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Research Article

Marginal Bone Loss and Peri-Implant Bleeding Around CAD/CAM Zirconia vs. Titanium Abutments with Concave Emergence Profiles: A Systematic Review and Meta-Analysis

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ABSTRACT

Background: Implant abutment material may influence peri-implant hard- and soft-tissue responses. Titanium remains widely used because of its mechanical reliability and established long-term clinical performance, whereas zirconia offers favorable esthetic characteristics and may influence plaque accumulation and peri-implant soft-tissue behavior. Variation in abutment customization, CAD/CAM fabrication, transmucosal contour, implant location, and follow-up duration contributes to heterogeneity in reported clinical outcomes.

Objective: This systematic review compared marginal bone-level outcomes and peri-implant soft-tissue health around zirconia and titanium implant abutments and examined abutment design and transmucosal geometry as potential sources of clinical heterogeneity.

Methods: This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) statement. We searched MEDLINE via PubMed, Embase, Scopus, Web of Science, and the Cochrane Central Register of Controlled Trials for prospective clinical studies directly comparing zirconia and titanium implant abutments; we also examined ClinicalTrials.gov and the reference lists of eligible publications. No language restriction was applied. Two reviewers independently screened records, assessed full-text eligibility, and extracted study and outcome data, resolving disagreements by discussion and consensus. We assessed randomized controlled trials with the Cochrane Risk of Bias 2 tool and non-randomized comparative studies with ROBINS-I. Publications originating from the same clinical population were identified by comparing study centers, investigators, sample characteristics, and follow-up periods, and were linked rather than treated as independent cohorts.

Results: Nineteen publications met the eligibility criteria, corresponding to twelve independent clinical investigations. Four publications followed a single randomized cohort over 1, 3, 5, and approximately 13 years (Sailer 2009 [5]; Zembic 2009 [6]; Zembic 2013 [7]; Humm 2023 [8]). Three publications followed a second cohort over 1, 3, and 5 years (Hosseini 2011 [9]; Hosseini 2013 [10]; Hosseini 2022 [11]). Two publications followed a third cohort over 1 and 5 years (Carrillo de Albornoz 2014 [14]; Ferrantino 2023 [15]). Two further publications reported a linked or related cohort at 3 years (de Oliveira Silva 2020 [20]; de Freitas 2021 [21]). The remaining eight publications (Lops 2013 [12]; Lops 2015 [13]; Bressan 2011 [16]; Cosgarea 2015 [17]; Payer 2015 [18]; Baldini 2016 [19]; Bittencourt 2023 [22]; Bharate 2020 [23]) were treated as independent investigations. Follow-up across the evidence base ranged from approximately 1 year to more than 13 years. Quantitative descriptive data for probing pocket depth, peri-implant bleeding, and marginal bone level or bone-level change were available for ten of the nineteen publications. Probing pocket depth was broadly

similar between zirconia and titanium groups across these studies. Bleeding parameters were reported using non-interchangeable measures (mean bleeding-on-probing scores, percentages of bleeding sites, and modified bleeding indices) and did not show a consistent direction of difference favoring either material. Marginal bone level or bone-level change was comparable between zirconia and titanium in most studies reporting this outcome, with a numerically greater bone-level change reported for zirconia relative to the titanium/metal group in one cohort at 5 years (Hosseini 2022 [11]). Bharate et al. 2020 [23] similarly reported significantly less 1-year crestal bone-height reduction around zirconia than titanium abutments (0.487 ± 0.159 mm vs 0.621 ± 0.207 mm; P=0.02) — the only study in the evidence base to report a statistically significant between-material difference for a hard-tissue outcome. Because of differences in outcome definitions, measurement time points, and the repeated-cohort structure of the evidence, these findings are reported as a narrative synthesis of study-level results; pooled quantitative effect estimates were not generated.

Conclusion: Zirconia and titanium abutments show broadly comparable clinical performance for probing depth, peri-implant bleeding, and marginal bone stability across the available prospective evidence, with an isolated exception in one cohort. Zirconia's principal reported advantage relates to esthetics in mucosally thin sites, whereas titanium is supported by the longest available follow-up data. Interpretation is limited by heterogeneity in abutment design, outcome definitions, incomplete reporting of transmucosal geometry, and the repeated-cohort structure of the literature.

Keywords: Zirconia, Titanium, Dental Implant Abutment, Marginal Bone Loss, Marginal Bone Level, Bleeding On Probing, Peri-Implant Tissue, CAD/CAM.

INTRODUCTION

Long-term success of implant-supported restorations depends on stable osseointegration, preservation of peri-implant marginal bone, and maintenance of a healthy peri-implant soft-tissue interface. Following implant placement and prosthetic rehabilitation, the peri-implant mucosa establishes a supracrestal tissue attachment consisting primarily of junctional epithelium and connective tissue. Maintenance of this tissue complex contributes to protection of the underlying implant–bone interface and may influence marginal bone remodeling, mucosal recession, and peri-implant inflammation.

The implant abutment forms an important component of this transmucosal interface. Its material composition, surface properties, dimensions, and emergence profile may influence plaque accumulation, soft-tissue adaptation, inflammatory response, mucosal appearance, and marginal bone stability. Abutment selection therefore carries both biological and prosthetic implications.

Titanium has traditionally served as the reference abutment material because of its biocompatibility, corrosion resistance, mechanical strength, and extensive long-term clinical documentation [1]. Nevertheless, its metallic color may produce gray discoloration through thin peri-implant mucosa, particularly in esthetically demanding anterior regions.

Zirconia, particularly yttria-stabilized tetragonal zirconia polycrystal, has been introduced as an alternative abutment material because of its favorable optical properties and biocompatibility. Its tooth-like color may improve the appearance of peri-implant mucosa, while differences in surface characteristics may influence plaque accumulation and soft-tissue response.

Advances in computer-aided design and computer-aided manufacturing have enabled individualized implant abutments with customized transmucosal contours. This development is clinically relevant because peri-implant tissue behavior may be affected not only by abutment material but also by its macrogeometry. Concave, straight, and convex emergence profiles provide different spatial relationships between the restoration and surrounding peri-implant tissues.

Clinical studies comparing zirconia and titanium abutments have reported variable findings for marginal bone levels, bleeding on probing, probing depth, soft-tissue recession, esthetic outcomes, and biological complications. Interpretation of the literature is further complicated by differences in abutment customization, implant position, prosthetic design, follow-up duration, and outcome definitions. Several publications also report different follow-up periods of the same clinical cohorts and therefore cannot be considered independent patient populations.

This systematic review therefore compared marginal bone-level outcomes and peri-implant soft-tissue health around zirconia and titanium implant abutments. Abutment customization, CAD/CAM fabrication, transmucosal emergence-profile geometry, implant location,

and duration of follow-up were also considered when interpreting the available evidence.

MATERIALS AND METHODS

Reporting Framework

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) statement [2].

Focused Review Question

Among adults receiving implant-supported fixed restorations, are peri-implant marginal bone levels and soft-tissue outcomes different around zirconia compared with titanium implant abutments?

2.3 PICO Framework

Component	Definition
Population	Adult patients receiving implant-supported fixed dental restorations
Intervention	Zirconia implant abutments
Comparison	Titanium implant abutments
Primary outcomes	Marginal bone-level change and peri-implant bleeding
Secondary outcomes	Probing pocket depth, plaque-related parameters, mucosal recession, esthetic outcomes, biological complications, prosthetic complications, implant survival, and abutment survival

Eligibility Criteria

Prospective human clinical studies directly comparing zirconia and titanium implant abutments in implant-supported fixed restorations were eligible. Randomized controlled trials, split-mouth randomized studies, prospective controlled clinical studies, and prospective comparative cohort studies were included. Studies reporting peri-implant hard-tissue, soft-tissue, esthetic, biological, or survival outcomes were considered. Animal experiments, in-vitro studies, finite-element analyses, case reports, uncontrolled case series, studies comparing zirconia and titanium implants rather than implant abutments, studies involving removable implant prostheses, and studies without a direct zirconia-versus-titanium abutment comparison were excluded.

Table 1. Eligibility Criteria

Domain	Inclusion criteria	Exclusion criteria
Population	Adult human participants with implant-supported fixed restorations	Animal and laboratory studies
Intervention	Zirconia implant abutments	Zirconia implants without zirconia abutments
Comparator	Titanium implant abutments	Studies without direct titanium comparison
Design	RCTs, split-mouth trials, prospective controlled and prospective comparative studies	Case reports, uncontrolled case series, in-vitro and finite-element studies
Prosthesis	Fixed implant-supported restorations	Removable implant prostheses
Outcomes	Peri-implant hard tissue, soft tissue, esthetic, or survival outcomes	No relevant comparative clinical outcome

Information Sources

Electronic searches were conducted in MEDLINE via PubMed, Embase, Scopus, Web of Science, and the Cochrane Central Register of Controlled Trials. ClinicalTrials.gov was examined for potentially relevant clinical trials. Reference lists of eligible studies and relevant systematic reviews were also examined to identify additional publications. No language restriction was applied during study identification.

Search Strategy

The search strategy combined terms relating to dental implant abutments, zirconia, titanium, and dental implants. The PubMed search incorporated the following concepts:

("Dental Abutments"[Mesh] OR abutment* OR "implant abutment*" OR "prosthetic abutment*") AND ("Zirconium"[Mesh] OR zirconia OR zirconium OR Y-TZP) AND

("Titanium"[Mesh] OR titanium) AND ("Dental Implants"[Mesh] OR implant*)

Outcome terms were not required in the principal search because restricting retrieval to specific outcomes such as marginal bone loss or bleeding on probing could have excluded otherwise eligible comparative studies. Terms relating to CAD/CAM fabrication, customization, emergence profile, concavity, and transmucosal contour were used to identify publications providing additional information regarding abutment design and geometry.

Study Selection

Two reviewers independently screened the titles and abstracts of the retrieved records according to the eligibility criteria. Potentially eligible publications underwent full-text assessment, and reviewers recorded reasons for exclusion. The two reviewers resolved disagreements about study eligibility through discussion and consensus.

Multiple publications originating from the same clinical trial or patient population were identified by comparing study centers, investigators, sample characteristics, interventions, and follow-up periods. Such publications were linked and not treated as independent clinical populations when doing so would result in duplicate inclusion of participants.

Data Extraction

Two reviewers independently extracted relevant information using a standardized data-extraction approach. Extracted information included author and publication year; study design; study population; sample size; number of implants; implant location; zirconia and titanium abutment characteristics; customized or prefabricated design; CAD/CAM fabrication; restoration characteristics; follow-up duration; emergence-profile characteristics when reported; marginal bone-level outcomes; bleeding on probing; probing pocket depth; plaque-related parameters; mucosal recession; esthetic outcomes; biological and prosthetic complications; and implant and abutment survival. Disagreements in extracted information were resolved through discussion and consensus.

Classification of Abutment Geometry

Transmucosal emergence-profile characteristics were extracted from the original publications when explicitly described, and were classified according to the terminology used by the study investigators (concave, straight, or convex). Studies that did not provide sufficient information regarding transmucosal geometry were classified as having an inadequately reported emergence profile. Emergence angle and emergence-profile curvature were treated as separate characteristics; a particular emergence angle was therefore not automatically interpreted as evidence of a concave profile.

Outcome Definitions

Marginal Bone-Level Change

Marginal bone-level change was evaluated as a continuous outcome expressed in millimeters. Studies were assessed for comparability of baseline definition, radiographic measurement method, reference point, and follow-up period before synthesis.

Peri-Implant Bleeding

The definition of peri-implant bleeding used in each study was examined before comparison. Bleeding outcomes reported as continuous percentages, binary events, or ordinal bleeding indices were treated separately because these measures are not statistically interchangeable.

Probing Pocket Depth

Probing pocket depth was evaluated in millimeters when comparable measurements were available.

Esthetic Outcomes

Esthetic outcomes included the Pink Esthetic Score, peri-implant mucosal discoloration, and other clinically reported soft-tissue esthetic measures.

Survival and Complications

Implant survival, abutment survival, biological complications, and prosthetic complications were extracted as reported by the original investigators.

Risk-of-Bias Assessment

Randomized controlled trials were assessed using the Cochrane Risk of Bias 2 tool [3], considering bias arising from the randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selection of reported results. Non-randomized comparative clinical studies were assessed using the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool [4]. Risk-of-bias assessments were conducted independently by two

reviewers, and disagreements were resolved through discussion and consensus.

Data Synthesis

Study-level outcome data for marginal bone level or bone-level change, probing pocket depth, and peri-implant bleeding were tabulated and compared descriptively across studies. Continuous bleeding percentages, ordinal bleeding indices, and binary bleeding events were kept separate and were not treated as interchangeable measures. Because of differences in outcome definitions, measurement time points, baseline reference points, and the repeated-cohort structure of the included publications, a pooled random-effects meta-analysis was not undertaken; findings are instead presented as a narrative, study-level synthesis.

Management of Repeated Publications

Multiple reports from the same underlying clinical trial were not treated as independent studies. Different follow-up publications were linked to their original cohorts, and where the same participants were reported at several follow-up periods, this relationship was recorded and preserved throughout the synthesis rather than combining repeated reports as independent observations. This approach prevented artificial inflation of the evidence base and of the effective participant sample.

RESULTS

Study Selection

The systematic search identified prospective clinical investigations directly comparing zirconia and titanium implant abutments. The eligible literature included both independent clinical trials and longitudinal publications reporting subsequent follow-up of previously enrolled participants. The study-selection process was documented according to PRISMA 2020, with reasons for exclusion recorded during full-text assessment.

Included Publications and Independent Cohorts

Nineteen publications met the eligibility criteria. Because several publications represented serial follow-up of the same underlying patient cohorts, the number of eligible publications exceeded the number of independent clinical investigations, which totaled twelve. The Sailer–Zembic randomized trial initially enrolled 22 patients with 40 implant-supported restorations and subsequently generated reports at 1, 3, 5, and approximately 13 years (Humm 2023 [8]); the 13-year report confirmed that its participants originated from this trial, in which 20 customized zirconia and 20 customized titanium abutments were initially randomized. The Hosseini cohort was reported at 1, 3, and 5 years, and the Carrillo de Albornoz cohort was followed to 5 years in the report by Ferrantino and colleagues. The de Oliveira Silva and de Freitas publications reported a linked or related population at 3 years. Lops 2013, Lops 2015, Bressan 2011, Cosgarea 2015, Payer 2015, Baldini 2016, Bittencourt 2023, and Bharate 2020 were treated as independent investigations, distinct from one another and from the linked cohorts above.

Table 2. Included Publications and Cohort Structure

Study	Design	Participants/implants	Follow-up	Cohort status
Sailer et al., 2009 [5]	RCT	22 patients; 40 implants initially	1 year	Sailer–Zembic–Humm cohort
Zembic et al., 2009 [6]	RCT follow-up	22 initially; 18 evaluated	3 years	Sailer–Zembic–Humm cohort
Zembic et al., 2013 [7]	RCT follow-up	18 patients at follow-up	5 years	Sailer–Zembic–Humm cohort
Humm et al., 2023 [8]	Long-term RCT follow-up	15 patients; 21 abutments (13 Zr, 8 Ti)	Mean 13.4 years	Sailer–Zembic–Humm cohort
Hosseini et al., 2011 [9]	RCT	36 initially	1 year	Hosseini cohort
Hosseini et al., 2013 [10]	Prospective follow-up	Same underlying population	3 years	Hosseini cohort
Hosseini et al., 2022 [11]	RCT follow-up	30 patients; 63 implants (31 Zr, 32 metal)	5 years	Hosseini cohort

Lops et al., 2013 [12]	Prospective comparative study	81 evaluated (36 Zr, 45 Ti)	5 years	Independent
Lops et al., 2015 [13]	Controlled clinical study	72 (33 Zr, 39 Ti)	2 years	Independent (overlap with Lops 2013 not confirmed in source material)
Carrillo de Albornoz et al., 2014 [14]	Controlled/RCT-derived trial	25 evaluated (11 Zr, 14 Ti)	1 year	Carrillo–Ferrantino cohort
Ferrantino et al., 2023 [15]	RCT follow-up	30 recruited; 25 completed long-term evaluation	5 years	Carrillo–Ferrantino cohort
Bressan et al., 2011 [16]	Prospective controlled clinical study	20 (20 Zr / 20 Ti sites)	Clinical follow-up	Independent
Cosgarea et al., 2015 [17]	Randomized controlled study	11 patients (11 Zr / 11 Ti sites)	Prospective	Independent
Payer et al., 2015 [18]	RCT	30 (15 Zr, 15 Ti)	24 months	Independent
Baldini et al., 2016 [19]	RCT	24 patients	12 months	Independent
de Oliveira Silva et al., 2020 [20]	Prospective comparative study	20	3 years	Linked with de Freitas cohort
de Freitas et al., 2021 [21]	Prospective longitudinal study	20	3 years	Linked with de Oliveira Silva cohort
Bittencourt et al., 2023 [22]	Randomized prospective controlled trial	35 originally; 26 restorations in 14 patients at long-term evaluation	≥7 years	Independent
Bharate et al., 2020 [23]	Comparative clinical study	Direct Zr/Ti comparison (n not specified in source material)	12 months	Independent

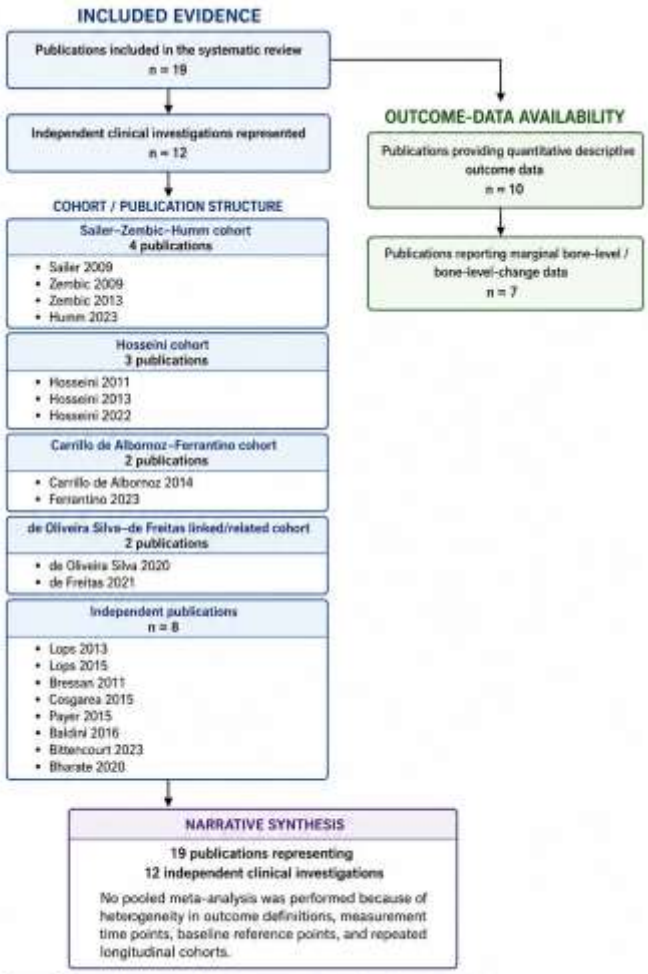

Figure 1. Flow and structure of publications and independent clinical investigations included in the systematic review.

Characteristics of the Evidence

The included studies comprised randomized controlled trials, within-participant comparisons, and prospective comparative clinical studies. Follow-up duration ranged from approximately 1 year to more than 13 years. Both customized and prefabricated abutments were represented, and studies were conducted in anterior, premolar, and posterior implant sites. Clinical outcomes included marginal bone-level change, probing pocket depth, bleeding on probing, plaque and bleeding indices, mucosal recession, peri-implant soft-tissue color, esthetic indices, biological and technical complications, and implant and abutment survival.

Considerable variation was observed in the reporting of transmucosal abutment geometry. Although some publications provided abutment-design information, a concave emergence profile was not consistently or explicitly established for any of the included studies in the material available for this review. Emergence-profile geometry was therefore extracted as a study characteristic rather than assumed from abutment material or emergence angle, and a concave-profile-specific comparison was not considered feasible.

Table 3. Abutment Design and Emergence-Profile Reporting

Study/cohort	Fabrication	Concave profile explicitly established?	Suitable for main Zr-vs-Ti synthesis?
Sailer–Zembic–Humm	Customized	Not established in available reports	Yes

Hosseini	Predesigned Zr/Ti system; CAD/CAM crown differs	Not established	Yes
Lops 2013	Clinical comparison	Not verified	Yes
Carrillo–Ferrantino	—	Not consistently described as concave	Yes
Payer	—	Not verified as concave	Yes
Bressan	—	Not primary focus	Yes (secondary esthetic outcome)
Cosgarea	—	Not primary focus	Yes (esthetic outcome)
Baldini	—	Not verified as concave	Yes
de Oliveira/de Freitas	—	Not established	Yes
Bittencourt	Prefabricated	Not concave-specific	Yes

Because a concave emergence profile could not be verified for any included study, restricting the review to concave-profile abutments was not adopted; doing so would have excluded the great majority of the otherwise-eligible clinical evidence.

Marginal Bone-Level Outcome

Marginal bone-level or bone-level change data were available for seven of the nineteen publications: Zembic 2009 [6], Zembic 2013 [7], Humm 2023 [8], Payer 2015 [18], Lops 2013 [12], Carrillo de Albornoz 2014 [14] (values reported radiographically), and Hosseini 2022 [11]. A further publication, Bharate 2020 [23], reported a related but distinct hard-tissue outcome — crestal bone-height reduction rather than bone level referenced to the implant shoulder — and is therefore considered separately below. At 3 and 5 years, the Sailer–Zembic cohort reported bone level separately for mesial and distal sites referenced to the implant shoulder, without a statistically significant between-material difference at either time point [6,7]. At 5 years, implant survival in this cohort was 88.9% for zirconia-supported restorations and 90% for titanium-supported restorations [7]. At 13 years, bone level was 2.38 ± 1.97 mm for zirconia and 2.00 ± 1.03 mm for titanium (Humm 2023 [8]). At 24 months, bone level was 1.48 ± 1.05 mm for zirconia and 1.43 ± 0.67 mm for titanium (Payer 2015 [18]). At 5 years, bone-level change was 0.4 ± 0.2 mm (zirconia) versus 0.5 ± 0.3 mm (titanium) in Lops 2013 [12], and 0.30 ± 1.10 mm (zirconia) versus −0.10 ± 0.40 mm (metal group) in Hosseini 2022 [11]. Bharate et al. 2020 [23] reported 1-year crestal bone-height reduction of 0.487 ± 0.159 mm around zirconia versus 0.621 ± 0.207 mm around titanium abutments, a statistically significant difference favoring zirconia (P=0.02) — the only statistically significant material-related difference for a hard-tissue outcome identified across the included evidence. These values were reported on differing baseline definitions, reference points, and follow-up durations across studies and were therefore not statistically pooled; the isolated significant finding in one 1-year study should be interpreted in the context of the larger body of evidence showing no consistent material effect, including the longest-followed cohort at 13 years.

Table 4. Reported Quantitative Outcomes by Study

Study	Zr n	Ti n	Follow-up	PPD Zr / Ti	BOP/bleeding Zr / Ti	MBL/BL Zr / Ti
Sailer 2009 [5]	19	12	1 y	3.5±0.7 / 3.3±0.6 mm	0.60±0.30 / 0.30±0.40	NR / NR
Zembic 2009 [6]	18	10	3 y	3.2±1.0 / 3.4±0.5 mm	0.40±0.40 / 0.20±0.30	Reported by mesial/distal site; no significant difference

Zembic 2013 [7]	18	10	5 y	3.3±0.6 / 3.6±1.1 mm	0.50±0.30 / 0.60±0.30	No significant difference; survival 88.9% Zr / 90% Ti
Humm 2023 [8]	13	8	13 y	3.84±1.70 / 3.18±0.65 mm	0.54±0.34 / 0.50±0.38	BL 2.38±1.97 / 2.00±1.03 mm
Payer 2015 [18]	15	15	24 mo	NR / NR	9.10%±4.34 / 7.40%±3.39	1.48±1.05 / 1.43±0.67 mm*
Lops 2013 [12]	36	45	5 y	2.6±0.5 / 2.7±0.4 mm	mBI 0.5±0.3 / 0.4±0.2	0.4±0.2 / 0.5±0.3 mm
Carrillo de Albornoz 2014 [14]	11	14	1 y	2.9±0.5 / 3.3±0.8 mm	NR / NR	Reported radiographically
Hosseini 2022 [11]	31	32 (metal)	5 y	NR / NR	No significant group difference reported	0.30±1.10 / −0.10±0.40 mm
Bittencourt 2023 [22]	Zr subgroup	Ti subgroup	≥7 y	Mid-buccal 4.25±1.28 / 4.47±1.32 mm	No significant difference reported	Not a primary reported outcome
Bharate 2020 [23]	NR	NR	12 mo	NR / NR	NR / NR	Bone-height reduction 0.487±0.159 / 0.621±0.207 mm; P=0.02, favors Zr

NR = not reported for this outcome/study in the material available for this review; mBI = modified bleeding index; BL = bone level.

Bleeding on Probing and Other Soft-Tissue Outcomes

Peri-implant bleeding was reported using non-interchangeable approaches across the clinical literature, including mean bleeding-on-probing scores (e.g., Sailer 2009 [5], Zembic 2009 [6], Zembic 2013 [7], Humm 2023 [8]), percentage of bleeding sites (Payer 2015 [18]), and modified bleeding indices (Lops 2013 [12]). Hosseini 2022 [11] and Bittencourt 2023 [22] reported no statistically significant between-group differences in bleeding parameters but did not provide group-specific numerical values in the material available for this review. Because these measures are not statistically equivalent, bleeding outcomes were not combined across studies.

Probing pocket depth was reported in six of the ten studies with quantitative data (Table 4) and was broadly similar between zirconia and titanium groups, without a consistent direction of difference. Bharate et al. 2020 [23] did not report probing depth or bleeding parameters and contributed only crestal bone-height data to the quantitative comparison. Other soft-tissue outcomes reported across the wider evidence base included plaque-related measures, mucosal recession, peri-implant tissue color (Bressan 2011 [16]; Cosgarea 2015 [17]), and esthetic indices including the Pink and White Esthetic Scores (Payer 2015 [18]; Bittencourt 2023 [22]), but comparable numerical values for these outcomes were not available in the material provided for this review.

Risk of Bias

Risk of bias was evaluated separately according to study design, using the Cochrane Risk of Bias 2 tool [3] for randomized studies and ROBINS-I [4] for non-randomized comparative studies. We considered risk-of-bias findings when interpreting the strength and consistency of the evidence, rather than relying solely on statistical significance.

DISCUSSION

This systematic review examined clinical evidence comparing zirconia and titanium implant abutments, with particular emphasis on marginal bone stability and peri-implant soft-tissue health. An important methodological observation was that the number of publications should not be equated with the number of independent trials: nineteen eligible publications corresponded to twelve independent clinical investigations, since the Sailer–Zembic–Humm, Hosseini, Carrillo–

Ferrantino, and de Oliveira Silva/de Freitas cohorts each generated more than one report. Treating these publications as separate independent studies would duplicate participants and would misrepresent the effective size of the evidence base.

Across the ten publications reporting quantitative values, probing pocket depth and peri-implant bleeding were broadly comparable between zirconia and titanium groups, without a consistent direction of difference favoring either material. Marginal bone-level or bone-level change was likewise comparable between materials in most reporting cohorts, including the longest-followed cohort at 13 years (Humm 2023 [8]), in which bone level was numerically similar between zirconia and titanium abutments, consistent with earlier systematic-review estimates of marginal bone stability for both materials [25,26]. Two exceptions were identified. In the Hosseini cohort at 5 years (Hosseini 2022 [11]), the zirconia group showed a numerically greater positive bone-level change than the titanium/metal group; this finding should be interpreted cautiously given the differing baseline and measurement conventions across studies and the absence of pooled statistical testing. More notably, Bharate et al. 2020 [23] reported a statistically significant reduction in 1-year crestal bone-height loss with zirconia compared with titanium (P=0.02) — the only statistically significant material-related difference for a hard-tissue outcome across the entire evidence base. This single short-term finding should not be generalized: it stands alone against a much larger and longer-followed body of evidence, including a 13-year randomized cohort, that shows no consistent material effect on marginal bone.

The available literature demonstrated substantial variability in abutment design. Although zirconia and titanium were the principal materials compared, studies also differed in CAD/CAM customization, implant location, prosthetic design, restoration retention, and follow-up duration. Transmucosal emergence-profile geometry represented another important source of variation. Restricting the review exclusively to concave abutments was not adopted because a concave profile could not be verified for any included study in the available material; excluding these studies would have substantially reduced the evidence base and could have introduced selection based on incomplete reporting rather than true geometric difference. Concavity was instead treated as an abutment characteristic to be reported where available, allowing the broader zirconia-versus-titanium evidence to be retained while preserving the clinically relevant question of whether transmucosal geometry modifies peri-implant tissue response.

Interpretation of peri-implant bleeding required particular methodological caution. Bleeding reported as a percentage of sites is not statistically identical to a mean bleeding-on-probing score or to an implant-level binary bleeding event, and ordinal bleeding indices cannot automatically be transformed into risk ratios; a prior systematic review of zirconia and titanium abutments reached a similar conclusion when qualitatively synthesizing biological outcomes across heterogeneous bleeding measures [24]. Preserving these distinctions across studies, rather than combining them, improved the validity of the comparison but limited the review to a narrative rather than a pooled quantitative synthesis for this outcome.

Marginal bone stability around implant-supported restorations is multifactorial. Material composition, implant–abutment connection, abutment height, soft-tissue phenotype, emergence profile, implant position, restoration design, loading protocol, and maintenance may all contribute to marginal bone remodeling. Any difference observed between zirconia and titanium in the included cohorts — including the isolated significant finding of Bharate et al. [23] — should therefore not automatically be interpreted as an isolated material effect.

Both zirconia and titanium remain clinically established abutment materials. Zirconia offers particular esthetic advantages in situations where metallic discoloration of thin peri-implant mucosa is a concern, whereas titanium has the most extensive long-term clinical documentation among the included cohorts, extending to approximately 13 years of follow-up.

The principal limitations of the available evidence included heterogeneity in abutment design, differences in outcome definitions, variable follow-up periods, incomplete reporting of emergence-profile geometry, the repeated-cohort structure of several frequently cited trials, and the resulting decision not to undertake pooled quantitative meta-analysis. A further limitation is that quantitative outcome values were available for only ten of the nineteen eligible publications in the material reviewed; the remaining publications

contributed to the characterization of study design and cohort structure but not to the quantitative comparison in Table 4.

Future randomized trials should report transmucosal abutment characteristics in greater detail, including emergence angle, profile curvature, abutment height, soft-tissue phenotype, and CAD/CAM customization. Standardizing bleeding-on-probing and marginal bone-level reporting, along with consistent baseline definitions and reference points, would improve the comparability and poolability of future studies.

CONCLUSION

Nineteen publications, corresponding to twelve independent clinical investigations, directly compared zirconia and titanium implant abutments in prospective clinical studies. Both materials demonstrated broadly comparable performance for probing pocket depth, peri-implant bleeding, and marginal bone stability across the available follow-up periods, which ranged from approximately 1 to more than 13 years, with two isolated exceptions — a numerically greater bone-level change with zirconia in one 5-year cohort, and a statistically significant reduction in 1-year crestal bone-height loss with zirconia in one comparative study — neither of which was corroborated by the larger and longer-followed body of evidence. No included study confirmed a concave emergence profile, and it should be considered a potential modifier of peri-implant tissue response for future investigation rather than assumed in studies that do not explicitly report abutment geometry. Because of heterogeneity in outcome definitions, follow-up duration, and the repeated-cohort structure of the literature, these findings are presented as a narrative synthesis rather than a pooled meta-analysis; further well-designed randomized trials using standardized definitions of emergence profile and peri-implant outcomes, and enabling formal statistical pooling, are required to clarify the interaction between abutment material and transmucosal design.

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Conflicts of Interest

The reviewers declare no conflicts of interest.

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