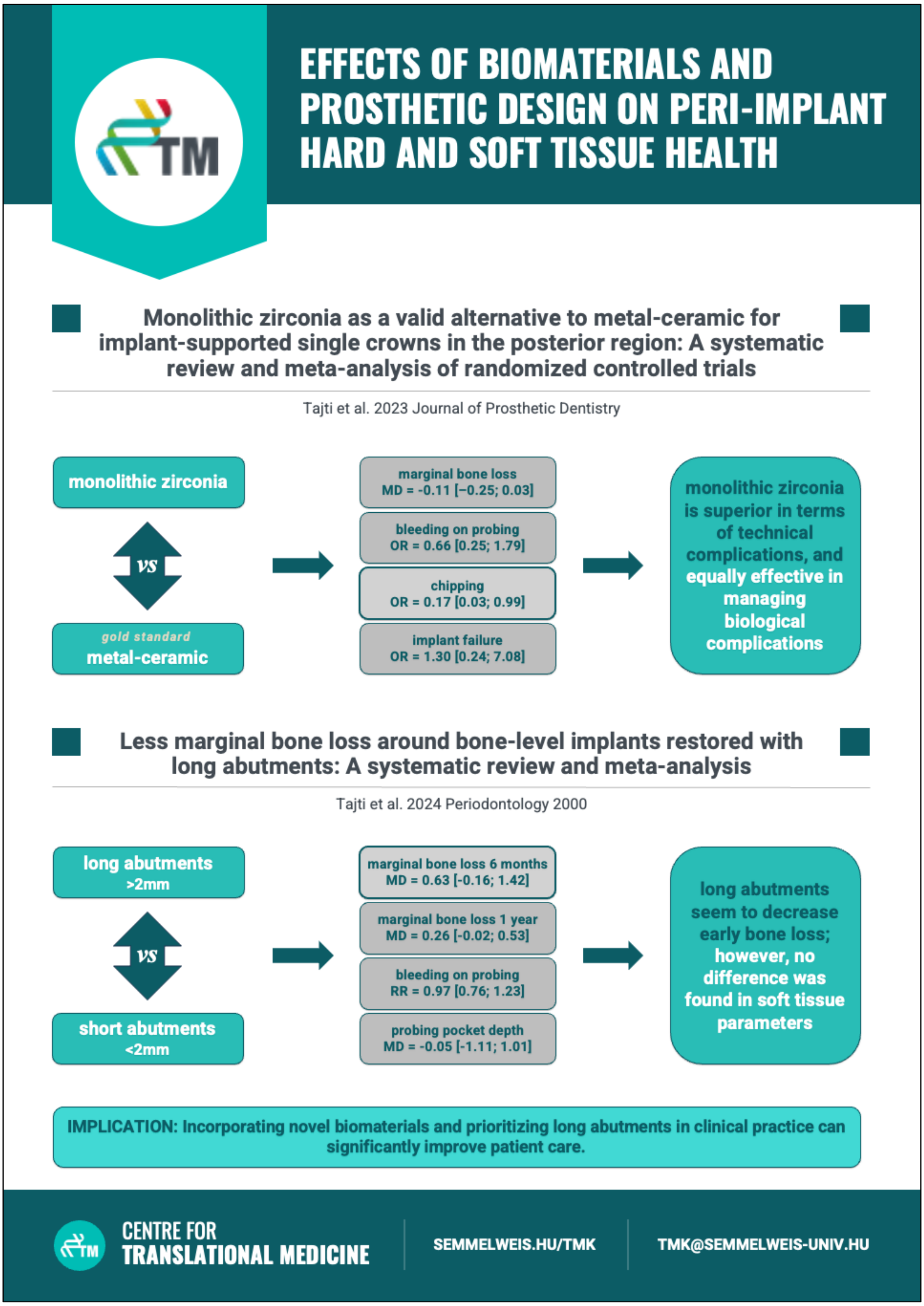
4. GRAPHICAL ABSTRACT



5. INTRODUCTION

5.1. Overview of the topic

5.1.1. What is the topic?

Investigating monolithic zirconia and metal-ceramic implant-supported SCs and evaluating short and long implant-abutment designs.

5.1.2. What is the problem to solve?

There is an unmet need for statistical analysis comparing the gold-standard metal-ceramic with the newer monolithic zirconia implant crowns, and conflicting data exist regarding the outcomes of using long and short implant abutments.

5.1.3. What is the importance of the topic?

This topic dives into the latest advancements in dental materials and prosthetic designs, focusing on how they impact treatment outcomes. By examining new materials, we gain valuable insights into ways to enhance durability, aesthetics, and biocompatibility in implant-supported restorations, especially with the integration of digital technologies. Addressing challenges in this area holds the potential to refine clinical decision-making, promoting long-term stability and function for many patients. Ultimately, these findings could help raise the standards of care in implant prosthodontics.

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

Our findings could guide clinical practices in implant prosthodontics, particularly in material selection for implant-supported restorations, ultimately improving patient outcomes. Additionally, the research may provide insights into the success rates associated with different implant-abutment lengths, offering evidence-based recommendations for clinicians. These insights have the potential to refine implant treatment protocols, reduce complications, and enhance long-term success rates in implant dentistry.

5.2. Marginal bone loss as a key factor in oral implantology

Single-tooth implant-supported restorations have proven to be reliable for restoring missing teeth in partially edentulous patients, mainly due to their high success rates (1-

4). The long-term survival of these restorations depends on various mechanical and biological factors, including the stability of the marginal bone and the formation of a supracrestal tissue attachment (STA) around implants (2, 4-13). Like natural teeth, STA forms a biological barrier around osseointegrated implants crucial for protecting the stability of peri-implant hard tissues (14-16). Following implant placement and abutment insertion, physiological bone remodeling occurs to establish this protective seal (14, 15), with most of the remodeling happening within the first year, particularly during the first six months (9). Early marginal bone loss (MBL) is a non-infective remodeling process that takes place during the first year after implant placement. It has a multifactorial etiology, influenced by both surgical factors (e.g., overheating during preparation, insufficient crestal bone width, implant malposition, implant surface characteristics) and prosthetic aspects (e.g., implant-abutment connection type, location of the implant-abutment microgap, multiple abutment disconnections, cement remnants, and early loading) (17-21). Previous studies have suggested that a variable amount of crestal bone loss may occur in order to provide the necessary space for STA establishment (22). The vertical mucosal thickness (VMT) required for STA around two-piece dental implants should be at least 2 mm to prevent further MBL (23, 24).

MBL, a key indicator of bone remodeling imbalance, plays a significant role in determining the long-term success of dental implants (5). However, several factors can influence MBL, including anatomy (25, 26), tooth-specific characteristics (27, 28), and implant-related variables (11, 25, 29-35). Moreover, the material of the restoration is another important consideration that may impact the outcome of implant-supported SCs (36). With the increasing variety of new restorative materials available for implant prosthodontics, clinicians often face challenges in selecting the most appropriate material to ensure optimal results (37).

5.3. Material choice of the restoration

Metal-ceramic crowns remain the gold standard for implant-supported restorations, with a 5-year survival rate of 98.3% (10). They offer excellent long-term outcomes, high mechanical stability, and acceptable esthetics (2, 38). In response to growing demand for more natural-looking restorations, ceramic systems have been developed, offering improved esthetics and biocompatibility (39-41). However, their tendency to fracture or chip limits their use (42).

Digital processing has expanded the use of ceramic materials, particularly high-strength oxide ceramic zirconia (ZrO_2) and reinforced glass-ceramics like lithium disilicate ($Li_2Si_2O_5$), with zirconia being the stronger of the two (36, 37, 43-46). A previous systematic review reported a 5-year survival rate of 95.8% for bi-layered all-ceramic implant-supported crowns (2). When comparing metal-ceramic crowns to veneered zirconia implant crowns, complication rates were similar, with the most common technical issue being veneering ceramic fractures (10, 47, 48). Another review found that chipping was more frequent in veneered zirconia crowns, occurring in 11.8% of cases after 5 years, though they offered superior esthetics compared to metal-ceramics (10, 49, 50).

Monolithic restorations, defined as un-veneered or micro-veneered, were introduced to address the technical issues associated with veneered reconstructions (36, 51-53). They allow for quicker production via a CAD/CAM workflow, resulting in a more precise marginal fit and efficient restorations (1, 10, 36, 45, 49, 54-57). Monolithic restorations are known for their excellent biocompatibility and superior mechanical strength due to increased layer thickness (45, 58, 59). A recent study by Pjetursson et al. has shown high short-term survival rates for both bi-layered and monolithic ceramic SCs, with significantly lower chipping rates in monolithic restorations; however, metal-ceramic crowns were not included in the analysis (36). Many studies on monolithic zirconia lack sufficient evidence or control groups (60); therefore, to strengthen the evidence, an objective and quantitative comparison was necessary.

5.4. Abutment design of the suprastructure

Several prosthetic design elements and factors may influence MBL, including retention type, abutment height, abutment design, implant-abutment connection, the number of disconnections and reconnections, occlusal overloading, and plaque accumulation (11, 28, 29, 31, 32, 34, 61). Among these, the height of prosthetic abutments has been extensively studied, as it may impact MBL (62, 63). Short abutments may lead to higher MBL due to inadequate vertical space for the establishment of STA, as the necessary VMT of at least 2 mm may not be achieved (22-24). Vervaeke et al. were among the first to conclude, in a nine-year follow-up study, that shorter abutments could result in greater bone loss (64). However, this was a prospective case series without a control group, which limited the strength of the evidence. Similarly, Chen et al. conducted a meta-analysis on the impact of abutment height on MBL but included retrospective and animal studies, which downgraded the overall quality of evidence (31). Another systematic review found that abutment height significantly affected MBL, with longer abutments associated with less bone loss (65). However, this review also relied on retrospective cohorts, lacked quantitative analysis, and demonstrated a moderate-to-high risk of bias. In contrast, a randomized controlled trial (RCT) by Linkevicius et al. found no significant differences in MBL between various abutment heights (66). Yet, the most recent meta-analysis concluded that shorter abutments were associated with higher MBL (67). This meta-analysis combined data from different follow-up periods and included studies with overlapping study groups and populations (20, 68), introducing a significant source of bias.

Recent reviews suggest that another abutment-related timing factor, namely the 'one abutment one time' protocol, could help reduce MBL as well (69-72). However, recent meta-analyses, including only non-randomized clinical trials, have reported mixed findings on whether this protocol benefits crestal bone levels (73, 74).

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6. OBJECTIVES

6.1. Study I – Investigating the potential benefits of using monolithic zirconia over metal-ceramic as implant-supported single crowns

A few studies have investigated monolithic zirconia implant-supported SCs compared with other materials, but no quantitative analysis has been conducted with the gold standard metal-ceramic crowns. Therefore, our aim was to conduct a systematic review and meta-analysis evaluating monolithic zirconia and metal-ceramic implant-supported SCs.

6.2. Study II – Investigating the influence of abutment height on crestal bone stability and peri-implant soft tissue health

Current literature evidence is inconclusive whether the height of the implant abutment influences the health of the peri-implant tissues. We aimed to investigate the effect of abutment height on crestal bone stability and peri-implant soft tissue health with the highest evidence-level methodology.

7. METHODS

Our systematic reviews and meta-analyses were reported according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 Statement (75). The review protocols were registered on PROSPERO (Study I: *CRD42021285227;* Study II: *CRD42022331923*), and the Cochrane Handbook's recommendations for Systematic Reviews of Interventions Version 6.1.0 (76) were followed.

7.1. Study I – Investigating the potential benefits of using monolithic zirconia over metal-ceramic as implant-supported single crowns

7.1.1. Systematic search

The focused question, formulated according to the Population, Intervention, Comparator, and Outcome (PICO) study design, was: How do monolithic zirconia SCs perform in clinical outcomes compared with metal-ceramic SCs as implant-supported restorations?

Population: partially edentulous patients in need of single implant restorations in the posterior region. Intervention: prosthetic rehabilitation with monolithic zirconia implant-supported SCs. Comparator: prosthetic rehabilitation with metal-ceramic implant-supported SCs. Outcomes: the main outcomes were MBL and restoration survival rates. Additional outcomes were BOP, chipping, screw-loosening, de-cementation, and implant survival rates.

The systematic literature search was performed in five databases, including MEDLINE (via PubMed), Cochrane Library (CENTRAL), Embase, Web of Science, and Scopus, on the 20th of October 2021, with an updated search on the 3rd of April 2023. No limits or other filters were applied. A supplementary manual search was performed to identify additional eligible articles from the reference lists of all included studies.

The research terms were as follows, customized for each database:

(monolithic OR full OR “full contour” OR “full-contour” OR fullcontour) AND (zirconia OR zircon OR zirconium OR “zirconium-oxide” OR “zirconium-dioxide” OR “zirconium dioxide” OR “zirconium oxide”) AND (metal OR “metal ceramic” OR “metal-ceramic” OR MC OR PFM OR “porcelain-fused-to-metal” OR “porcelain fused to metal” OR “porcelain-fused-metal”) AND (implant OR “implant-supported” OR “implant supported” OR “implant-retained” OR “implant retained”) AND (single OR “single-tooth” OR crown OR fixed implant denture OR fixed partial denture OR fixed dental prosthesis)

For inclusion, studies had to meet the following criteria: they must be RCTs, human studies with at least 20 patients treated, and have a follow-up period of at least 1 year after restoration insertion. The studies needed to provide precise details on the restoration material used (monolithic zirconia, minimally or micro-veneered zirconia with veneering ceramics only on non-functional areas, metal-ceramics) and clearly describe the type of restoration (cement- or screw-retained, one-piece or two-piece, SC). Additionally, any brands and types of titanium implants used, and thorough reporting of clinical outcomes were required. Studies that did not meet these criteria were excluded: questionnaires, case reports, case series, retrospective studies, and those reporting on other restoration materials (fully veneered zirconia, lithium disilicate).

7.1.2. Study selection and data collection

The publications found through the searches were imported into a reference management software, EndNote X9 (Clarivate Analytics, Philadelphia, PA, USA) (77).

Two reviewers (PT and ES) screened the records by title and abstract, resolving any disagreements through discussion. They independently assessed the full texts of the selected studies and examined reference lists for additional potential studies. Cohen's Kappa coefficient was calculated to assess agreement at both stages. Any remaining disagreements were resolved by a third reviewer (KM).

Two authors (PT and ES) independently extracted data from the selected articles. The following parameters were collected and recorded: first author, year of publication, study design, study setting, planned number of patients, number of patients at completion, dropout rates, mean age of patients, age range, number of implants, implant system, implant level, implant material, augmentation, type of restoration, type of retention, type of cement, follow-up time, and outcomes, including the number of complications (chipping, screw-loosening, de-cementation), biological parameters (MBL, bleeding on probing (BOP)), and implant and restoration failures.

Restoration failure in this study was defined according to the criteria set by Pjetursson et al., which includes SCs that were lost, removed, or remade due to implant loss, repeated retention loss, repeated screw loosening, or unpolishable ceramic chipping. The restoration survival rate accounted for SCs that remained in place throughout the observation period, regardless of any modifications. Repaired ceramic chippings were classified as technical complications rather than failures (36).

7.1.3. Quality assessment and certainty of evidence

The risk of bias was independently assessed by two reviewers (PT and ES) using the Cochrane Risk of Bias Tool 2 for RCTs (78). In cases of disagreement, a third reviewer (KM) was consulted to reach a final decision.

The certainty of the evidence was evaluated using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach (79).

7.1.4. Data synthesis and analysis

Data synthesis was conducted following the methods recommended by the Cochrane Collaboration's working group on systematic reviews (76). For continuous outcomes, the mean difference (MD) in MBL between the monolithic zirconia and metal-ceramic groups was calculated using the sample size, mean, and standard deviation (SD) extracted from each study. The SD was conservatively estimated for the Weigl et al. article, where it was not provided (80). Odds ratios (OR) with 95% confidence intervals (CI) were used for categorical outcomes, and pooled ORs were calculated using the Mantel-Haenszel method (81-83). The restricted maximum-likelihood estimator was applied for continuous outcomes, while the Paule-Mandel method (84) was used for OR measures. Forest plots displayed the effect sizes with 95% CIs for all included studies.

Cochran's Q test and Higgins & Thompson's I^2 statistics were used to assess between-study heterogeneity (85); however, publication bias could not be evaluated due to the limited number of studies. All tests were performed with a preset p-value of 0.05 using the meta package in R (86, 87).

In the Cheng et al. article, the number of patients (n=38) did not align with the number of implants (n=70) (52). Consequently, following Higgins et al.'s recommendations, intracluster correlation coefficient (ICC) values were used to adjust for potential within-patient correlations (76). Since no other articles reported such values, the sensitivity of the results was tested with ICC values of 0 and 1. The average cluster size (M) was calculated by dividing the total number of implants by the total number of patients. The design effect was then computed as $1 + (M - 1) \times ICC$, and this was used to adjust the sample size by dividing the number of implants in each group by the design effects, rounding up to the nearest whole number.

7.2. Study II – Investigating the influence of abutment height on crestal bone stability and peri-implant soft tissue health

7.2.1. Systematic search

We structured our research question using the PICO framework. Eligible studies included RCTs and non-randomized prospective interventional studies that involved partially edentulous patients requiring implant restorations. These studies compared prosthetic rehabilitation with long abutments (>2 mm) and short abutments (<2 mm). The primary outcome assessed was MBL, with secondary outcomes including BOP and probing pocket depth (PPD).

For inclusion, studies had to meet the following criteria: human studies with at least 20 participants, a follow-up period of at least 6 months, any brand and type of titanium, bone-level or platform-switching (PS) implants, detailed reporting of biological outcomes, and detailed reporting of abutment height (short abutments <2 mm and long abutments ≥2 mm) with fixed single or partial restorations (up to 3-unit restorations). Excluded studies involved guided bone regeneration, tissue-level (one-piece) implants, zirconia implants, and study types such as questionnaires, case reports, case series, and non-randomized retrospective studies.

A systematic search was conducted across five medical databases: MEDLINE (PubMed), EMBASE, Web of Science, CENTRAL, and Scopus. The initial search covered the period from inception to 16th May 2022, with an updated search conducted in 10th January 2023.

The following search terms were applied in each database:

(dental implant OR dental implantation OR osseointegrated OR oral implant OR implant) AND (abutment height OR collar height OR running space OR abutment length OR collar length OR neck length OR smooth neck portion OR transmucosal height OR gingival height) AND (influence OR comparison OR difference OR different OR short OR long)

No filters were applied during the search process. Additionally, a manual search was carried out through the reference lists of all included articles to identify further potential studies.

7.2.2. Study selection and data collection

EndNote reference management software was used to organize and manage the records (77).

After removing duplicates, two review authors (PT and ES) independently screened the remaining records based on titles and abstracts. Subsequently, full-text assessments were carried out by the same two authors. At each stage, Cohen's Kappa coefficient was calculated to assess agreement. Additionally, the reference lists of eligible articles were manually searched for further potential studies. Any disagreements between the authors were resolved through discussion or involving a third reviewer (KM).

Two authors (PT and ES) independently extracted the data, resolving disagreements through discussion until consensus was reached or, if necessary, consulting a third author (KM). The extracted data included: first author, year of publication, study design, study setting, number of participants, number of implants planned, number of implants at the study's conclusion, mean age of participants, implant type, surgical site, use of the ‘one abutment one time’ protocol, restoration type, fixation type, loading protocol, implant placement level, follow-up time, and outcome parameters.

None of the studies that reported multiple interventions in one participant provided ICC values. The common mean and SD were calculated using the appropriate formula for independent groups (e.g., thin vs. thick mucosa). For dependent groups (e.g., mesial and distal measurements), the average SD was used as a pooled SD, serving as an upper boundary estimate for the true SD, assuming a positive correlation between the measurements.

7.2.3. Quality assessment and certainty of evidence

The quality of each included study was independently assessed by two reviewers (PT and ES) using the Cochrane Risk of Bias Tool 2 for RCTs (78) and the ROBINS-I tool for non-randomized studies (88). A third reviewer (KM) was involved if necessary to resolve any disagreements.

We evaluated the certainty of the evidence using the GRADE approach (79).

7.2.4. Data synthesis and analysis

Statistical analyses were performed using R (89). For calculations and plotting, the **meta** (89) and **dmetar** (90) packages were utilized. For MBL and PPD, we calculated the pooled MD with 95% CI. BOP was analyzed as a binary variable, and pooled risk ratios (RR) with 95% CI were calculated. The Mantel-Haenszel method was used for pooling, and the exact Mantel-Haenszel method (without continuity correction) was applied to handle zero cell counts.

A random-effects meta-analysis model with the Hartung-Knapp adjustment was employed in all cases to reduce the risk of false positives. Forest plots were used to summarize the results visually. To estimate τ^2, the restricted maximum likelihood (REML) method was applied, and the Q profile method was used to calculate the CI of τ^2 (90). Statistical heterogeneity across trials was assessed using the Cochrane Q test and I^2 values (85).

For studies with multiple interventions in the same subjects (62, 91-94), we performed a sample size correction based on the recommendations of Higgins et al. (76). Two calculations were made using two different ICC values: one assuming ICC=0, indicating complete independence between interventions, and another assuming ICC=0.5, indicating significant dependence. Both results are presented in the forest plots for comparison.

8. RESULTS

8.1. Study I – Investigating the potential benefits of using monolithic zirconia over metal-ceramic as implant-supported single crowns

8.1.1. Search and selection characteristics of the included studies

The electronic search yielded 2,030 articles after duplicate removal. Title and abstract evaluation narrowed the selection to 11 records, with an inter-rater agreement of κ=0.95. Four eligible articles were identified after full-text analysis, achieving an inter-rater agreement of κ=1.00. Screening the reference lists of these eligible articles did not uncover any additional studies. Most studies were excluded for using different veneering ceramics on zirconia, multi-unit restorations, or lithium disilicate (95-100). The summary of the selection process is presented in Figure 1 (101).

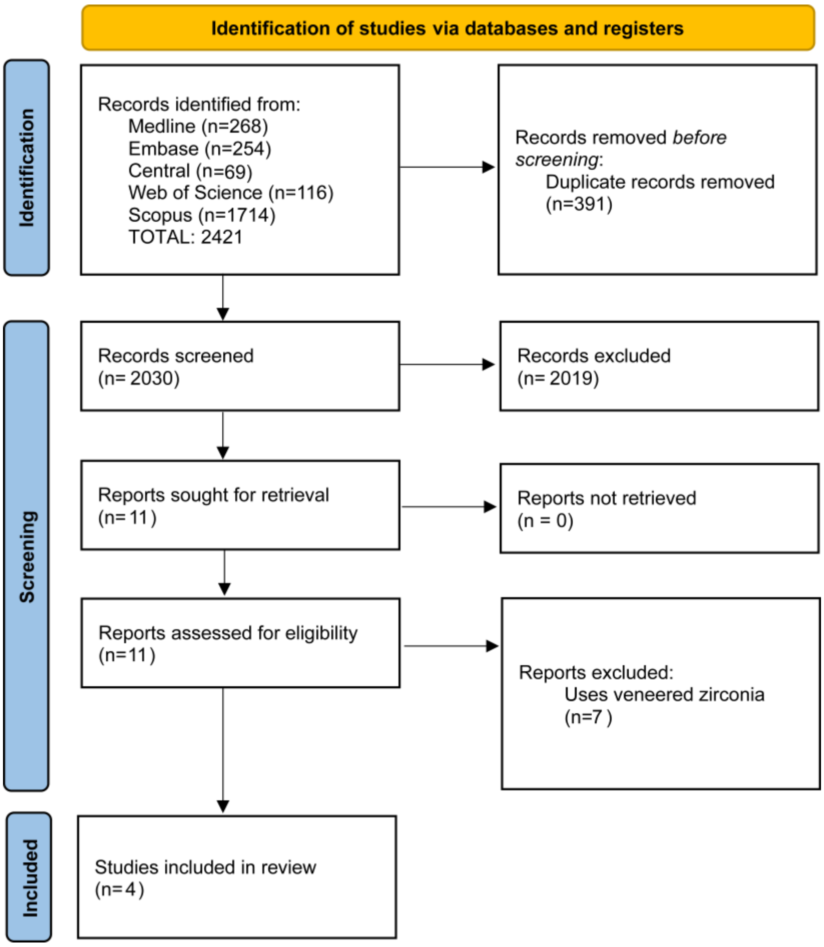

Figure 1. Flowchart of the selection process for Study I based on the PRISMA 2020 statement (101)

8.1.2. Characteristics of the included studies

The characteristics of the identified RCTs are presented in detail in Table 1. All the included studies evaluated monolithic zirconia and metal-ceramic titanium implant-supported SCs in the posterior region of the maxilla, replacing missing premolars and molars. One study was a split-mouth trial (80), while the other three were parallel-group trials (52, 57, 102). All four studies followed participants over 1 year. Three studies focused on monolithic zirconia (57, 80, 102), and one examined micro-veneered zirconia (52). By the end of the 1-year follow-up, a total of 240 implant-supported SCs were included: 50% were screw-retained, and 50% were cemented. Of these, 35.8% were monolithic zirconia, 15% were micro-veneered zirconia, and 49.2% were metal-ceramic. In the monolithic zirconia group, 59% of the SCs were screw-retained, while 41% were cemented. In the metal-ceramic group, 40.7% were screw-retained, and 59.3% were cemented. One study used a fully digital workflow (102) to fabricate zirconia crowns, while the other three utilized hybrid workflows (52, 57, 80).

Table 1. Basic characteristics of the included studies for Study I (101)

Study				**Population**				**Implant**				
First author	**Year**	**Design**	**Setting**	**No. of subjects planned**	**No. of subjects at the end**	**Drop-out (%)**	**Mean age (years)**	**No.**	**System**	**Level**	**Material**	**Augmentation**
Mangano (102)	2018	RCT	University	50	50	0	52.6	50	Exacone, Leone Implants	Bone	Titanium	no
Cheng (52)	2019	RCT	Medical center	40	38	nr	MZ: 48.1 MC: 47.8	70	Straumann	Tissue	Titanium	nr
Weigl (80)	2019	RCT	Clinic	22	22	0	43	44	Ankylos, Dentsply Sirona Implants	Bone	Titanium	minor if needed
Mühlemann (57)	2020	RCT	University	76	74	nr	57.7	76	Straumann	Bone	Roxolid	nr

MC: metal-ceramic; MZ: monolithic zirconia; nr: not reported; RCT: randomized controlled trial

Table 1. continued (101)

Study	Restoration						Outcomes	
	Monolithic zirconia			Metal-ceramic				
First author	Retention	Type	Type of cement if used	Retention	Type	Type of cement if used	Biological parameters	Prosthetic parameters
Mangano (102)	cement	SC	nr	cement	SC	nr	MBL, PPD, BOP, peri-implant mucositis, peri-implantitis	abutment loosening, abutment fracture, chipping, fracture of the restoration, patient satisfaction, time and cost aspects, implant-crown success
Cheng (52)	screw, cement	SC	resin	screw, cement	SC	resin	MBL	coping fracture, fracture of veneering ceramic, screw-loosening, de-cementation, implant loss
Weigl (80)	screw	SC	-	cement	SC	resin	MBL, BOP, PI	screw-loosening, de-cementation, filling defect, fixation time, contact, fit, patient questionnaire, implant loss
Mühlemann (57)	screw	SC	-	screw	SC	-	MBL, PPD, BOP, PCR, KMW	abutment fracture, ceramic fracture, anatomical form, proximal contact, occlusal contact, marginal fit, color match, occlusal wear, patient satisfaction, fracture of the abutment screw, abutment screw loosening, fracture of implant, implant loss, loss of filling

BOP: bleeding on probing; KMW: keratinized mucosa width, MBL: marginal bone loss; nr: not reported; PCR: plaque control record; PI: plaque index; PPD: probing pocket depth; SC: single crown

8.1.3. Results of the synthesis and certainty of evidence

Three studies involving 168 implant-supported SCs were included in the analysis of MBL. Using a random-effects model, the MD in MBL was –0.11 mm, indicating 0.11 mm less bone loss around monolithic zirconia restorations (n=85) compared to metal-ceramic restorations (n=83) over a 1-year follow-up period (MD –0.11, 95% CI: [–0.25; 0.03], P=0.61, I^2=0%). However, this difference did not reach statistical or clinical significance between the two groups. The lack of heterogeneity across studies, as indicated by the I^2 test, suggests consistency in the results. The certainty of the evidence was rated as moderate. The data are illustrated in Figure 2 (101).

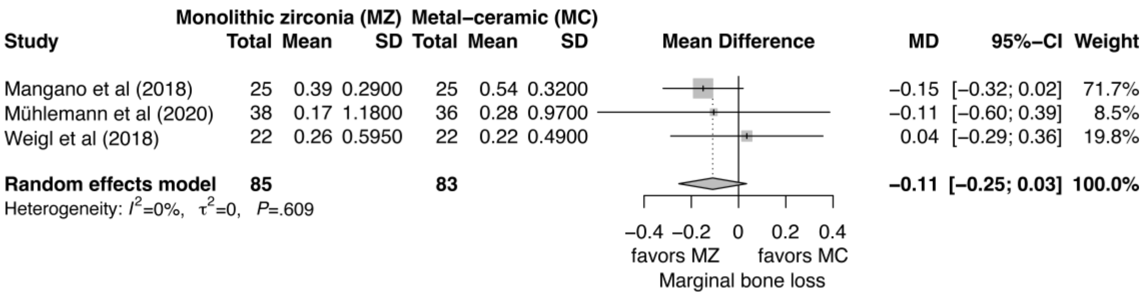

Figure 2. Forest plot shows no significant difference in marginal bone loss between monolithic zirconia and metal-ceramic single crowns (101)

A total of 168 implant-supported SCs from three studies were included in the analysis of BOP. Using a random-effects model, the OR was 0.66, suggesting that the odds of BOP were 34% lower around monolithic zirconia restorations (n=85) compared to metal-ceramic restorations (n=83) over a 1-year follow-up period (OR 0.66, 95% CI: [0.25; 1.79], P=0.90, I^2=0%). However, this difference did not reach statistical or clinical significance. The I^2 test indicates no heterogeneity across studies, suggesting consistency in the results. The certainty of evidence is moderate. The analysis is displayed in Figure 3 (101).

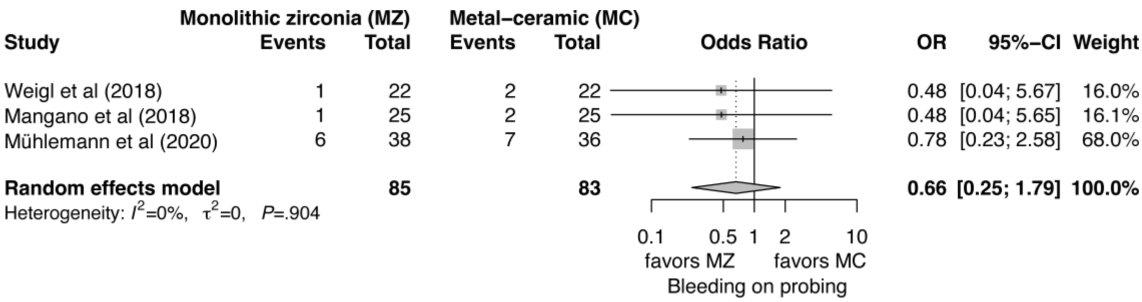

Figure 3. Forest plot shows less bleeding on probing around monolithic zirconia compared to metal-ceramic single crowns (101)

Initially, four studies involving 237 implant-supported SCs were included in the analysis of chipping, as shown in Figure 4A. The OR was 0.33, suggesting that the odds of chipping were approximately 67% lower in monolithic zirconia restorations (n=120) compared to metal-ceramic restorations (n=117) over a 1-year follow-up period. However, this difference did not reach statistical significance (OR 0.33, 95% CI: [0.07; 1.58], P=0.44, I^2=0%). The I^2 test indicated no heterogeneity across the included studies, and the certainty of evidence was rated as moderate (101).

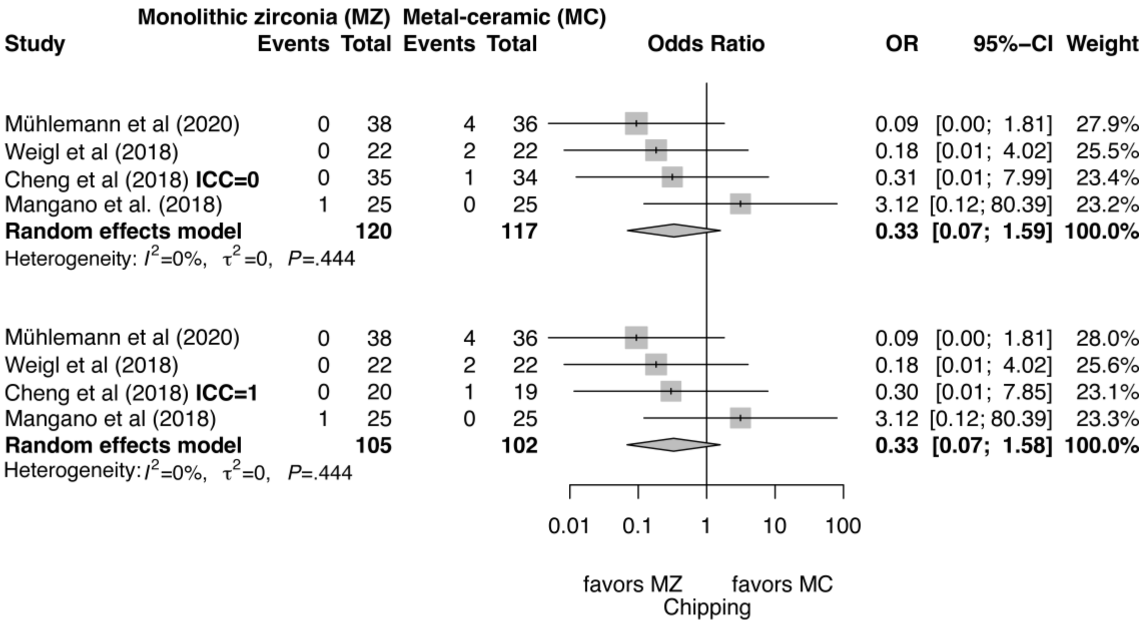

Figure 4A. No significant difference in chipping between monolithic zirconia and metal-ceramic single crowns when including all eligible data (101)

In the monolithic zirconia group, there was one instance of chipping caused by the patient's bruxism, affecting the mesio-vestibular cusp. The damaged crown was redesigned and remade. Excluding this outlier study from the analysis reduced the heterogeneity among patients. The revised analysis, which included 187 implant-supported SCs, is presented in Figure 4B. According to the random-effects model, the odds of chipping were significantly reduced by 83% in monolithic zirconia restorations (n=95) compared to metal-ceramic ones (n=92) over a 1-year follow-up period (OR 0.17, 95% CI: [0.03; 0.99], P=0.87, I^2=0%). The I^2 test suggested no heterogeneity across the studies, and the certainty of evidence was rated as moderate. The forest plots demonstrate that the ICC=0 and ICC=1 calculations resulted in the same pooled values based on corrected sample sizes from the Cheng et al. article (101).

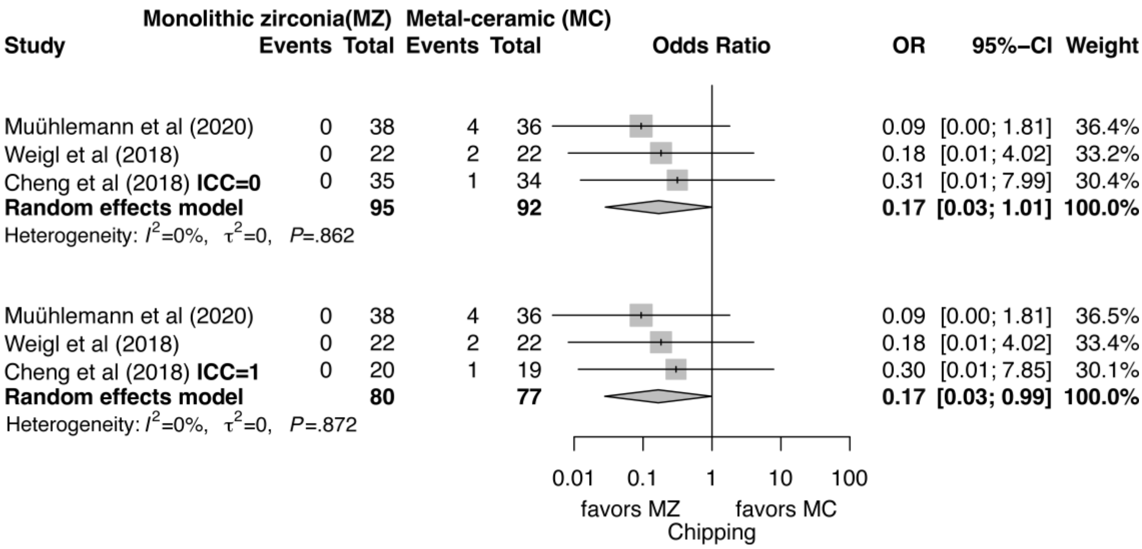

Figure 4B. Significantly less chipping in monolithic zirconia single crowns when excluding patient with bruxism (101)

All four studies, comprising a total of 240 implants with SCs, were included in the analysis of implant failure. According to the random-effects model, there was no significant difference in implant failure between the monolithic zirconia group (n=122) and the metal-ceramic group (n=118) over a 1-year follow-up period (OR 1.30, 95% CI: [0.24; 7.08], P=0.96, I^2=0%). The I^2 test indicated no heterogeneity among the studies. The certainty of the evidence was rated as moderate. The forest plot in Figure 5 also shows that the corrected sample sizes based on the ICC=0 and ICC=1 calculations from the Cheng et al. article resulted in pooled values differing by less than 0.1 (101).

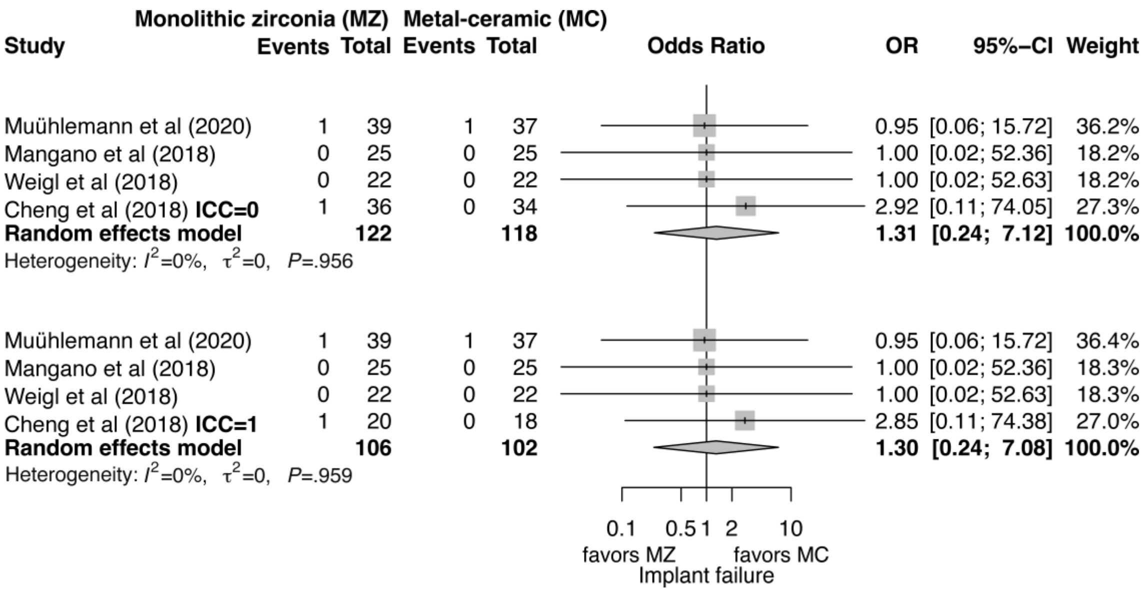

Figure 5. No significant difference in implant failure between monolithic zirconia and metal-ceramic single crowns (101)

8.1.4. Qualitative analysis

In the analysis of implant survival, two implants (1.6%) in the monolithic zirconia group were lost due to osseointegration issues and implant fracture, while the metal-ceramic group experienced the loss of one implant (0.8%) also due to osseointegration. This resulted in implant survival rates of 98.4% for the monolithic zirconia group and 99.2% for the metal-ceramic group (101).

Regarding restoration failure and survival, four studies enclosing 240 implant-supported SCs were analyzed. The restoration survival rate in the monolithic zirconia group was 97.5%, with three crown failures (2.46%) attributed to implant failure and material chipping. In contrast, the metal-ceramic group had a restoration survival rate of 99.1%, with one crown failure (0.85%) due to implant failure (101).

In the analysis of screw-retained implant-supported SCs from three studies, it was found that 2.82% of zirconia crowns experienced screw loosening, compared to 10.6% of metal-ceramic crowns within one year (101).

For the analysis of cemented implant-supported SCs in three studies, none of the zirconia crowns (0%) had issues with loss of retention due to de-cementation, while 5.71% of metal-ceramic crowns experienced this problem over the same one-year period (101).

Overall, when considering technical complications across 237 implant-supported SCs, metal-ceramic crowns had a higher rate of complications (12.8%) compared to monolithic zirconia crowns (3.33%), with 15 and 4 affected SCs, respectively (101).

8.1.5. Risk of bias assessment

The quality assessment revealed some concerns across all four studies. While random sequence generation was performed in each study, only one study provided information regarding allocation sequence concealment (57). Additionally, a pre-specified analysis plan was reported in just one study (102). One study disclosed financial reimbursement from Institute Straumann AG and 3M (57), while the other three studies declared no conflicts of interest (52, 80, 102).

8.2. Study II – Investigating the influence of abutment height on crestal bone stability and peri-implant soft tissue health

8.2.1. Search and selection characteristics of the included studies

The systematic search yielded 4,055 articles after the removal of duplicates. Following title and abstract screening, 16 records were selected (κ=0.91). Full-text evaluation ultimately identified eight eligible articles (κ=0.97). A manual hand search of reference lists yielded no additional articles. The selection process is summarized in Figure 2 (103).

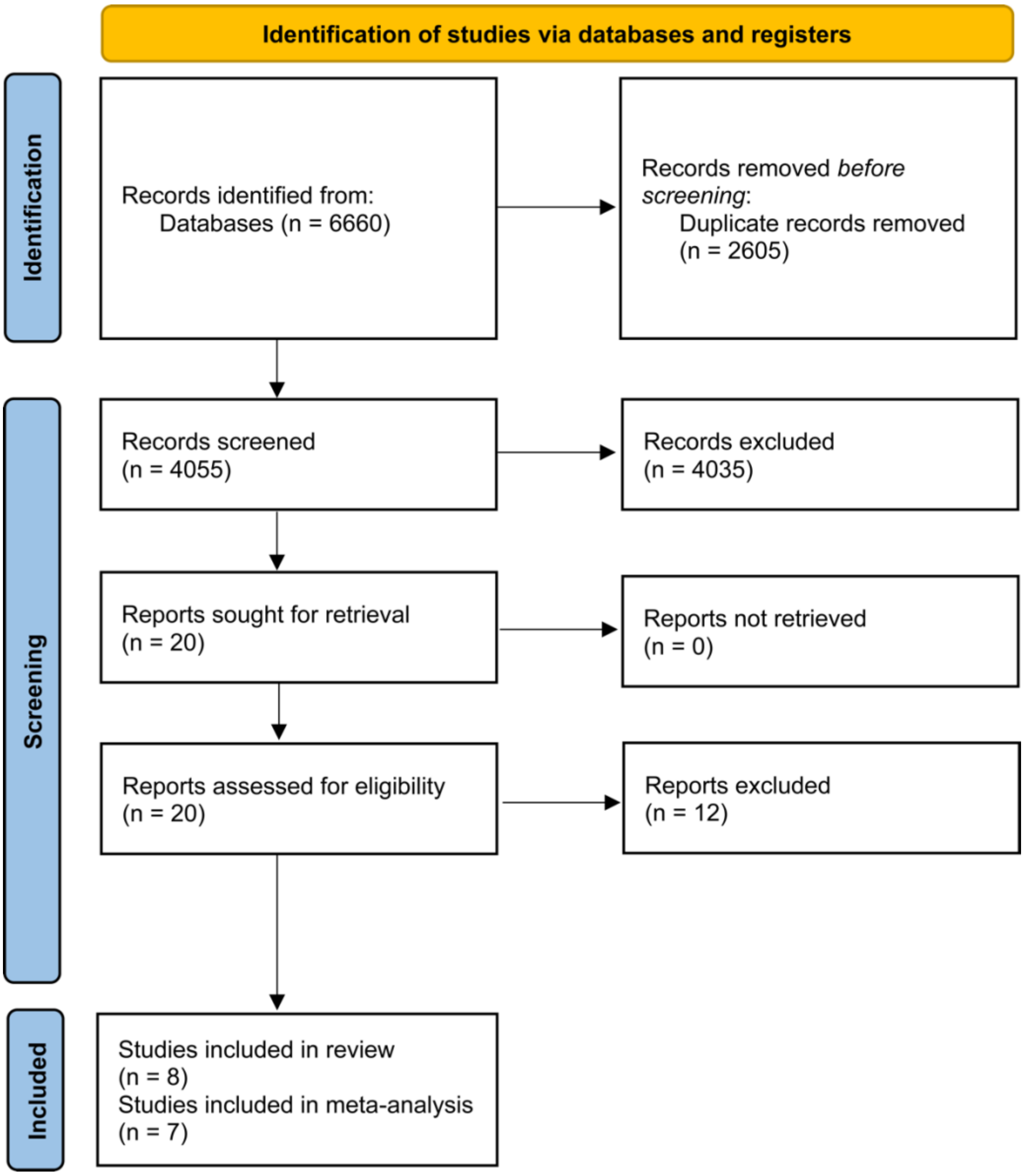

Figure 6. Flowchart of the selection process based on PRISMA 2020 statement (103)

8.2.2. Characteristics of the included studies

The characteristics of the identified studies for the systematic review and meta-analysis are presented in detail in Table 2. Eight studies were included in the systematic review (20, 62, 66, 91-94, 104), with seven contributing to the meta-analysis (20, 62, 66, 91-94). Of all, seven were RCTs, while one was a non-randomized prospective interventional study (94). All implants in the studies were titanium, bone-level, PS, and placed either epi- or subcrestally without the need for hard or soft tissue augmentation. Healing periods across the studies ranged from 2 to 4 months. Two studies followed a two-stage protocol with submerged healing before healing abutments were inserted (20, 94). Three studies provided 6-month follow-up data (20, 62, 93), while seven reported 12-month outcomes (20, 66, 91-94, 104). The 'one abutment one time' protocol was implemented in five studies (62, 91-93, 104). All included studies assessed bone-level changes, five investigated BOP (20, 66, 91, 92, 104), and two evaluated PPD (66, 92).

Table 2. Basic characteristics of the included studies for Study II (103)

Study					Population		Implant						
First author	**Year**	**Design**	**Setting**	**ICC**	**Mean age (years)**	**No. of subjects**	**No. at beginning**	**No. at the end**	**System**	**Platform**	**Type**	**Material**	**Connection type**
Linkevicius (66)	2022	RCT	university	Not needed	46	60	60	55	NucleOSS	PS	bone-level	titanium	internal conical
Munoz (92)	2021	RCT	university	Applied but nr	1 mm: 56.5 3 mm: 53.8	69	112	99	Klockner Implant System	PS	bone-level	titanium	internal hexagone
Borges (104)	2021	RCT	private center	Not needed	1 mm: 67 2 mm: 62	33	68	59	Astratech	PS	bone-level	titanium	internal conical
Spinato (20)	2019	RCT	private center	Not needed	51.3	70	70	66	Lugano	PS	bone-level	titanium	internal hexagone
Pico (93)	2019	RCT	university	Not applied	1 mm: 55.6 3 mm: 52.3	33	66	66	LASAK	PS	bone-level	titanium	internal conical
Borges (91)	2018	RCT	private center	Not applied	1 mm: 67 2 mm: 62	33	68	63	Astratech	PS	bone-level	titanium	internal conical
Blanco (62)	2018	RCT	university	Not applied	1 mm: 55.8 3 mm: 52.3	22	44	42	LASAK	PS	bone-level	titanium	internal conical
Spinato (94)	2017	NRT	private center	Not applied	<1.6 mm: 56.9 >2.4 mm: 52.2	93	110	110	Shape-1, hybrid	PS	bone-level	titanium	internal hexagone

1 mm: short abutment group; 2 mm: long abutment group; 3 mm: long abutment group; <1.6 mm: short abutment group; >2.4 mm: long abutment group

Table 2. continued (103)

Study: First author	Study: Year	Implant placement level	Surgical site	Soft or hard tissue augmentation	Loading protocol	Restoration	Follow-up months	Abutment height (short)	Abutment height (long)	OAOT protocol	Outcomes
Linkevicius (66)	2022	epicrestal	posterior	no	conventional	screw-retained single-unit	12	0.7 mm	2.4 mm	–	MBL, PPD, BOP, PI
Munoz (92)	2021	subcrestal	posterior	no	conventional	screw-retained single- or multi-unit	12	1 mm	3 mm	applied	MBL, VMT, PPD, BOP
Borges (104)	2021	epi- or subcrestal	posterior	no	conventional	screw-retained splinted crowns	1, 4, 12, 36	1 mm	2 mm	applied	MBL, BOP, KM
Spinato (20)	2019	epicrestal	posterior	no	conventional	screw-retained single-unit	4, 6, 12	1 mm	3 mm	–	MBL, mPI, mSBI, VMT
Pico (93)	2019	epi- or subcrestal	posterior	no	conventional	screw-retained multi-unit	3, 6, 12	1 mm	3 mm	applied	IPBL
Borges (91)	2018	epi- or subcrestal	posterior	no	conventional	screw-retained splinted crowns	1, 4, 12	1 mm	2 mm	applied	MBL, KM, BOP
Blanco (62)	2018	epicrestal	nr	no	conventional	screw-retained bridges	3, 6	1 mm	3 mm	applied	MBL
Spinato (94)	2017	epicrestal	nr	no	conventional	cement-retained single- or multi-unit	12	<1.6 mm	>2.4 mm	–	MBL

BOP, bleeding on probing; ICC, intracluster correlation coefficient; IPBL, interproximal bone level; KM, keratinized mucosa; MBL, marginal bone loss; MC, metal-ceramic; mPI, modified plaque index; mSBI, modified sulcus bleeding index; MZ, monolithic zirconia; nr, not reported; NRT, non-randomized trial; OAOT, one abutment one time; PI, plaque index; PPD, probing pocket depth; RCT, randomized controlled trial; VMT, vertical mucosal thickness

8.2.3. Results of the synthesis and certainty of evidence

Three studies, with 174 implants in total, were included in this analysis. According to the random-effects model, the long abutment group demonstrated 0.63 mm less MBL at the 6-month follow-up (ICC=0.5, MD 0.63, 95% CI: [-0.16; 1.42], I^2=93.99%, p<0.001) (Figure 7). The certainty of evidence was rated as moderate. As illustrated in the forest plots (Figure 7), there was almost no difference between the calculations based on the corrected sample sizes of the related articles. The ICC=0 and ICC=0.5 calculations yielded the same pooled values (p=0.980) (103).

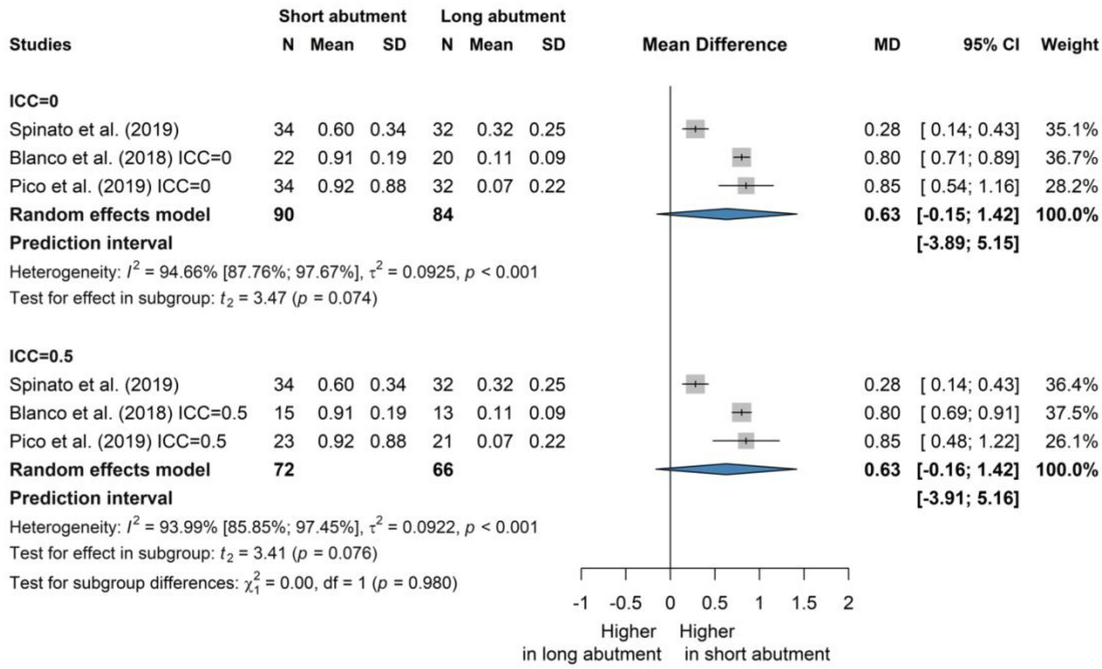

Figure 7. Forest plot shows less marginal bone loss with long abutments at 6-month follow-up (103)

A total of 384 implants from six studies were included in this analysis. The long abutment group demonstrated a reduction in MBL of 0.26 mm at the 1-year follow-up (ICC=0.5, MD 0.26, 95% CI: [-0.02; 0.53], I^2=73.25%, p=0.002) (Figure 8). The certainty of evidence was rated as high. As shown in the forest plots (Figure 8), there was almost no difference between the calculations based on the corrected sample sizes of the related articles. The ICC=0 and ICC=0.5 calculations resulted in a difference of less than 0.1 in pooled values (p=0.948) (103).

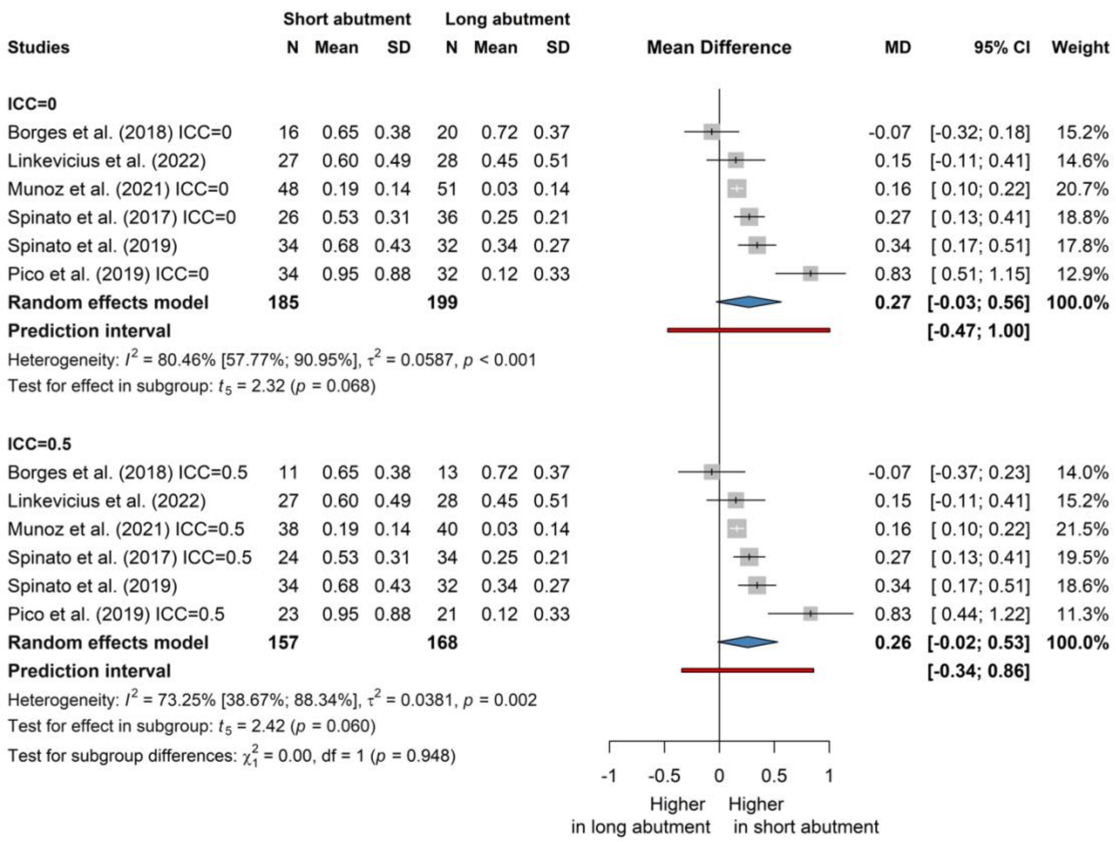

Figure 8. Forest plot shows less marginal bone loss with long abutments at 1-year follow-up (103)

A subgroup analysis of six studies indicated no difference in MBL at the 1-year follow-up when definitive abutments were placed immediately after implant placement (p=0.973). This is illustrated in Figure 9 with ICC=0.5 and Figure 10 with ICC=0 calculations (103).

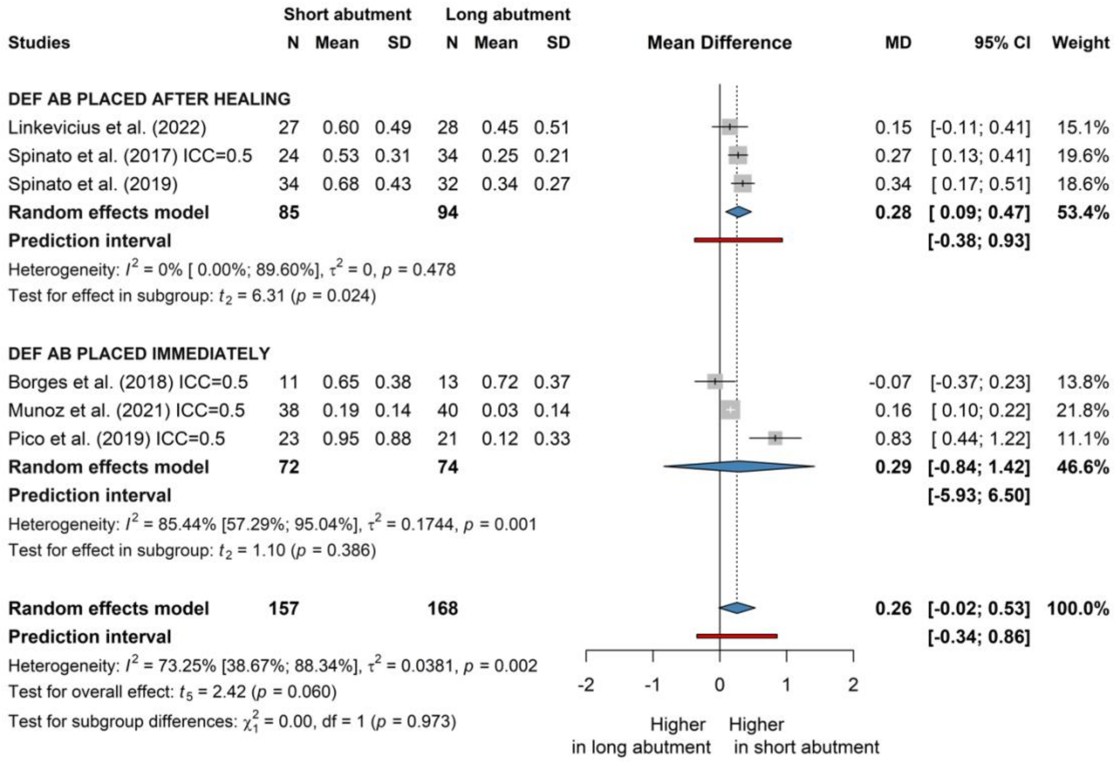

Figure 9. Forest plot shows no difference in marginal bone loss between subgroups of ‘one abutment one time’ and conventional placement protocols at 1-year follow-up (ICC=0.5) (103)

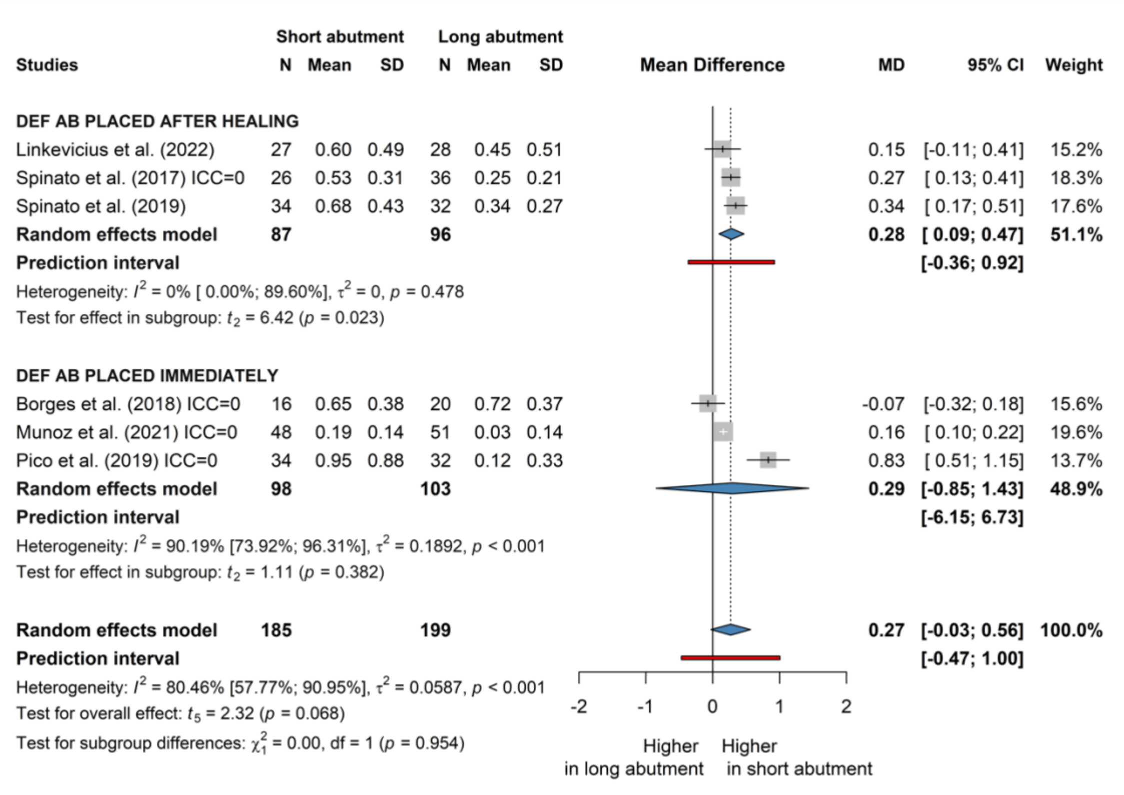

Figure 10. Forest plot shows no difference in marginal bone loss between subgroups of ‘one abutment one time’ and conventional placement protocols at 1-year follow-up (ICC=0) (103)

DOI:10.14753/SE.2025.3193

Excluding the article of Spinato et al. (94) and focusing solely on RCTs, the random effects meta-analysis demonstrated a reduced MBL of 0.26 mm in the long abutment group at the 1-year follow-up (ICC=0.5, MD 0.26, 95% CI: [-0.12; 0.65], I2=77%) as shown in Figure 11 (103).

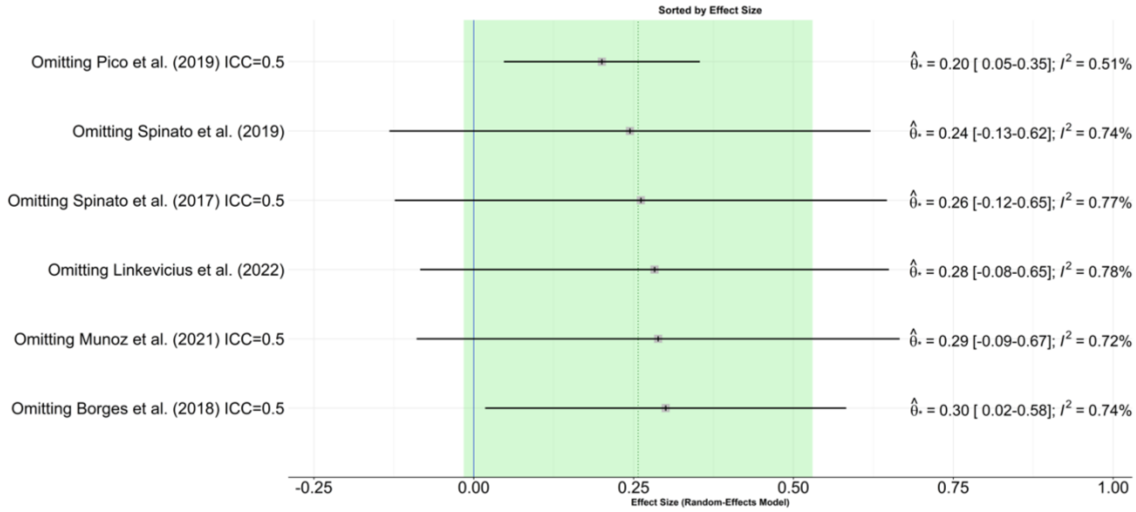

Figure 11. Leave-one-out analysis of marginal bone loss at 1-year follow-up (103)

In the analysis of four studies involving a total of 256 implants, no significant difference in BOP was observed between different abutment heights at the 1-year follow-up (ICC=0.5, RR 0.97, 95% CI: [0.76; 1.23], I2=0%, p=0.927) as illustrated in Figure 12. The certainty of evidence for this outcome is moderate. The forest plots in Figure 12 indicate minimal variation between calculations based on the corrected sample sizes from the related articles, with both ICC=0 and ICC=0.5 calculations showing less than 0.1 difference in pooled values (p=0.950) (103).

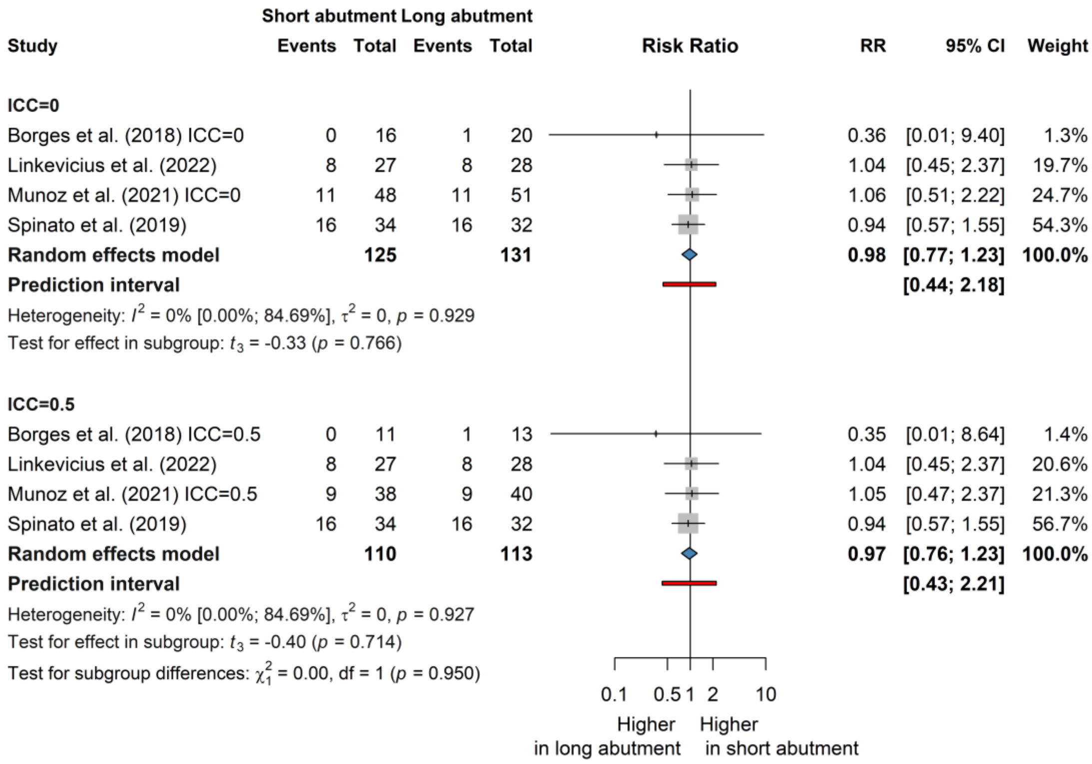

Figure 12. Forest plot shows no difference in bleeding on probing between different abutment heights at 1-year follow-up (103)

DOI:10.14753/SE.2025.3193

In the analysis of two studies involving a total of 154 implants, no significant difference in PPD was found between different abutment heights at the 1-year follow-up (ICC=0.5, MD -0.05, 95% CI: [-1.11; 1.01], I2=0%, p=0.650) as shown in Figure 13. The certainty of evidence for this outcome was rated as moderate. The forest plots in Figure 13 indicate minimal differences in calculations based on the corrected sample sizes of the related articles, with both ICC=0 and ICC=0.5 calculations showing less than 0.1 difference in pooled values (p=0.933) (103).

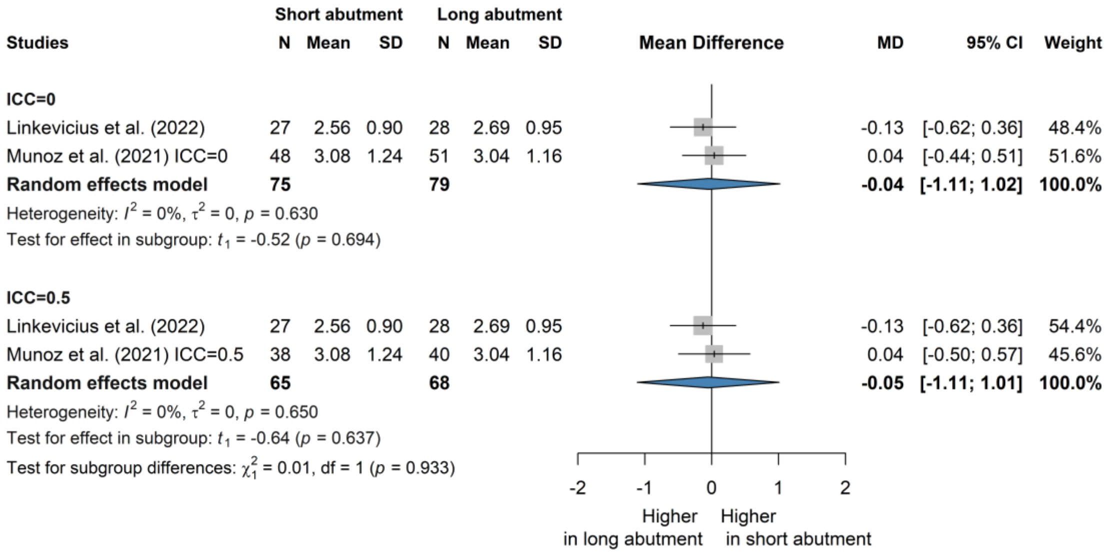

Figure 13. Forest plot shows no difference in probing pocket depth between different abutment heights at 1-year follow-up (103)

8.2.3. Risk of bias assessment

The overall risk of bias assessment revealed a low risk for three RCTs (20, 91, 92). However, three other RCTs showed some concerns due to the absence of pre-specified analysis plans (62, 66, 93). The non-randomized study exhibited a moderate risk of bias (94).

DOI:10.14753/SE.2025.3193

9. DISCUSSION

9.1. Summary of findings, international comparisons

Study I aimed to assess the findings of currently available RCTs that compare monolithic zirconia and metal-ceramic implant-supported SCs in the posterior region. The focus was on evaluating biological outcomes and technical complications associated with both types of restorations to provide clinicians with valuable insights for treatment decision-making. To our knowledge, this was the first meta-analysis published on this specific topic.

MBL is a key criterion for evaluating implant success (5). Both monolithic zirconia and metal-ceramic restorations showed favorable outcomes over one year, with no significant differences between the groups. This aligns with a recent clinical study that also found no difference between these materials (60). It has been suggested that restoration material does not influence stress distribution around implants (105, 106), which may explain these findings. However, these results should be interpreted cautiously, as the number of studies and the duration of follow-up were limited. In one study, minor bone augmentation was performed as needed without balancing between the groups (80). Since MBL tends to be more pronounced at grafted sites (9, 107), it would be ideal to exclude subjects who underwent bone augmentation or to ensure equal distribution between groups. With this in mind, no differences in MBL were observed in that particular study (80).

The adhesion of peri-implant soft tissue is critical for maintaining crestal bone stability and achieving optimal aesthetics in implant-supported restorations (108, 109). Although the mean BOP was slightly lower in the monolithic zirconia group, the difference was statistically not significant. These findings suggest that the type of restoration could influence BOP. Polished zirconia has been shown to accumulate less bacteria and promote better cell adhesion compared to glazed ceramics (44, 110). As a result, with more stable supracrestal tissue attachment and reduced plaque accumulation, bleeding may also be minimized (80).

Chipping of the veneering material remains a common technical issue in metal-ceramic restorations (3). Monolithic restorations may improve outcomes by eliminating the need for veneering ceramics (48, 57). This analysis included micro-veneered zirconia restorations, as veneering layers were limited to non-functional areas (52). A significant difference in chipping rates was observed between the two groups, with monolithic restorations experiencing fewer incidents. Since chipping is often caused by residual thermal stresses in veneering ceramics (47, 48), it is expected that monolithic restorations would perform better in this regard, as reported in previous studies (36). Recent studies have highlighted that monolithic zirconia crowns, with superior mechanical properties, are less prone to chipping compared to veneered restorations, and have also demonstrated their fracture resistance and mechanical reliability under varying occlusal conditions (111, 112). However, Mangano et al. reported one case of chipping in a monolithic zirconia crown, which was attributed to bruxism-related higher occlusal loading. The crown was remade, and this incident was classified as a restoration failure rather than a complication in this study (102).

In the monolithic zirconia group, one reduced-diameter titanium-zirconium implant was lost despite a recent meta-analysis showing high survival and success rates, along with increased mechanical strength for titanium-zirconium implants (113). However, Mühlemann's study indicated that using this implant negatively affected survival rates (57). Another implant failure in the monolithic zirconia group was due to a loss of osseointegration three months after the definitive crown was placed, though the study did not discuss the specific causes (52). In the metal-ceramic group, one implant was lost after three months without signs of inflammation, and it was suggested that intense biomechanical overload during chewing might have caused the failure (57). The implant survival rates were 98.4% for monolithic zirconia and 99.2% for metal-ceramic, aligning with previous reviews (36, 49). Given these outcomes, it can be hypothesized that implant failure was likely not influenced by the restoration material, though the available data remains limited.

In three instances, the restorations failed due to implant failure, while in one case, the crown had to be remade because of unpolishable chipping. The survival rate was 97.5% for the monolithic zirconia group and 99.1% for the metal-ceramic group. These findings are consistent with previously reported high survival rates of monolithic zirconia implant-supported SCs, as noted by Donker et al. and Pjetursson et al. (8, 36). Our systematic review and meta-analysis further supports these conclusions.

Regarding technical complications, screw-loosening occurred in 2.82% of monolithic zirconia SCs and 10.6% of metal-ceramic SCs. The higher rate of screw-loosening in the metal-ceramic group may be linked to their internal octagon implant-abutment connection, as conical connections are known to reduce the likelihood of screw-loosening (8, 12). The de-cementation rate was 0% for monolithic zirconia and 5.71% for metal-ceramic crowns. Prior studies have indicated that different retention methods affect biological and technical complication rates (7, 11, 13), suggesting the need for further investigation into the impact of retention types. Given the unequal distribution of cemented and screw-retained crowns between the two groups and the small sample size, the results regarding retention types should be approached with caution.

Study II assessed the biological outcomes of bone-level implants restored with varying abutment heights within the ‘one abutment one time’ protocol.

The rate of bone turnover is highest during the first six months and then gradually decreases over time (9, 114, 115). It is essential to assess MBL at various time points separately, as MBL during the first year may serve as a strong predictor of long-term implant failure (9). Our findings align with these statements, as the results showed a significant difference in MBL at the 6-month follow-up, highlighting the high rate of bone remodeling during this period.

Regarding early MBL in our study, the analysis showed higher bone levels in the long abutment group. Although these results were statistically not significant, the reduced bone loss observed in this group at both 6 and 12 months of follow-up demonstrated clinical relevance. A possible explanation could be the formation of stable STA and the positioning of abutment-crown microgaps. With short abutments in patients with a thin phenotype, the VMT may not be sufficient to create STA, leading to MBL to establish adequate vertical dimensions for STA (24). In cases where a short abutment is used with a thick phenotype, the microgap and associated inflammatory response are positioned closer to the bone crest, potentially increasing bone resorption (62, 116, 117). Despite the lack of a statistically significant difference, our results contrast with previous meta-analyses, possibly due to our study's more refined statistical approach (31, 67).

Due to the limited dataset, a meta-analysis of late MBL could not be performed in this study, as only one trial with a 3-year follow-up period was available (104). That study reported no significant difference in MBL between short and long abutments at long-term follow-up. Similarly, Vervaeke et al. found no significant difference in long-term peri-implant bone loss associated with varying abutment heights in their 9-year prospective case series (64).

A subgroup analysis revealed no significant difference in MBL when definitive abutments were placed immediately after implant placement. Although this analysis included only a few studies, it highlights an ongoing debate in the literature. Canullo et al. suggested that the 'one abutment one time' approach could minimize MBL (17). Similarly, a recent meta-analysis of four studies reported significantly greater bone loss with multiple abutment placements (74). Borges et al. examined this concept along with abutment height over a 3-year follow-up, concluding that long definitive abutments inserted immediately post-surgery present a favorable treatment option for maintaining crestal bone (104). However, other systematic reviews found insufficient evidence to support this conclusion (118, 119). These mixed findings reinforce the need for further research to provide more definitive answers on this still-debated topic.

Key indicators of soft tissue health include BOP and PPD, which reflect inflammation and attachment loss (120). Our analysis found no significant differences in BOP or PPD between the study groups. This suggests that abutment height alone may not significantly impact soft tissue health; rather, prosthetic factors and individual oral hygiene practices may play a more crucial role (121-123). Most recent meta-analysis could not evaluate this outcome due to the limited available data (67).

Several clinical and anatomical factors, such as implant depth, angulation, interocclusal space, and soft tissue height, play a role in selecting abutment height (124). Previously, VMT was considered a key factor in maintaining crestal bone levels (14). Linkevicius et al. suggested that initial VMT affects crestal bone changes (25). A meta-analysis from 2016 also indicated that implants placed in thicker peri-implant soft tissue areas experienced significantly less MBL than those with thinner mucosa (24). However, it is essential to note that these studies did not account for abutment height. In our study, two trials examined MBL in relation to abutment heights and VMT (20, 92). Contrary to earlier findings, these studies showed that MBL was not correlated with VMT. As this remains controversial, further research is needed to clarify the relationship between abutment height, VMT, and MBL.

9.2. Strengths

One of the strengths of our studies is the pre-registered, well-established, and published methodology, which enhances the transparency and rigor of the research process. Study I exhibited low statistical heterogeneity regarding MBL, BOP, chipping, and implant failure, indicating consistent results. Furthermore, the inclusion of only RCTs provides greater credibility to the findings. The strengths of Study II included a more refined statistical analysis and seven RCTs, which enhanced the robustness of the findings. The included studies demonstrated a low-to-moderate risk of bias, indicating a reliable assessment of the outcomes. Additionally, the GRADE assessment indicated high-to-moderate certainty of evidence, further supporting the validity of the conclusions drawn from the study.

9.3. Limitations

The main limitations were the low number of articles and the short-term follow-up periods for our studies; therefore, publication bias could not be examined either. For the same reason, other outcomes in Study I, such as patient satisfaction, cost, and time aspects of the prosthetic procedures, could not be evaluated. Furthermore, there was heterogeneity among the included patients and restorations concerning various factors such as retention types, implant types, implant-abutment connections, abutment materials and manufacturing methods, vertical implant positions, workflows, temporomandibular disorders, and smoking habits. Study II showed high statistical heterogeneity, as well as differences in study characteristics, such as variations in restoration and retention types, follow-up periods, implant connection types, implant placement levels, and soft tissue phenotypes.

10. CONCLUSIONS

1. At one-year follow-up, monolithic zirconia and metal-ceramic restoration types demonstrated similar outcomes regarding MBL, BOP, survival, and failure rates. However, monolithic zirconia exhibited significantly less chipping than metal-ceramic restorations over the same period. Based on the current studies, monolithic zirconia is a valid alternative for implant-supported SCs in the short term with less technical complications. Nonetheless, additional research is essential to confirm the long-term clinical performance of monolithic zirconia single implant crowns.

2. Longer abutments on bone-level implants appear to be a favorable treatment option for reducing early MBL. While the timing of abutment connection may not significantly influence biological outcomes over a short-term follow-up period, further studies are necessary to validate these findings and explore their implications for long-term clinical practice.

11. IMPLEMENTATION FOR PRACTICE

The importance of early implementation of scientific findings in clinical settings has been well-documented (125, 126).

Incorporating monolithic zirconia as the material for implant-supported SCs in routine clinical practice can significantly decrease complication rates. This shift can lead to more reliable and efficient restorations, promoting better adaptation of soft tissues around the implants. Ultimately, this approach could enhance the overall success of dental implants, fostering healthier outcomes for patients.

Clinicians are likely to prioritize using long abutments when restoring dental implants because they significantly reduce bone loss and promote more stable soft tissues around the implant. This stability can improve patient outcomes, leading to more predictable long-term results regarding function and aesthetics. Given these advantages, long abutments may emerge as the preferred choice for implant restorations in clinical practice whenever feasible, allowing dental professionals to enhance the overall success and longevity of implant-supported solutions.

12. IMPLEMENTATION FOR RESEARCH

Future research should involve well-designed RCTs with larger sample sizes and more standardized reporting on biological outcomes and complications, including horizontal and vertical mucosal thickness, probing depths, peri-implant mucositis, and peri-implantitis. We strongly recommend that the factors contributing to the heterogeneity observed in our study be considered in future investigations. It would also be valuable to examine aesthetic outcomes and the interaction of peri-implant mucosa with both restoration materials and assess recession measures.

Furthermore, additional research is necessary to fully comprehend the long-term effects of varying abutment heights. To achieve this, more homogeneous study designs should be implemented, considering factors such as implant placement levels, abutment designs, and types of restorations, all with extended follow-up periods, ideally through split-mouth trials. Future studies should also concentrate on the ‘one abutment one time’ protocol and monitor VMT to resolve existing controversies regarding their potential impacts.

13. IMPLEMENTATION FOR POLICYMAKERS

Dental policymakers must recognize the importance of using monolithic zirconia SCs alongside long abutments in implant restorations, as this combination can help reduce complications and improve patient outcomes. By understanding the advantages of long abutments, policymakers can support guidelines that encourage their adoption in everyday practice, leading to better stability of the soft tissues around implants and less bone loss over time. Additionally, the decision between using monolithic zirconia or metal-ceramic crowns is vital, as evidence suggests that monolithic zirconia may result in less complications and better integration with soft tissues.

To make this a reality, allocating resources for ongoing education is essential, ensuring that dental professionals are updated with the latest research and techniques regarding abutment height and material choice. Furthermore, supporting the development of printed zirconia restorations and exploring advancements in materials will be important for future improvements in implant dentistry.

Finally, it is crucial to encourage further research to substantiate these findings, as current evidence remains limited. By taking an active role in these initiatives, policymakers can significantly enhance the predictability of long-term patient outcomes and elevate the overall standards of care in implant dentistry.

14. FUTURE PERSPECTIVES

Future perspectives in this field should focus on conducting long-term clinical trials to understand better the durability and performance of different restoration materials, such as monolithic zirconia and metal-ceramic crowns. Additionally, further research is needed to explore the interaction between these materials and peri-implant soft tissues, as well as their impact on esthetic outcomes and long-term stability. It is also essential to prioritize long-term randomized controlled trials examining the height and 3D design of implant abutments. These studies will provide valuable insights to guide clinicians in making more refined treatment decisions.

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16. BIBLIOGRAPHY

16.1. Publications related to the thesis

Tajti P, Solyom E, Czumbel LM, Szabó B, Fazekas R, Németh O, Hermann P, Gerber G, Hegyi P, Mikulás K. (2023) Monolithic zirconia as a valid alternative to metal-ceramic for implant-supported single crowns in the posterior region: A systematic review and meta-analysis of randomized controlled trials. J Prosthet Dent. Online ahead of print.

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Tajti P, Solyom E, Váncsa S, Mátrai P, Hegyi P, Varga G, Hermann P, Borbély J, Sculean A, Mikulás K. (2024) Less marginal bone loss around bone-level implants restored with long abutments: A systematic review and meta-analysis. Periodontol 2000, 94: 627-638.

D1, IF: 17.5

16.2. Publications not related to the thesis

Szalai E, **Tajti P**, Szabó B, Kói T, Hegyi P, Czumbel LM, Varga G, Kerémi B. (2023) Organoleptic and halitometric assessments do not correlate well in intra-oral halitosis: a systematic review and meta-analysis. J Evid Based Dent Pract, 23: 101862.

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Q1, IF: 2.9

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Q4

Radoczy-Drajko Zs, Windisch P, Svidro E, **Tajti P**, Molnar B, Gerber G. (2021) Clinical, radiographical and histological evaluation of alveolar ridge preservation with an autogenous tooth derived particulate graft in EDS class 3–4 defects. BMC Oral Health 21: 63.

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