

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

PhD Thesis

Péter Tajti DMD

Translational Medicine Program
Dental Research Division
SEMMELWEIS UNIVERSITY



Supervisor:

Krisztina Mikulás, DMD, PhD

Official reviewers:

Victor-Vlad Costan, MD, DMD, PhD

Oleh Andrukhov, DMD, PhD

Head of the Complex

Nándor Ács, MD, DSc

Examination Committee:

Members of the Complex

Károly Bartha, DMD, PhD

Examination Committee:

Andrea Harnos, MSc, PhD

Ákos Nagy, DMD, PhD

Victor-Vlad Costan, MD, DMD, PhD

Budapest

2025

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

Albert Einstein

TABLE OF CONTENT

1. LIST OF ABBREVIATIONS	5
2. STUDENT PROFILE.....	7
2.1. Vision and mission statement, specific goals	7
2.2. Scientometrics	7
2.3. Future plans	7
3. SUMMARY OF THE PHD.....	8
4. GRAPHICAL ABSTRACT	9
5. INTRODUCTION.....	10
5.1. Overview of the topic	10
5.1.1. What is the topic?	10
5.1.2. What is the problem to solve?	10
5.1.3. What is the importance of the topic?	10
5.1.4. What would be the impact of our research results?	10
5.2. Marginal bone loss as a key factor in oral implantology.....	10
5.3. Material choice of the restoration	11
5.4. Abutment design of the suprastructure	12
6. OBJECTIVES.....	14
6.1. Study I – Investigating the potential benefits of using monolithic zirconia over metal-ceramic as implant-supported single crowns.....	14
6.2. Study II – Investigating the influence of abutment height on crestal bone stability and peri-implant soft tissue health.....	14
7. METHODS.....	15
7.1. Study I – Investigating the potential benefits of using monolithic zirconia over metal-ceramic as implant-supported single crowns.....	15

7.1.1. Systematic search	15
7.1.2. Study selection and data collection	16
7.1.3. Quality assessment and certainty of evidence	17
7.1.4. Data synthesis and analysis	17
7.2. Study II – Investigating the influence of abutment height on crestal bone stability and peri-implant soft tissue health.....	18
7.2.1. Systematic search	18
7.2.2. Study selection and data collection	19
7.2.3. Quality assessment and certainty of evidence	19
7.2.4. Data synthesis and analysis	20
8. RESULTS	21
8.1. Study I – Investigating the potential benefits of using monolithic zirconia over metal-ceramic as implant-supported single crowns.....	21
8.1.1. Search and selection characteristics of the included studies	21
8.1.2. Characteristics of the included studies	22
8.1.3. Results of the synthesis and certainty of evidence	25
8.1.4. Qualitative analysis.....	30
8.1.5. Risk of bias assessment	30
8.2. Study II – Investigating the influence of abutment height on crestal bone stability and peri-implant soft tissue health.....	31
8.2.1. Search and selection characteristics of the included studies	31
8.2.2. Characteristics of the included studies	32
8.2.3. Results of the synthesis and certainty of evidence	35
8.2.3. Risk of bias assessment	41
9. DISCUSSION.....	42
9.1. Summary of findings, international comparisons.....	42

9.2. Strengths	46
9.3. Limitations	46
10. CONCLUSIONS	47
11. IMPLEMENTATION FOR PRACTICE	48
12. IMPLEMENTATION FOR RESEARCH.....	49
13. IMPLEMENTATION FOR POLICYMAKERS.....	50
14. FUTURE PERSPECTIVES	51
15. REFERENCES	52
16. BIBLIOGRAPHY	66
16.1. Publications related to the thesis	66
16.2. Publications not related to the thesis	66
17. ACKNOWLEDGEMENTS.....	68

1. LIST OF ABBREVIATIONS

BOP	bleeding on probing
CI	confidence interval
GRADE	grading of recommendations assessment, development, and evaluation
ICC	intraclass 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

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

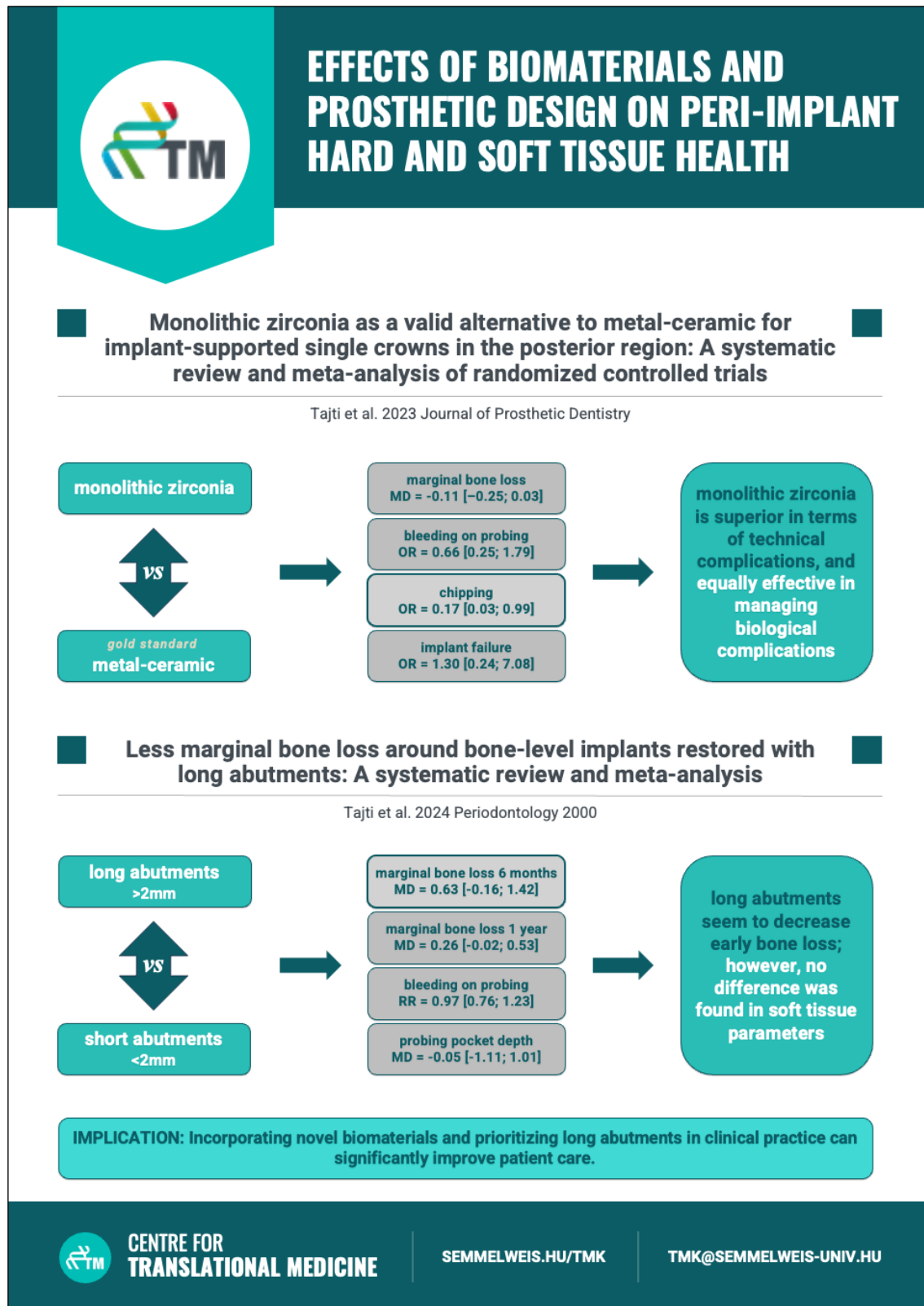
Material and prosthetic design choices for single implant restorations call for an update as novel biomaterials and controverting studies about abutment design have appeared in the field of implant prosthodontics.

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.

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 ($\text{Li}_2\text{Si}_2\text{O}_5$), 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).

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, intraclass 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 **dmeter** (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 $\kappa=0.95$. Four eligible articles were identified after full-text analysis, achieving an inter-rater agreement of $\kappa=1.00$. 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).

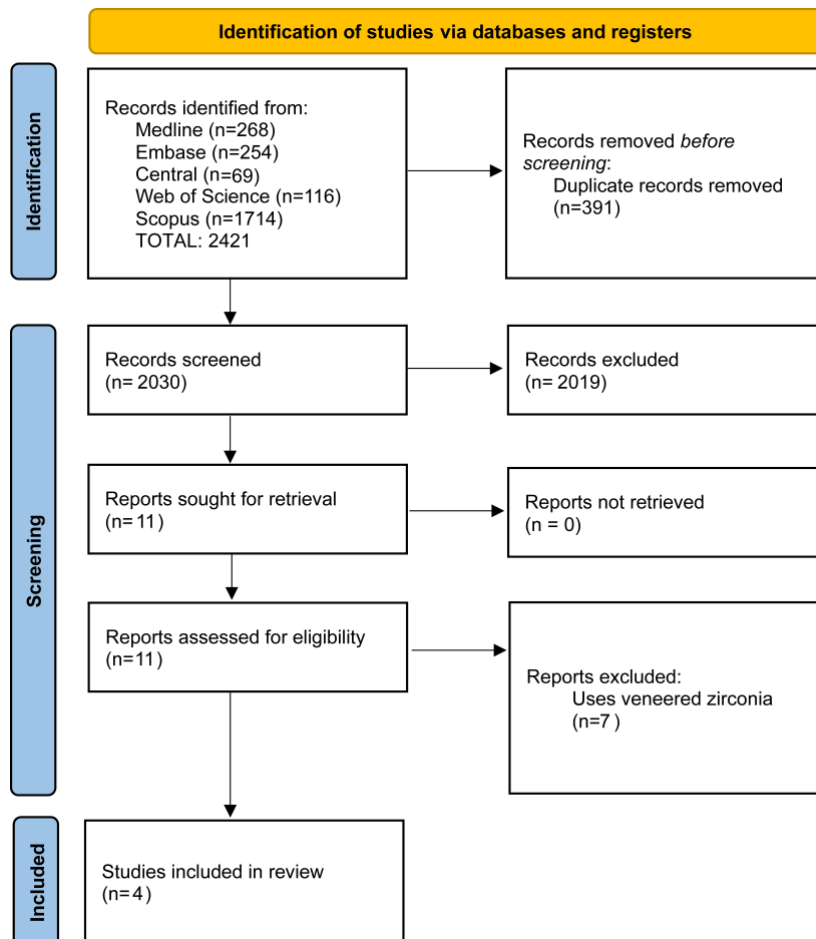


Figure 1. Flowchart of the selection process for Study I based on the PRISMA 2020 statement (101)

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			Biological parameters	Prosthetic parameters
First author	Retention	Type	Type of cement if used	Retention	Type	Type of cement if used		
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).

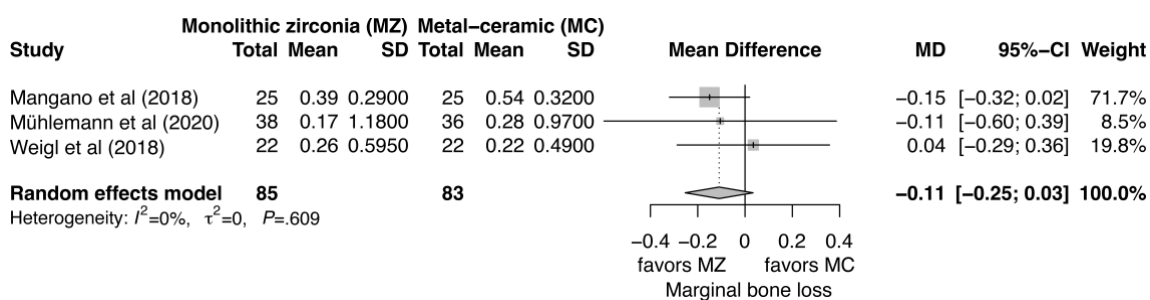


Figure 2. Forest plot shows no significant difference in marginal bone loss between monolithic zirconia and metal-ceramic single crowns (101)

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, I²=0%). However, this difference did not reach statistical or clinical significance. The I² 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).

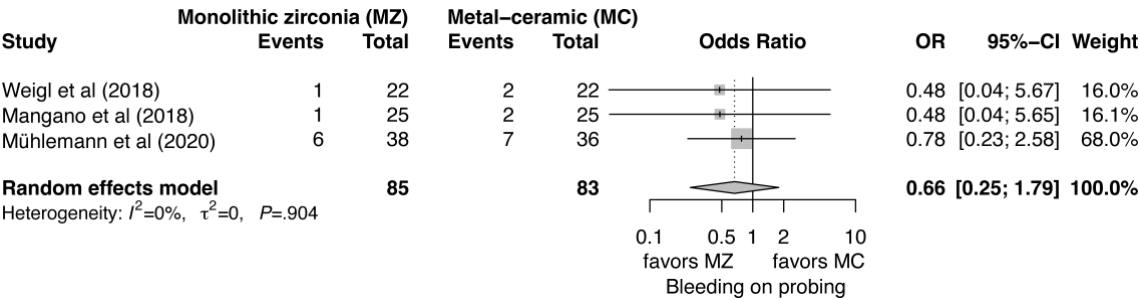


Figure 3. Forest plot shows less bleeding on probing around monolithic zirconia compared to metal-ceramic single crowns (101)

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).

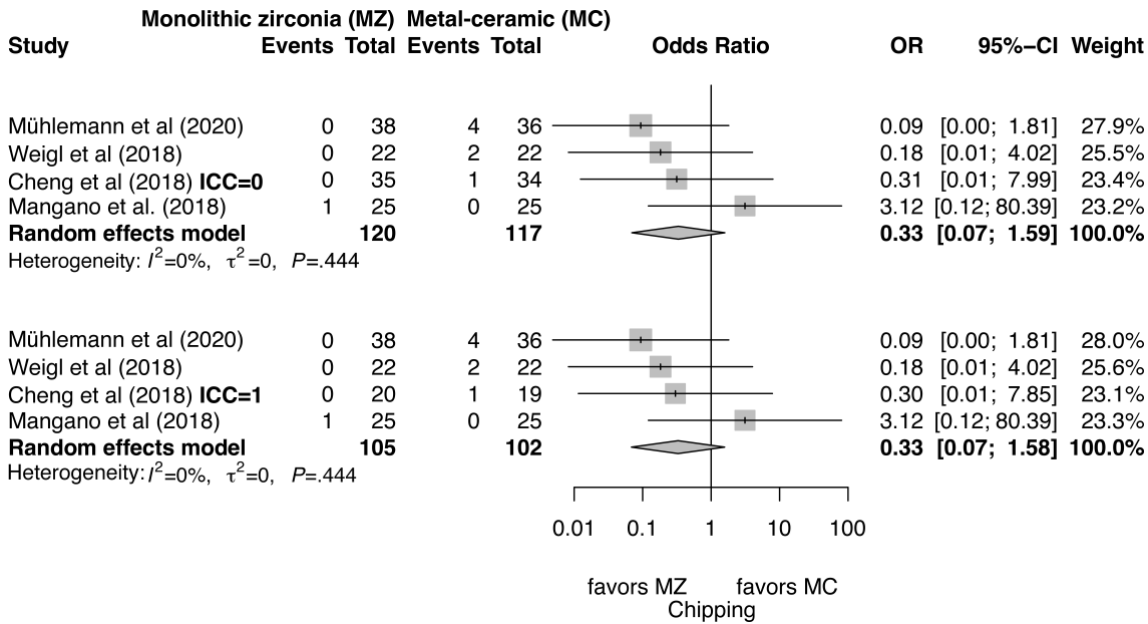


Figure 4A. No significant difference in chipping between monolithic zirconia and metal-ceramic single crowns when including all eligible data (101)

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).

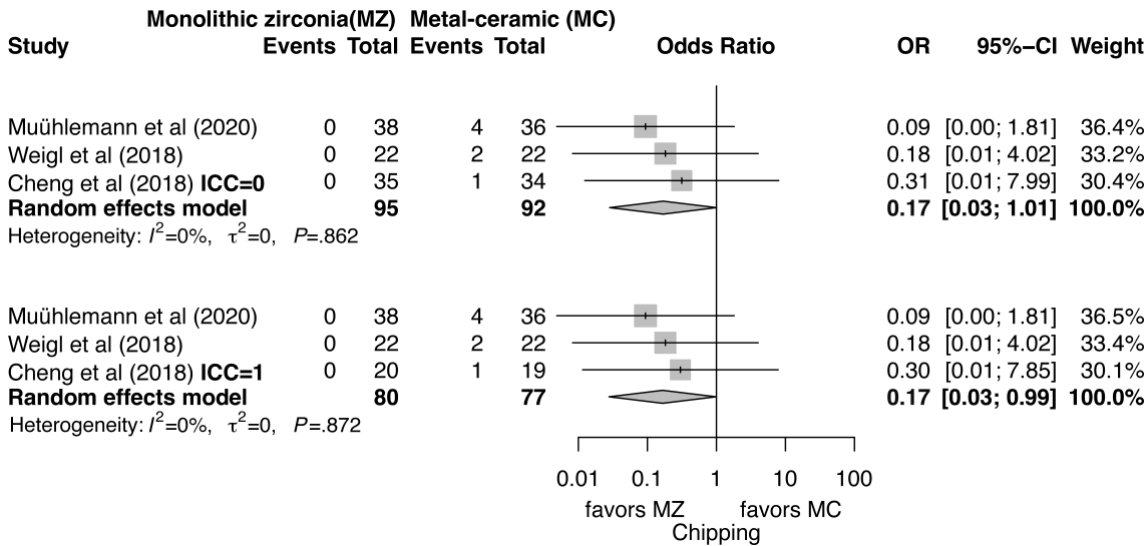


Figure 4B. Significantly less chipping in monolithic zirconia single crowns when excluding patient with bruxism (101)

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).

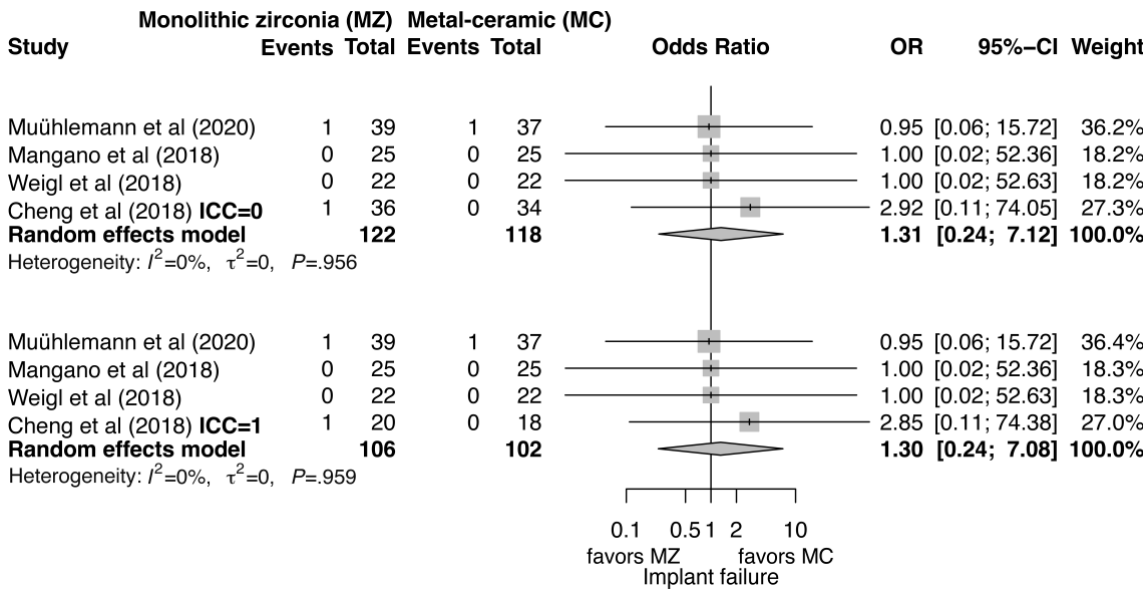


Figure 5. No significant difference in implant failure between monolithic zirconia and metal-ceramic single crowns (101)

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 ($\kappa=0.91$). Full-text evaluation ultimately identified eight eligible articles ($\kappa=0.97$). A manual hand search of reference lists yielded no additional articles. The selection process is summarized in Figure 2 (103).

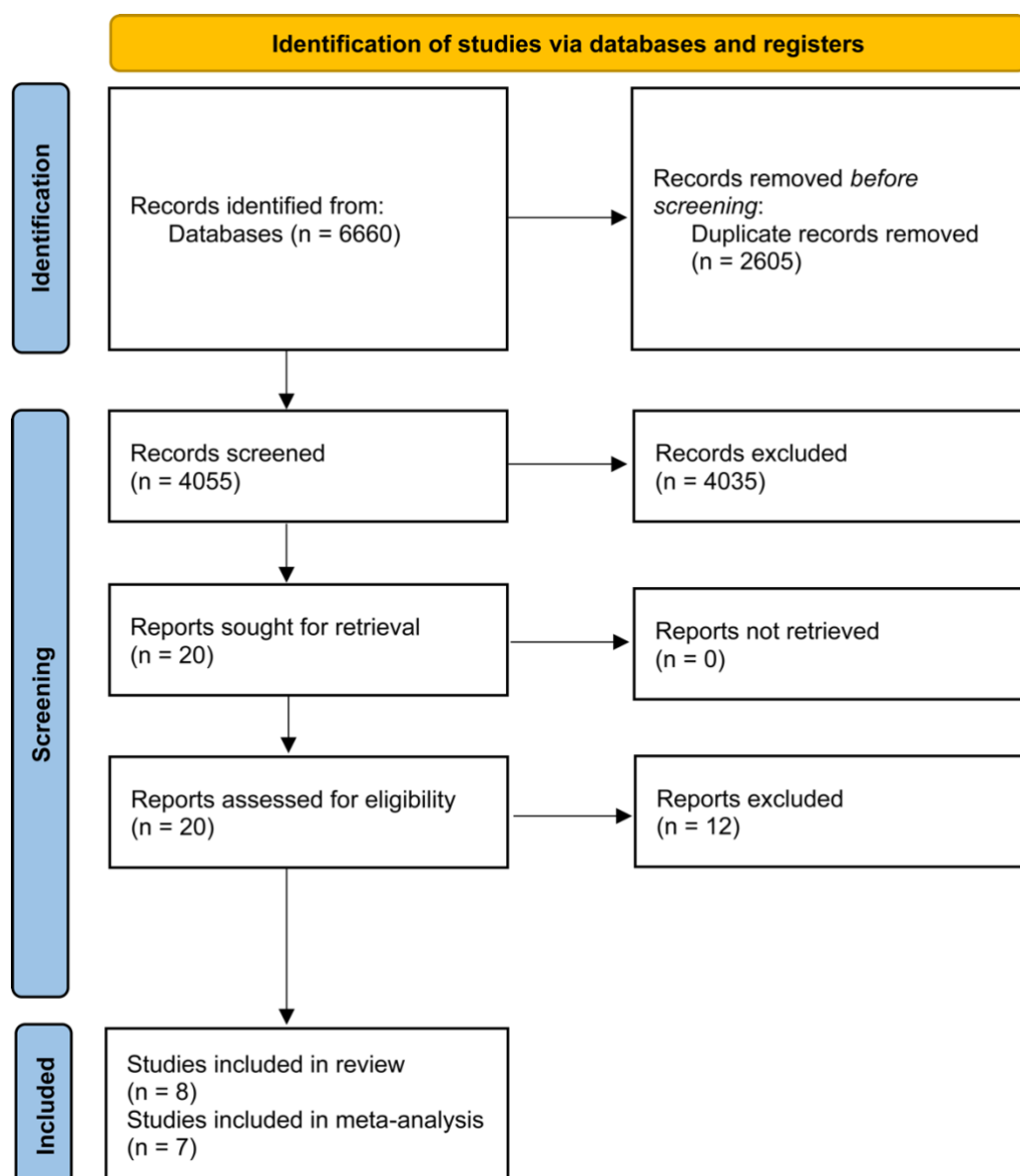


Figure 6. Flowchart of the selection process based on PRISMA 2020 statement (103)

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		Implant	Surgical	Soft or hard	Loading	Restoration	Follow-	Abutment	Abutment	OAOT	Outcomes
First author	Year	placement level	site	tissue augmentation	protocol		up months	height (short)	height (long)	protocol	
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).

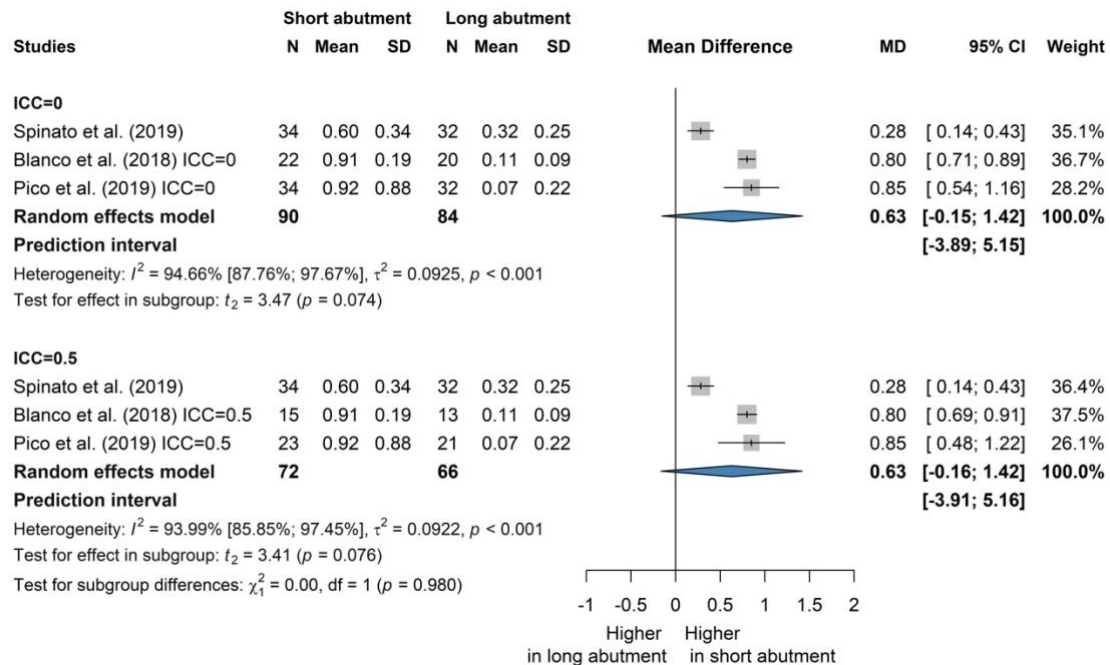


Figure 7. Forest plot shows less marginal bone loss with long abutments at 6-month follow-up (103)

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).

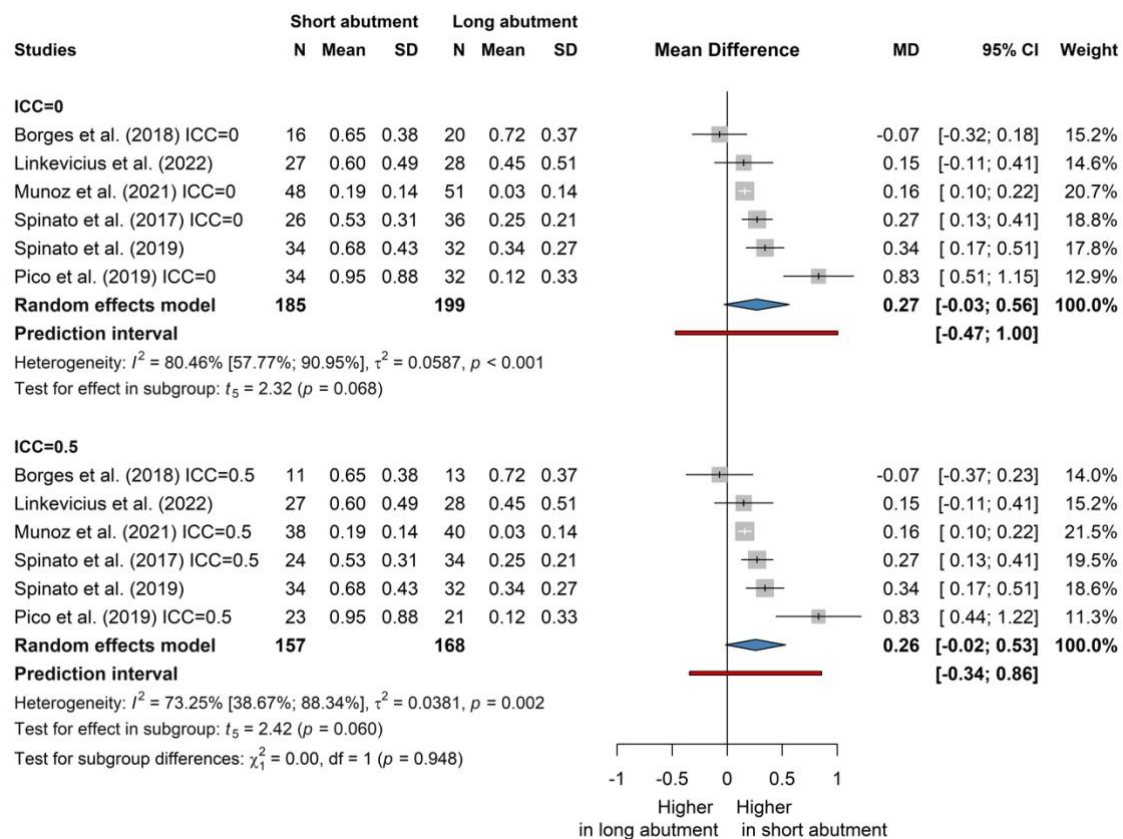


Figure 8. Forest plot shows less marginal bone loss with long abutments at 1-year follow-up (103)

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).

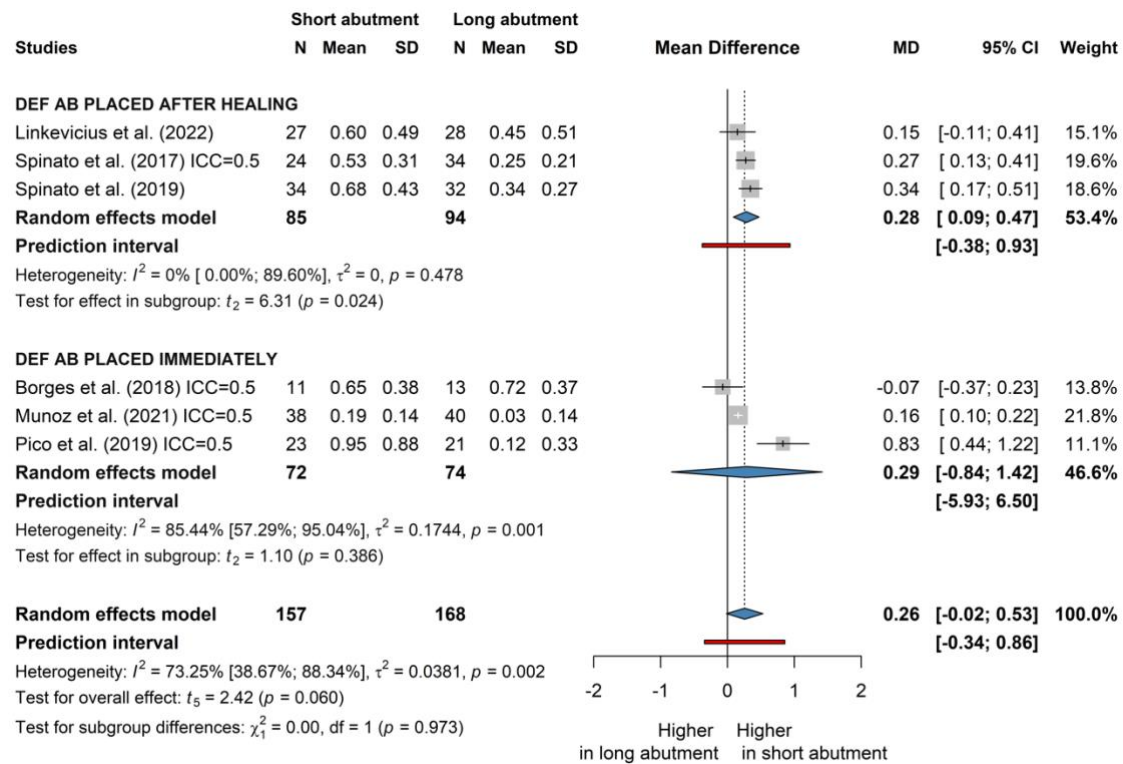


Figure 9. Forest plot shows no difference in marginal bone loss between subgroups of ‘one abutment one time’ and conventional placement protocols at 1-year follow-up (ICC=0.5) (103)

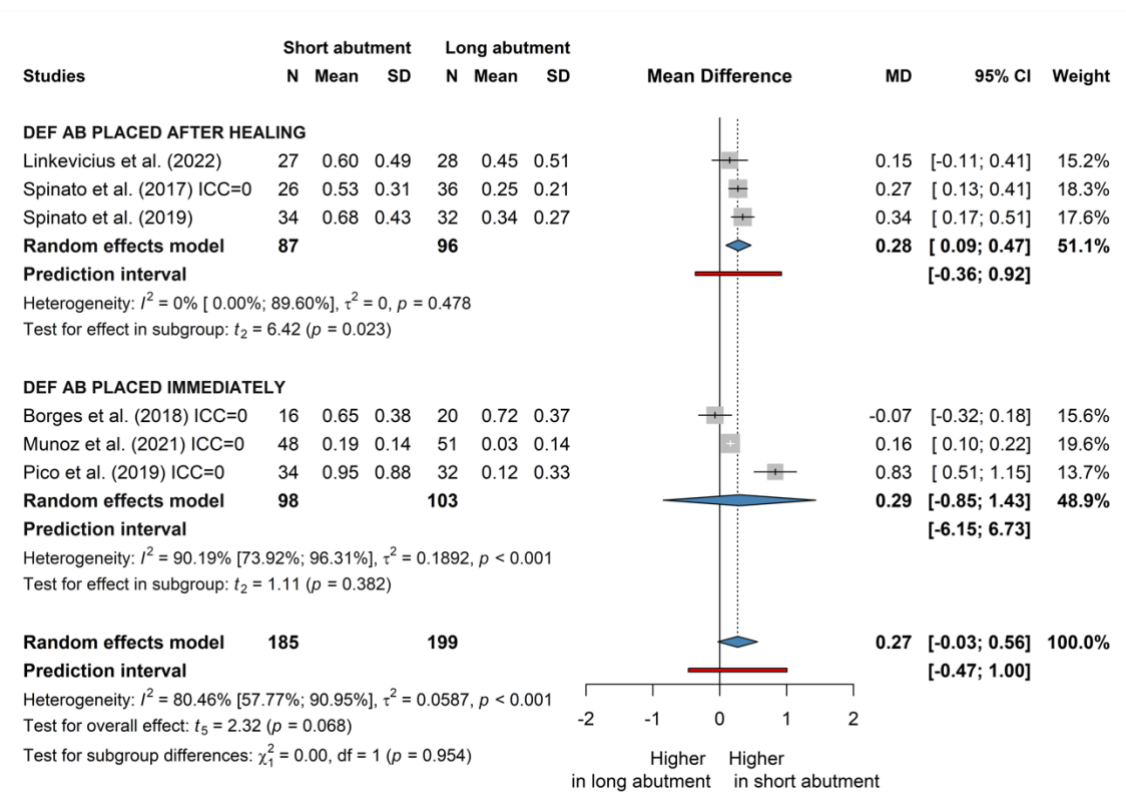


Figure 10. Forest plot shows no difference in marginal bone loss between subgroups of ‘one abutment one time’ and conventional placement protocols at 1-year follow-up (ICC=0) (103)

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).

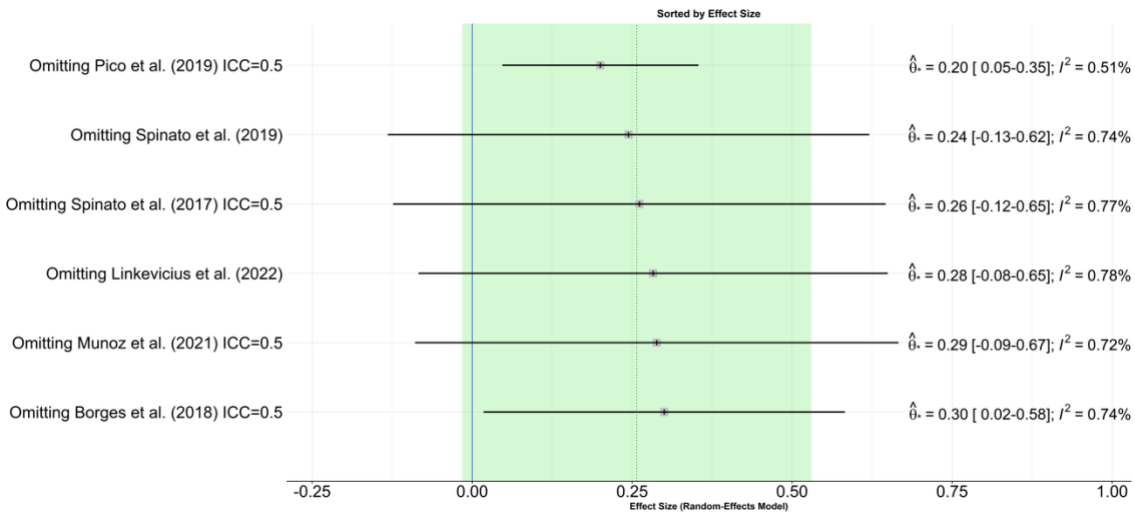


Figure 11. Leave-one-out analysis of marginal bone loss at 1-year follow-up (103)

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).

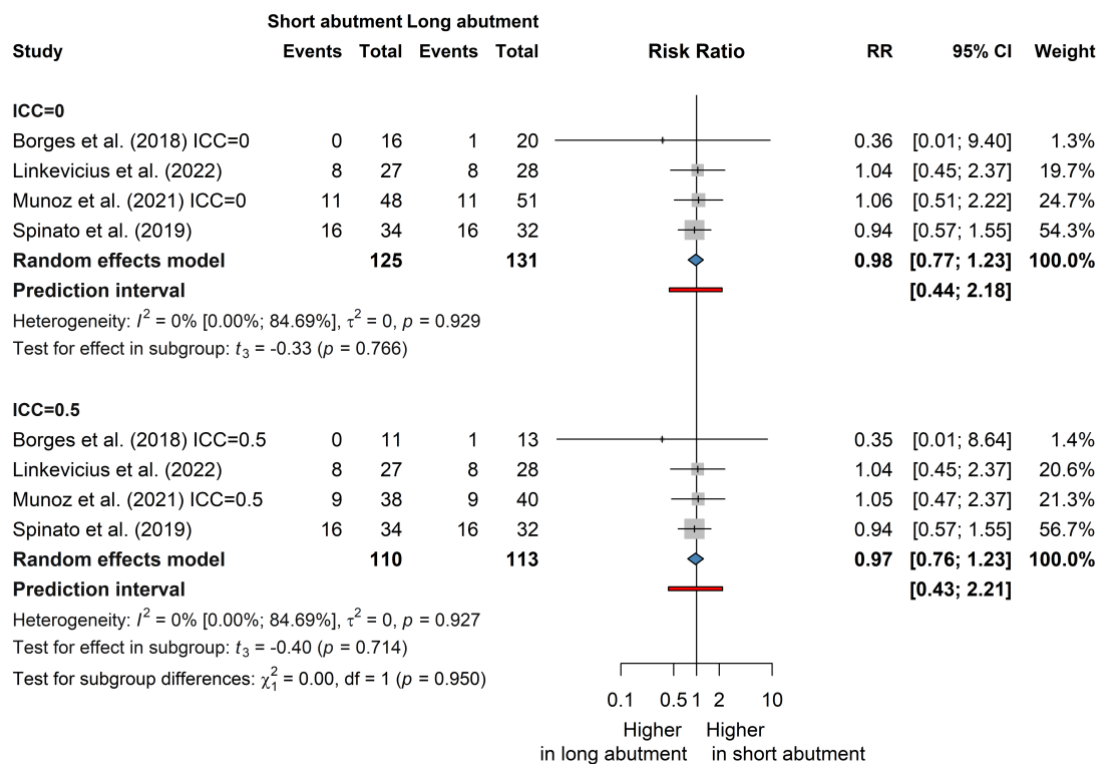


Figure 12. Forest plot shows no difference in bleeding on probing between different abutment heights at 1-year follow-up (103)

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).

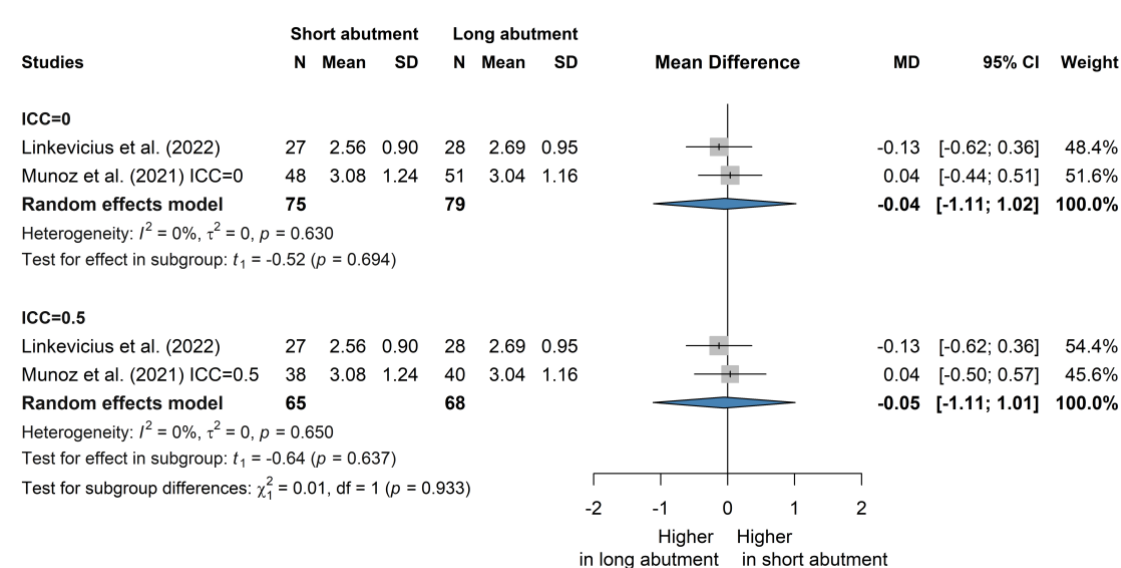


Figure 13. Forest plot shows no difference in probing pocket depth between different abutment heights at 1-year follow-up (103)

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).

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.

15. REFERENCES

1. Joda T, Bragger U. Complete digital workflow for the production of implant-supported single-unit monolithic crowns. *Clin Oral Implants Res.* 2014;25(11):1304-6.
2. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. *Clin Oral Implants Res.* 2012;23 Suppl 6:2-21.
3. Pjetursson BE, Thoma D, Jung R, Zwahlen M, Zembic A. A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. *Clin Oral Implants Res.* 2012;23 Suppl 6:22-38.
4. Renvert S, Persson GR, Pirih FQ, Camargo PM. Peri-implant health, peri-implant mucositis, and peri-implantitis: Case definitions and diagnostic considerations. *J Clin Periodontol.* 2018;45 Suppl 20:S278-S85.
5. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. *Int J Oral Maxillofac Implants.* 1986;1(1):11-25.
6. Alqutaibi AY, Alnazzawi AA, Algabri R, Aboalrejal AN, AbdElaziz MH. Clinical performance of single implant-supported ceramic and metal-ceramic crowns: A systematic review and meta-analysis of randomized clinical trials. *J Prosthet Dent.* 2021;126(3):369-76.
7. Dini C, Borges GA, Costa RC, Magno MB, Maia LC, Barao VAR. Peri-implant and esthetic outcomes of cemented and screw-retained crowns using zirconia abutments in single implant-supported restorations-A systematic review and meta-analysis. *Clin Oral Implants Res.* 2021;32(10):1143-58.
8. Donker VJJ, Raghoobar GM, Jensen-Louwerse C, Vissink A, Meijer HJA. Monolithic zirconia single tooth implant-supported restorations with CAD/CAM titanium abutments in the posterior region: A 1-year prospective case series study. *Clin Implant Dent Relat Res.* 2022;24(1):125-32.

9. Galindo-Moreno P, Leon-Cano A, Ortega-Oller I, Monje A, Francisco OV, Catena A. Marginal bone loss as success criterion in implant dentistry: beyond 2 mm. *Clin Oral Implants Res.* 2015;26(4):e28-e34.
10. Pjetursson BE, Valente NA, Strasding M, Zwahlen M, Liu S, Sailer I. A systematic review of the survival and complication rates of zirconia-ceramic and metal-ceramic single crowns. *Clin Oral Implants Res.* 2018;29 Suppl 16:199-214.
11. Sailer I, Muhlemann S, Zwahlen M, Hammerle CH, Schneider D. Cemented and screw-retained implant reconstructions: a systematic review of the survival and complication rates. *Clin Oral Implants Res.* 2012;23 Suppl 6:163-201.
12. Vinhas AS, Aroso C, Salazar F, Lopez-Jarana P, Rios-Santos JV, Herrero-Climent M. Review of the Mechanical Behavior of Different Implant-Abutment Connections. *Int J Environ Res Public Health.* 2020;17(22).
13. Wittneben JG, Millen C, Bragger U. Clinical performance of screw- versus cement-retained fixed implant-supported reconstructions--a systematic review. *Int J Oral Maxillofac Implants.* 2014;29 Suppl:84-98.
14. Berglundh T, Lindhe J. Dimension of the periimplant mucosa. Biological width revisited. *J Clin Periodontol.* 1996;23(10):971-3.
15. Cochran DL, Hermann JS, Schenk RK, Higginbottom FL, Buser D. Biologic width around titanium implants. A histometric analysis of the implanto-gingival junction around unloaded and loaded nonsubmerged implants in the canine mandible. *J Periodontol.* 1997;68(2):186-98.
16. Jepsen S, Caton JG, Albandar JM, Bissada NF, Bouchard P, Cortellini P, et al. Periodontal manifestations of systemic diseases and developmental and acquired conditions: Consensus report of workgroup 3 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *J Clin Periodontol.* 2018;45 Suppl 20:S219-S29.
17. Canullo L, Bignozzi I, Cocchetto R, Cristalli MP, Iannello G. Immediate positioning of a definitive abutment versus repeated abutment replacements in post-extractive implants: 3-year follow-up of a randomised multicentre clinical trial. *Eur J Oral Implantol.* 2010;3(4):285-96.

18. Oh T-J, Yoon J, Misch C, Wang H-L. The Causes of Early Implant Bone Loss: Myth or Science? *Journal of periodontology*. 2002;73:322-33.
19. Qian J, Wennerberg A, Albrektsson T. Reasons for marginal bone loss around oral implants. *Clin Implant Dent Relat Res*. 2012;14(6):792-807.
20. Spinato S, Stacchi C, Lombardi T, Bernardello F, Messina M, Zaffe D. Biological width establishment around dental implants is influenced by abutment height irrespective of vertical mucosal thickness: A cluster randomized controlled trial. *Clin Oral Implants Res*. 2019;30(7):649-59.
21. Tatarakis N, Bashutski J, Wang H-L, Oh T-J. Early Implant Bone Loss: Preventable or Inevitable? *Implant Dentistry*. 2012;21(5).
22. Abrahamsson I, Zitzmann N, Berglundh T, Wennerberg A, Ja L. Bone and Soft Tissue Integration to Titanium Implants with Different Surface Topography: An Experimental Study in the Dog. *The International journal of oral & maxillofacial implants*. 2001;16:323-32.
23. Linkevicius T, Apse P, Grybauskas S, Puisys A. Reaction of crestal bone around implants depending on mucosal tissue thickness. A 1-year prospective clinical study. *Stomatologija / issued by public institution "Odontologijos studija"* [et al]. 2009;11:83-91.
24. Suarez-Lopez Del Amo F, Lin GH, Monje A, Galindo-Moreno P, Wang HL. Influence of Soft Tissue Thickness on Peri-Implant Marginal Bone Loss: A Systematic Review and Meta-Analysis. *J Periodontol*. 2016;87(6):690-9.
25. Linkevicius T, Puisys A, Steigmann M, Vindasiute E, Linkeviciene L. Influence of Vertical Soft Tissue Thickness on Crestal Bone Changes Around Implants with Platform Switching: A Comparative Clinical Study. *Clin Implant Dent Relat Res*. 2015;17(6):1228-36.
26. Manz MC. Factors associated with radiographic vertical bone loss around implants placed in a clinical study. *Ann Periodontol*. 2000;5(1):137-51.

27. Albrektsson T, Dahlin C, Jemt T, Sennerby L, Turri A, Wennerberg A. Is marginal bone loss around oral implants the result of a provoked foreign body reaction? *Clin Implant Dent Relat Res.* 2014;16(2):155-65.
28. Quirynen M, Naert I, van Steenberghe D. Fixture design and overload influence marginal bone loss and fixture success in the Branemark system. *Clin Oral Implants Res.* 1992;3(3):104-11.
29. Abrahamsson I, Berglundh T, Lindhe J. The mucosal barrier following abutment dis/reconnection. An experimental study in dogs. *J Clin Periodontol.* 1997;24(8):568-72.
30. Chappuis V, Bornstein MM, Buser D, Belser U. Influence of implant neck design on facial bone crest dimensions in the esthetic zone analyzed by cone beam CT: a comparative study with a 5-to-9-year follow-up. *Clin Oral Implants Res.* 2016;27(9):1055-64.
31. Chen Z, Lin CY, Li J, Wang HL, Yu H. Influence of abutment height on peri-implant marginal bone loss: A systematic review and meta-analysis. *J Prosthet Dent.* 2019;122(1):14-21 e2.
32. Lazzara RJ, Porter SS. Platform switching: a new concept in implant dentistry for controlling postrestorative crestal bone levels. *Int J Periodontics Restorative Dent.* 2006;26(1):9-17.
33. Pozzi A, Agliardi E, Tallarico M, Barlattani A. Clinical and radiological outcomes of two implants with different prosthetic interfaces and neck configurations: randomized, controlled, split-mouth clinical trial. *Clin Implant Dent Relat Res.* 2014;16(1):96-106.
34. Souza AB, Alshihri A, Kammerer PW, Araujo MG, Gallucci GO. Histological and micro-CT analysis of peri-implant soft and hard tissue healing on implants with different healing abutments configurations. *Clin Oral Implants Res.* 2018;29(10):1007-15.
35. Sutter, Weber, Sorensen, Belser. The new restorative concept of the ITI dental implant system: design and engineering. *Int J Periodontics Restorative Dent.* 1993;13(5):409-31.

36. Pjetursson BE, Sailer I, Latyshev A, Rabel K, Kohal RJ, Karasan D. A systematic review and meta-analysis evaluating the survival, the failure, and the complication rates of veneered and monolithic all-ceramic implant-supported single crowns. *Clin Oral Implants Res.* 2021;32 Suppl 21:254-88.
37. Spitznagel FA, Horvath SD, Gierthmuehlen PC. Prosthetic protocols in implant-based oral rehabilitations: A systematic review on the clinical outcome of monolithic all-ceramic single- and multi-unit prostheses. *Eur J Oral Implantol.* 2017;10 Suppl 1:89-99.
38. Hofstede TM, Ercoli C, Hagan ME. Alternative complete-arch cement-retained implant-supported fixed partial denture. *J Prosthet Dent.* 1999;82(1):94-9.
39. Filser F, Kocher P, Weibel F, Luthy H, Scharer P, Gauckler LJ. Reliability and strength of all-ceramic dental restorations fabricated by direct ceramic machining (DCM). *Int J Comput Dent.* 2001;4(2):89-106.
40. Gracis S, Thompson VP, Ferencz JL, Silva NR, Bonfante EA. A new classification system for all-ceramic and ceramic-like restorative materials. *Int J Prosthodont.* 2015;28(3):227-35.
41. Pietrobon N, Paul SJ. All-ceramic restorations: a challenge for anterior esthetics. *J Esthet Dent.* 1997;9(4):179-86.
42. Schwarz S, Schroder C, Hassel A, Bomicke W, Rammelsberg P. Survival and chipping of zirconia-based and metal-ceramic implant-supported single crowns. *Clin Implant Dent Relat Res.* 2012;14 Suppl 1:e119-25.
43. Hisbergues M, Vendeville S, Vendeville P. Zirconia: Established facts and perspectives for a biomaterial in dental implantology. *J Biomed Mater Res B Appl Biomater.* 2009;88(2):519-29.
44. Linkevicius T. The Novel Design of Zirconium Oxide-Based Screw-Retained Restorations, Maximizing Exposure of Zirconia to Soft Peri-implant Tissues: Clinical Report After 3 Years of Follow-up. *Int J Periodontics Restorative Dent.* 2017;37(1):41-7.
45. Pjetursson BE, Fehmer V, Sailer I. EAO Position Paper: Material Selection for Implant-Supported Restorations. *Int J Prosthodont.* 2022;35(1):7-16.

46. Zhang Y, Lawn BR. Novel Zirconia Materials in Dentistry. *J Dent Res*. 2018;97(2):140-7.
47. Swain MV. Unstable cracking (chipping) of veneering porcelain on all-ceramic dental crowns and fixed partial dentures. *Acta Biomater*. 2009;5(5):1668-77.
48. Zhang Y, Kelly JR. Dental Ceramics for Restoration and Metal Veneering. *Dent Clin North Am*. 2017;61(4):797-819.
49. Rabel K, Spies BC, Pieralli S, Vach K, Kohal RJ. The clinical performance of all-ceramic implant-supported single crowns: A systematic review and meta-analysis. *Clin Oral Implants Res*. 2018;29 Suppl 18:196-223.
50. Sadowsky SJ. Has zirconia made a material difference in implant prosthodontics? A review. *Dent Mater*. 2020;36(1):1-8.
51. Carames J, Marques D, Malta Barbosa J, Moreira A, Crispim P, Chen A. Full-arch implant-supported rehabilitations: A prospective study comparing porcelain-veneered zirconia frameworks to monolithic zirconia. *Clin Oral Implants Res*. 2019;30(1):68-78.
52. Cheng CW, Chien CH, Chen CJ, Papaspyridakos P. Randomized Controlled Clinical Trial to Compare Posterior Implant-Supported Modified Monolithic Zirconia and Metal-Ceramic Single Crowns: One-Year Results. *J Prosthodont*. 2019;28(1):15-21.
53. Rammelsberg P, Lorenzo Bermejo J, Kappel S, Meyer A, Zenthofer A. Long-term performance of implant-supported metal-ceramic and all-ceramic single crowns. *J Prosthodont Res*. 2020;64(3):332-9.
54. Freire Y, Gonzalo E, Lopez-Suarez C, Suarez MJ. The Marginal Fit of CAD/CAM Monolithic Ceramic and Metal-Ceramic Crowns. *J Prosthodont*. 2019;28(3):299-304.
55. Joda T, Bragger U. Time-Efficiency Analysis Comparing Digital and Conventional Workflows for Implant Crowns: A Prospective Clinical Crossover Trial. *Int J Oral Maxillofac Implants*. 2015;30(5):1047-53.
56. Joda T, Bragger U. Time-efficiency analysis of the treatment with monolithic implant crowns in a digital workflow: a randomized controlled trial. *Clin Oral Implants Res*. 2016;27(11):1401-6.

57. Mühlemann S, Lakha T, Jung RE, Hammerle CHF, Benic GI. Prosthetic outcomes and clinical performance of CAD-CAM monolithic zirconia versus porcelain-fused-to-metal implant crowns in the molar region: 1-year results of a RCT. *Clin Oral Implants Res.* 2020;31(9):856-64.
58. Denry I, Kelly JR. State of the art of zirconia for dental applications. *Dent Mater.* 2008;24(3):299-307.
59. Honda J, Komine F, Kamio S, Taguchi K, Blatz MB, Matsumura H. Fracture resistance of implant-supported screw-retained zirconia-based molar restorations. *Clin Oral Implants Res.* 2017;28(9):1119-26.
60. Shen XT, Li JY, Luo X, Feng Y, Gai LT, He FM. Peri-implant marginal bone changes with implant-supported metal-ceramic or monolithic zirconia single crowns: A retrospective clinical study of 1 to 5 years. *J Prosthet Dent.* 2021.
61. van Steenberghe D, Naert I, Jacobs R, Quirynen M. Influence of inflammatory reactions vs. occlusal loading on peri-implant marginal bone level. *Adv Dent Res.* 1999;13:130-5.
62. Blanco J, Pico A, Caneiro L, Novoa L, Batalla P, Martin-Lancharro P. Effect of abutment height on interproximal implant bone level in the early healing: A randomized clinical trial. *Clin Oral Implants Res.* 2018;29(1):108-17.
63. Spinato S, Galindo-Moreno P, Bernardello F, Zaffe D. Minimum Abutment Height to Eliminate Bone Loss: Influence of Implant Neck Design and Platform Switching. *Int J Oral Maxillofac Implants.* 2018;33(2):405-11.
64. Vervaeke S, Collaert B, Cosyn J, De Bruyn H. A 9-Year Prospective Case Series Using Multivariate Analyses to Identify Predictors of Early and Late Peri-Implant Bone Loss. *Clin Implant Dent Relat Res.* 2016;18(1):30-9.
65. Del Amo FS, Romero-Bustillos M, Catena A, Galindo-Moreno P, Sanchez-Suarez JM, Garaicoa-Pazmino C. Effect of Abutment Height on Marginal Bone Loss Around Dental Implants: A Systematic Review. *Int J Prosthodont.* 2022.
66. Linkevicius T, Alkimavicius J, Linkevicius R, Gineviciute E, Linkeviciene L. Effect of Ti-Base Abutment Gingival Height on Maintenance of Crestal Bone in Thick

Biotype Patients: A Randomized Clinical Trial with 1-Year Follow-up. *Int J Oral Maxillofac Implants*. 2022;37(2):320-7.

67. Munoz M, Vilarrasa J, Ruiz-Magaz V, Albertini M, Nart J. Influence of the abutment height on marginal bone level changes around two-piece dental implants: Meta-analysis and trial sequential analysis of randomized clinical trials. *Clin Oral Implants Res*. 2022.

68. Spinato S, Stacchi C, Lombardi T, Bernardello F, Messina M, Dovigo S, et al. Influence of abutment height and vertical mucosal thickness on early marginal bone loss around implants: A randomised clinical trial with an 18-month post-loading clinical and radiographic evaluation. *Int J Oral Implantol (Berl)*. 2020;13(3):279-90.

69. Atieh MA, Tawse-Smith A, Alsabeeha NHM, Ma S, Duncan WJ. The One Abutment-One Time Protocol: A Systematic Review and Meta-Analysis. *J Periodontol*. 2017;88(11):1173-85.

70. Degidi M, Nardi D, Piattelli A. One abutment at one time: non-removal of an immediate abutment and its effect on bone healing around subcrestal tapered implants. *Clin Oral Implants Res*. 2011;22(11):1303-7.

71. Grandi T, Guazzi P, Samarani R, Garuti G. Immediate positioning of definitive abutments versus repeated abutment replacements in immediately loaded implants: effects on bone healing at the 1-year follow-up of a multicentre randomised controlled trial. *Eur J Oral Implantol*. 2012;5(1):9-16.

72. Koutouzis T, Gholami F, Reynolds J, Lundgren T, Kotsakis GA. Abutment Disconnection/Reconnection Affects Peri-implant Marginal Bone Levels: A Meta-Analysis. *Int J Oral Maxillofac Implants*. 2017;32(3):575-81.

73. Pommer B, Danzinger M, Leite Aiquel L, Pitta J, Haas R. Long-term outcomes of maxillary single-tooth implants in relation to timing protocols of implant placement and loading: Systematic review and meta-analysis. *Clin Oral Implants Res*. 2021;32 Suppl 21:56-66.

74. Vatenas I, Linkevicius T. One abutment one time vs. repeatable abutment disconnections in implants, restored with cemented / screw retained fixed partial dentures:

Marginal bone level changes. A systematic review and meta-analysis. *Stomatologija*. 2021;23(2):35-40.

75. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.

76. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, et al. *Cochrane Handbook for Systematic Reviews of Interventions* version 6.5 (updated August 2024). Cochrane; 2024.

77. The EndNote Team. *EndNote*. EndNote 20 ed. Philadelphia, PA: Clarivate; 2013.

78. Higgins JP, Altman DG, Gotzsche PC, Juni P, Moher D, Oxman AD, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*. 2011;343:d5928.

79. GRADEpro. *GRADEpro Guideline Development Tool* [Software]. McMaster University and Evidence Prime; 2021.

80. Weigl P, Saarepera K, Hinrikus K, Wu Y, Trimpou G, Lorenz J. Screw-retained monolithic zirconia vs. cemented porcelain-fused-to-metal implant crowns: a prospective randomized clinical trial in split-mouth design. *Clin Oral Investig*. 2019;23(3):1067-75.

81. Mantel N, Haenszel W. Statistical aspects of the analysis of data from retrospective studies of disease. *J Natl Cancer Inst*. 1959;22(4):719-48.

82. Robins J, Greenland S, Breslow NE. A general estimator for the variance of the Mantel-Haenszel odds ratio. *Am J Epidemiol*. 1986;124(5):719-23.

83. Thompson SG, Turner RM, Warn DE. Multilevel models for meta-analysis, and their application to absolute risk differences. *Stat Methods Med Res*. 2001;10(6):375-92.

84. Paule RC, Mandel J. Consensus Values and Weighting Factors. *J Res Natl Bur Stand* (1977). 1982;87(5):377-85.

85. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med*. 2002;21(11):1539-58.

86. R Core Team. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. 2021.

87. Schwarzer G, Carpenter JR, Rücker G, SpringerLink. *Meta-Analysis with R*. 1st 2015. ed. Cham: Springer International Publishing : Imprint: Springer; 2015.
88. Sterne JA, Hernan MA, Reeves BC, Savovic J, Berkman ND, Viswanathan M, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ*. 2016;355:i4919.
89. Schwarzer G. *Meta-Analysis in R*. 2022. p. 510-34.
90. Harrer M, Cuijpers P, Furukawa T, Ebert D. *Doing meta-analysis with R : a hands-on guide*. First edition. ed. Boca Raton, FL: CRC Press; 2021.
91. Borges T, Leitao B, Pereira M, Carvalho A, Galindo-Moreno P. Influence of the abutment height and connection timing in early peri-implant marginal bone changes: A prospective randomized clinical trial. *Clin Oral Implants Res*. 2018;29(9):907-14.
92. Munoz M, Busoms E, Vilarrasa J, Albertini M, Ruiz-Magaz V, Nart J. Bone-level changes around implants with 1- or 3-mm-high abutments and their relation to crestal mucosal thickness: A 1-year randomized clinical trial. *J Clin Periodontol*. 2021;48(10):1302-11.
93. Pico A, Martin-Lancharro P, Caneiro L, Novoa L, Batalla P, Blanco J. Influence of abutment height and implant depth position on interproximal peri-implant bone in sites with thin mucosa: A 1-year randomized clinical trial. *Clin Oral Implants Res*. 2019;30(7):595-602.
94. Spinato S, Bernardello F, Sassatelli P, Zaffe D. Hybrid Implants in Healthy and Periodontally Compromised Patients: A Preliminary Clinical and Radiographic Study. *Int J Periodontics Restorative Dent*. 2017;37(2):195-202.
95. Bösch A, Jung RE, Sailer I, Goran B, Hämmerle CH, Thoma DS. Single-Tooth Replacement Using Dental Implants Supporting All-Ceramic and Metal-Based Reconstructions: results at 18 Months of Loading. *International journal of periodontics & restorative dentistry*. 2018;38(2):173-9.
96. Haghi HR, Ghanbarzadeh J, Kiamanesh E. A randomized clinical trial comparing the clinical fit and chairside adjustment time for implant-supported crowns fabricated by fully digital and partially digital techniques. *J Prosthet Dent*. 2022.

97. Hosseini M, Worsaae N, Schiodt M, Gotfredsen K. A 1-year randomised controlled trial comparing zirconia versus metal-ceramic implant supported single-tooth restorations. *European journal of oral implantology*. 2011;4(4):347-61.
98. Sailer I, Zembic A, Jung RE, Siegenthaler D, Holderegger C, Hämmerle CH. Randomized controlled clinical trial of customized zirconia and titanium implant abutments for canine and posterior single-tooth implant reconstructions: preliminary results at 1 year of function. *Clinical oral implants research*. 2009;20(3):219-25.
99. Weigl P, Trimpou G, Grizas E, Hess P, Nentwig GH, Lauer HC, et al. All-ceramic versus titanium-based implant supported restorations: Preliminary 12-months results from a randomized controlled trial. *J Adv Prosthodont*. 2019;11(1):48-54.
100. Zembic A, Bösch A, Jung RE, Hämmerle CH, Sailer I. Five-year results of a randomized controlled clinical trial comparing zirconia and titanium abutments supporting single-implant crowns in canine and posterior regions. *Clinical oral implants research*. 2013;24(4):384-90.
101. Tajti P, Solyom E, Czumbel LM, Szabo B, Fazekas R, Nemeth O, et al. 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*. 2023.
102. Mangano F, Veronesi G. Digital versus Analog Procedures for the Prosthetic Restoration of Single Implants: A Randomized Controlled Trial with 1 Year of Follow-Up. *Biomed Res Int*. 2018;2018:5325032.
103. Tajti P, Solyom E, Vancsa S, Matrai P, Hegyi P, Varga G, et al. Less marginal bone loss around bone-level implants restored with long abutments: A systematic review and meta-analysis. *Periodontol 2000*. 2024;94(1):627-38.
104. Borges T, Montero J, Leitao B, Pereira M, Galindo-Moreno P. Periimplant bone changes in different abutment heights and insertion timing in posterior mandibular areas: Three-year results from a randomized prospective clinical trial. *Clin Oral Implants Res*. 2021;32(2):203-11.

105. Datte CE, Tribst JP, Dal Piva AO, Nishioka RS, Bottino MA, Evangelhista AM, et al. Influence of different restorative materials on the stress distribution in dental implants. *J Clin Exp Dent*. 2018;10(5):e439-e44.
106. Kaleli N, Sarac D, Kulunk S, Ozturk O. Effect of different restorative crown and customized abutment materials on stress distribution in single implants and peripheral bone: A three-dimensional finite element analysis study. *J Prosthet Dent*. 2018;119(3):437-45.
107. Inglam S, Suebnukarn S, Tharanon W, Apatananon T, Sitthiseripratip K. Influence of graft quality and marginal bone loss on implants placed in maxillary grafted sinus: a finite element study. *Med Biol Eng Comput*. 2010;48(7):681-9.
108. Abrahamsson I, Berglundh T, Wennstrom J, Lindhe J. The peri-implant hard and soft tissues at different implant systems. A comparative study in the dog. *Clin Oral Implants Res*. 1996;7(3):212-9.
109. Coli P, Christiaens V, Sennerby L, Bruyn H. Reliability of periodontal diagnostic tools for monitoring peri-implant health and disease. *Periodontol 2000*. 2017;73(1):203-17.
110. Linkevicius T, Valantiejene V, Alkimavicius J, Gineviciute E, Andrijauskas R, Linkeviciene L. The Effect of a Polishing Protocol on the Surface Roughness of Zirconium Oxide. *Int J Prosthodont*. 2020;33(2):217-23.
111. Seo MG, Ko KH, Huh YH, Park CJ, Cho LR. Effect of Occlusal and Axial Thickness on the Fracture Load of Implant-Supported Monolithic Zirconia Crowns. *Int J Oral Maxillofac Implants*. 2024;0(0):1-22.
112. Strasding M, Marchand L, Merino E, Zarauz C, Pitta J. Material and abutment selection for CAD/CAM implant-supported fixed dental prostheses in partially edentulous patients - A narrative review. *Clin Oral Implants Res*. 2024;35(8):984-99.
113. Altuna P, Lucas-Taule E, Gargallo-Albiol J, Figueras-Alvarez O, Hernandez-Alfaro F, Nart J. Clinical evidence on titanium-zirconium dental implants: a systematic review and meta-analysis. *Int J Oral Maxillofac Surg*. 2016;45(7):842-50.

114. Lombardi T, Berton F, Salgarello S, Barbalonga E, Rapani A, Piovesana F, et al. Factors Influencing Early Marginal Bone Loss around Dental Implants Positioned Subcrestally: A Multicenter Prospective Clinical Study. *J Clin Med*. 2019;8(8).
115. Smith DE, Zarb GA. Criteria for success of osseointegrated endosseous implants. *J Prosthet Dent*. 1989;62(5):567-72.
116. Boynuegri AD, Yalim M, Nemli SK, Erguder BI, Gokalp P. Effect of different localizations of microgap on clinical parameters and inflammatory cytokines in peri-implant crevicular fluid: a prospective comparative study. *Clin Oral Investig*. 2012;16(2):353-61.
117. Hermann JS, Cochran DL, Nummikoski PV, Buser D. Crestal bone changes around titanium implants. A radiographic evaluation of unloaded nonsubmerged and submerged implants in the canine mandible. *J Periodontol*. 1997;68(11):1117-30.
118. Perrotti V, Zhang D, Liang A, Wong J, Quaranta A. The Effect of One-Abutment at One-Time on Marginal Bone Loss Around Implants Placed in Healed Bone: A Systematic Review of Human Studies. *Implant Dent*. 2019;28(6):603-12.
119. Soliman G, Guazzato M, Klineberg I, Chang MC, Ellakwa A. Influence of Platform Switching, Abutment Design and Connection Protocols on the Stability of Peri-Implant Tissues. A Systematic Review. *Eur J Prosthodont Restor Dent*. 2021;29(4):194-207.
120. Lang NP, Bartold PM. Periodontal health. *J Periodontol*. 2018;89 Suppl 1:S9-S16.
121. Katafuchi M, Weinstein BF, Leroux BG, Chen YW, Daubert DM. Restoration contour is a risk indicator for peri-implantitis: A cross-sectional radiographic analysis. *J Clin Periodontol*. 2018;45(2):225-32.
122. Serino G, Strom C. Peri-implantitis in partially edentulous patients: association with inadequate plaque control. *Clin Oral Implants Res*. 2009;20(2):169-74.
123. Yi Y, Koo KT, Schwarz F, Ben Amara H, Heo SJ. Association of prosthetic features and peri-implantitis: A cross-sectional study. *J Clin Periodontol*. 2020;47(3):392-403.

124. Giglio GD. Abutment selection in implant-supported fixed prosthodontics. *Int J Periodontics Restorative Dent*. 1999;19(3):233-41.
125. Hegyi P, Erőss B, Izbéki F, Párniczky A, Szentesi A. Accelerating the translational medicine cycle: the Academia Europaea pilot. *Nat Med*. 2021;27(8):1317-9.
126. Hegyi P, Petersen OH, Holgate S, Erőss B, Garami A, Szakács Z, et al. Academia Europaea Position Paper on Translational Medicine: The Cycle Model for Translating Scientific Results into Community Benefits. *Journal of Clinical Medicine*. 2020;9(5):1532.

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.

D1, IF: 4.3

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.

Q1, IF: 4.1

Szalai E, **Tajti P**, Szabó B, Hegyi P, Czumbel LM, Shojazadeh S, Varga G, Németh O, Kerémi B. (2023) Daily use of chlorine dioxide effectively treats halitosis: A meta-analysis of randomised controlled trials PLoS One, 18: e0280377.

Q1, IF: 2.9

Tajti P., Gerber G, Hermann P, Schmidt P. (2023) Complex rehabilitation of erosive tooth wear with digital workflows Fogorvosi Szemle 116: 168-174.

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.

Q1, IF: 3.747

17. ACKNOWLEDGEMENTS

I want to express my deepest gratitude to those without whom this scientific work would not have been possible.

Firstly, I am incredibly grateful to my supervisor, Krisztina Mikulás, DMD, PhD. Without her help, my research and the writing of this thesis would not have been possible. From the moment I started my PhD, she has been there for me professionally and personally. Her dedication to research and patient care constantly motivated and inspired me, and I'm genuinely grateful for her guidance throughout this journey.

I want to express my gratitude to Péter Hermann, DMD, MSc, PhD, Head of the Department of Prosthodontics at Semmelweis University, for allowing me to join the Centre for Translational Medicine PhD Program.

I want to sincerely thank Péter Hegyi, MD, PhD, DSc, MAE, Director of the Centre for Translational Medicine. Being part of this program allowed me to join an inspiring research team, where I gained a deeper understanding of the value of high-quality research.

I would also like to thank Gábor Varga, PhD, DSc, MAE, the head of the doctoral program, for his support and guidance during my research.

I appreciate the invaluable contributions of the following people as well: Szilárd Váncsa, MD, PhD, Márk László Czumbel, DMD, PhD, Bence Szabó, PhD, Péter Mátrai, PhD, Eleonóra Sólyom, DMD, without whom my research would not have been possible.

Finally, I want to thank my family and friends for their constant support during my PhD studies.