Clinical, Cosmetic and Investigational Dentistry

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REVIEW

Clinical and Esthetic Outcomes of Anodized Titanium Abutments: A Systematic Review of Randomized Controlled Trials

Aldilla Miranda[1,2], Ira Komara[2], Arief Cahyanto[3,4], Cortino Sukotjo[5], Agus Susanto[2]

[1]Faculty of Medicine, Universitas Padjadjaran, Sumedang, West Java, Indonesia; [2]Department of Periodontology, Faculty of Dentistry, Universitas Padjadjaran, Sumedang, West Java, Indonesia; [3]Department of Clinical Sciences, College of Dentistry, Ajman University, Ajman, United Arab Emirates; [4]Centre of Medical and Bio-allied Health Sciences Research, Ajman University, Ajman, United Arab Emirates; [5]Department of Prosthodontics, School of Dental Medicine, University of Pittsburgh, Pittsburgh, PA, USA

Correspondence: Aldilla Miranda, Universitas Padjadjaran, Jln. Ir. Soekarno km. 21, Jatinangor, Sumedang, West Java, Indonesia, 45363, Tel +62-227794120, Email aldilla.miranda@unpad.ac.id

Abstract: Titanium is widely used for dental implant abutments due to its mechanical strength, biocompatibility, and corrosion resistance; however, its gray coloration can compromise esthetic outcomes, particularly in patients with thin or translucent gingival biotypes. Anodization, a surface modification technique altering the titanium oxide layer, has been proposed to improve soft tissue aesthetics by producing abutments with warmer tones (eg, pink or gold) that harmonize with the surrounding gingiva. This systematic review aimed to evaluate the clinical and aesthetic outcomes of anodized titanium abutments compared to non-anodized titanium and other materials, with a focus on peri-implant soft tissue health and visual integration. Following PRISMA 2020 guidelines, a comprehensive search was conducted in Scopus, PubMed, and ScienceDirect for Randomized Controlled Trials (RCTs) published between 2013 and 2024. Eligibility followed the PICOS framework. Nine RCTs with parallel or split-mouth designs and follow-ups from six weeks to two years were included. Esthetic outcomes were assessed using CIELab spectrophotometry and the Pink Esthetic Score (PES), while clinical parameters included mucosal recession, probing depth, plaque accumulation, gingival inflammation, and bleeding on probing. Study quality was appraised using the Cochrane Risk of Bias 2.0 tool. Anodized titanium abutments demonstrated enhanced aesthetic outcomes, especially in thin gingival biotypes, by improving colour harmony and reducing grayish shine-through. Pink-anodized abutments also showed better soft tissue integration compared to controls. However, clinical improvements such as reductions in inflammation, plaque, or recession were modest, inconsistent, and often statistically insignificant across studies. While anodization appears safe and beneficial for visual outcomes, its functional clinical advantages remain uncertain. These findings call for cautious interpretation and highlight the need for further well-powered, standardized long-term RCTs to validate the broader clinical relevance.
Keywords: anodized titanium abutments, dental implants, peri-implant soft tissue, esthetic outcomes

Introduction

Regenerative techniques in dentistry have garnered significant attention due to the increasing demand for effective restoration and regeneration of missing oral tissues, including bone and soft tissues surrounding dental implants and natural teeth, thereby ensuring optimal functional and aesthetic outcomes. Autogenous bone grafting remains the gold standard due to its superior osteogenic, osteoinductive, and osteoconductive properties. However, limitations such as donor site morbidity and limited availability have driven clinicians to explore alternative biomaterials, including allografts, xenografts, synthetic substitutes, autologous cell-based hyaluronic acid grafts, and platelet-rich fibrin (PRF). While regenerative biomaterials primarily address the structural regeneration of bone, the successful long-term performance of dental implants equally depends on the integrity and stability of peri-implant soft tissues.[1,2]

Titanium (Ti) remains the most used material for dental implant abutments due to its superior biocompatibility, corrosion resistance, and mechanical properties.[3–5] Titanium implants inherently form a thin (typically ranging from 1 to 20 nm) stable titanium oxide (TiO_2) layer, which significantly contributes to their high corrosion resistance and biological

Received: 2 May 2025
Accepted: 7 August 2025
Published: 29 August 2025

inertness. This naturally occurring oxide layer facilitates initial interactions with soft tissues through the fundamental adsorption of proteins, thereby promoting initial soft tissue healing and stabilization.[6,7]

Despite these inherent advantages, the native TiO_2 film's thin and amorphous structure limits its potential to integrate effectively and durably with peri-implant soft tissues, particularly in terms of esthetic and biological stability. Its characteristic gray color can compromise esthetic outcomes, especially in patients with thin gingival biotypes, where soft tissue translucency may allow the metallic hue to shine through, posing significant challenges in the anterior, obvious regions of the mouth.[8–10] In addition to aesthetics, the transmucosal portion of the abutment plays a vital role in peri-implant soft tissue health. This region is vulnerable to bacterial colonization and inflammation due to its exposure to the oral environment and limited epithelial adherence.[11,12] Surface treatments on implant abutments enhance cell proliferation, tissue attachment, and aesthetics while reducing the risk of inflammation.[13–16]

Stabilizing connective tissue and epithelial attachment are crucial for protecting implants from bacteria and minimizing the risk of peri-implantitis. These modifications enhance both aesthetic and biological compatibility, ensuring successful outcomes in dental implant therapy.[11,16,17] Electrochemical anodization, utilizing electrolytes such as sulfuric, acetic, and hydrochloric acids, is a cost-effective method for modifying titanium surfaces. This process creates a nano-structured TiO_2 layer by immersing titanium in an electrolyte and applying voltage. The resulting layer enhances cell adhesion, promotes tissue integration, and improves aesthetics by reducing metallic shine. Anodization alters the TiO_2 layer thickness, changing surface coloration without affecting chemical composition or biocompatibility. By adjusting anodization parameters, it is possible to optimize titanium abutment color, notably achieving a yellow hue for better aesthetic integration with translucent restorations.[7,18–20]

The gingival biotype, whether thin or thick, plays a pivotal role in determining implant success. Thin biotypes, characterized by increased translucency and limited vascularity, are more prone to gingival recession and inflammatory complications such as peri-implant mucositis and peri-implantitis. These anatomical limitations reduce their ability to form a protective barrier against microbial and mechanical insults, thereby increasing the risk of implant failure. In contrast, thick biotypes exhibit superior vascularization and tissue robustness, offering greater resistance to inflammation and peri-implant breakdown. Anodized titanium abutments with controlled micro- and nano-scale topographies have been shown to enhance fibroblast adhesion and proliferation, especially in thin biotypes. This promotes the formation of a stable soft tissue seal at the transmucosal interface, which is essential for maintaining peri-implant health and minimizing soft tissue recession.[9,21–26]

Although in vitro studies have consistently demonstrated favorable biological responses to anodized titanium, clinical findings remain inconclusive due to substantial heterogeneity in study designs, outcome parameters, and follow-up durations.[18,27,28] This variability limits the ability to draw definitive conclusions regarding the effectiveness of anodized titanium abutments in real-world clinical settings. To address inconsistencies in previous literature, this review deliberately focuses on randomized controlled trials (RCTs), which provide higher methodological rigor and stronger clinical relevance than observational or in vitro studies. Additionally, the gingival biotype was considered as a moderating factor, since tissue thickness critically affects both esthetic and clinical outcomes of anodized titanium abutments. This targeted approach supports a more consistent and clinically relevant synthesis of evidence.

This systematic review aims to critically synthesize the available clinical data on anodized titanium abutments, evaluating their esthetic and clinical outcomes. The clinical indicators evaluated include the depth of investigation, bleeding index, height and width of the peri-implant area, mucosal recession, color of the peri-implant area, plaque index, and modified gingival index. The aesthetic aspect is assessed using the Pink Aesthetic Score (PES) and CIELab Spectrophotometry. By synthesizing existing evidence, this review seeks to clarify the extent to which anodization enhances peri-implant soft tissue esthetics and biological integration and whether these improvements translate into consistent clinical performance across diverse patient populations and gingival biotypes.

Methods

Study Design

This systematic review adhered to the PRISMA 2020 guidelines.[29,30] It examined studies assessing the impact of anodized titanium abutments on peri-implant soft tissue health across various gingival biotypes. To maintain methodological transparency, the review protocol was pre-registered with PROSPERO (CRD4202338771).

Search Strategy

A comprehensive electronic literature search was conducted across Scopus, PubMed, and ScienceDirect to identify relevant studies published between 2013 and December 2024. The following search combinations were employed: "anodized" OR "anodizing" OR "anodic oxidation" AND "titanium abutment" AND "clinical". This methodology assessed the effects of anodized titanium abutments on peri-implant tissue outcomes, focusing on clinical and aesthetic outcomes.

Eligibility Criteria

Studies were included based on the following PICOS (Population, Intervention, Comparison, Outcome, Study Design) criteria (Table 1). The literature search was executed by initially screening titles and abstracts; then, full-text articles were evaluated when titles and abstracts did not provide sufficient information. Full texts of the included articles were then reviewed. To collect data, the full texts of the included articles were read, and all relevant data were extracted using pre-determined fields in a uniform data extraction sheet.

Data Extraction and Quality Assessment

A comprehensive database search was conducted, and duplicate studies were removed using Mendeley software. Titles and abstracts were screened, followed by a full-text review of relevant articles. Two authors independently extracted data and assessed the risk of bias (M.A., K.I)., resolving disagreements with a third reviewer (S.A). The Cochrane Risk of Bias 2.0 tool assessed six dimensions of bias, categorizing articles into low-, moderate-, or high-risk classifications.[31,32]

Data Synthesis

The data were synthesized qualitatively to summarize the characteristics of the included studies, assess the effects of interventions, and identify patterns in aesthetic and clinical outcomes associated with anodized titanium abutments. This stratified analysis provides a comprehensive explanation of how anodized titanium abutments impact peri-implant aesthetics and health across various clinical scenarios.

This systematic review did not include a meta-analysis or statistical measurement due to significant heterogeneity in study parameters, comparison materials, and control groups. The included studies used various abutment materials, including zirconia, non-anodized titanium, gold-anodized titanium, and pink-anodized titanium, each with distinct optical properties and colour stability. Additionally, methodological inconsistencies, such as differences in spectrophotometric devices, colour measurement techniques, and the absence of standardized peri-implant soft tissue thickness control, contributed to variable colour difference (ΔE) outcomes.

Result

The PRISMA flowchart in Figure 1 illustrates the study selection process. The initial electronic database search identified 473 references. After removing 18 duplicates and screening titles and abstracts, 69 studies were selected for review. Sixty

Table 1 PICOS Framework

Population	Studies involving patients with titanium abutments subjected to anodization treatment.
Intervention	Anodization of the titanium abutment surface.
Comparison	Studies comparing anodized and non-anodized (control) or zirconia abutments.
Outcome	Measured outcomes related to peri-implant tissue health (eg, probing depth, bleeding on probing, inflammation level) and aesthetic outcomes (eg, Pink Esthetic Score, CIELab spectrophotometry).
Study Design	Only clinical trials with clinical assessments of anodized titanium abutments.

https://doi.org/10.2147/CCIDE.S535430

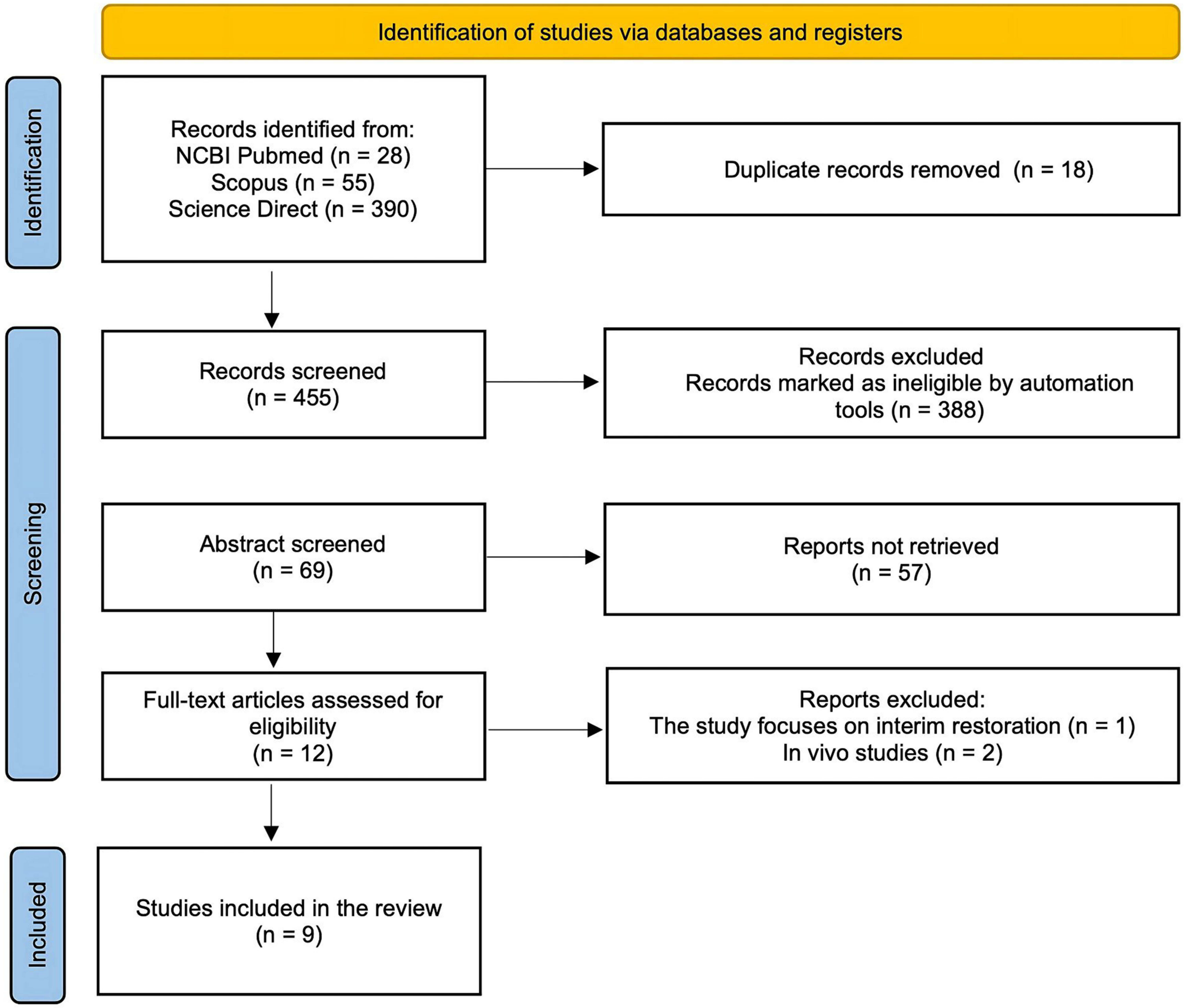

Figure 1 PRISMA 2020 flow diagram of study selection process.

articles were excluded because they needed to meet the eligibility criteria. Nine studies met all inclusion criteria and were included in the qualitative synthesis and analysis.[8,9,19,26,33–37]

The characteristics of the nine included studies, summarized in Table 2, highlight diverse methodologies and clinically relevant outcomes. These randomized controlled trials (RCTs), utilizing parallel or split-mouth designs, investigated the effect of anodized titanium abutments on peri-implant soft tissue outcomes over follow-up periods ranging from six weeks to two years. Sample sizes varied from 20 to 80 abutments, ensuring robust data for analysis. Interventions primarily involved anodized titanium abutments with pink, gold, or yellow surfaces, compared to non-anodized titanium or zirconia abutments. The classification of articles based on the results, as illustrated in Figure 2, highlights two primary domains of evaluation: aesthetic outcomes and peri-implant tissue health. Figures 3 and 4 provide a comprehensive summary of the quality of the RCTs included in this analysis.

Table 3 illustrates that the aesthetic performance of anodized abutments was mainly assessed using spectrophotometry measurements, Pink Esthetic Scores (PES), and Peri-implant Tissue Dimensions (thickness and width). Table 4 presents a detailed analysis of key clinical indicators, including gingival recession, probing depth, plaque index, gingival index, and bleeding on probing (BOP), across studies evaluating anodized titanium abutments. Studies assessing clinical

Table 2 Characteristics of Included Articles

Author Name	Publication year	Duration of Study	Number of Samples	Measurement Parameters
Farrag KM & Khamis MM.[4]	2023	18 months	60 abutments (Dentium Co, Ltd).: 1. Pink-neck anodized titanium Initial: n = 30Final: n = 28 2. Control Initial: n = 30Final: n = 28	1. Modified Pink Esthetic Score (MPES) 2. Peri-implant tissue height 3. Peri-implant tissue thickness 4. Probing depth 5. Soft tissue recession 6. Modified Plaque Index 7. Bleeding on Probing 8. Modified Gingival Index
Vazouras K et al[5]	2022	1 week, 1 year	20 abutments (Genesis, Keystone Dental): 1. Pink anodized titanium, n = 4 2. Zirconia, n = 16	1. Gingival biotype distribution 2. CIELab spectrophotometry 3. Pink Esthetic Score
Dib-Zaitum I et al[28]	2022	2 months	20 abutments (Galimplant®) 1. Regular Control.,n = 10 2. Regular Pink anodized, n = 10	1. Biological width 2. Keratinized tissue width 3. Level Vascularization 4. Level inflammation
Wang T et al[27]	2020	2 months	44 abutments (Ankylos C/X; Dentsply Sirona) 1. Control, n = 11 2. Pink anodized, n = 11 3. Gold anodized, n = 11 4. Zirconia, n = 11	1. Gingival Thickness Mean 2. CIELab spectrophotometry
Bittner N et al[21]	2020	6 months	40 abutments (PrimaConnex™, Keystone Dental): 1. Control, n = 20 2. Pink anodization, n = 20	1. Gingival biotype distribution 2. CIELab spectrophotometry 3. Mucosa recession
Gil MS et al[32]	2019	3 months	80 Abutments (Atlantis) 1. Control, n = 40 2. Pink anodization, n = 40	CIELab spectrophotometry
Hall et al[30]	2018	6 weeks, 6 months, 2 years	70 abutments (Brånemark System, TiUnite): 1. ControlInitial: n = 35Final: n = 26 2. Yellow anodized Initial: n = 35Final: n = 26	1. Peri-implant tissue height 2. Peri-implant tissue width 3. Peri-implant probing depth 4. Plaque Index 5. Gingival Index Bleeding on Probing 6. Bleeding on abutment removal
Gil MS et al[13]	2017	3 months	40 abutments (Keystone Dental): 1. Control, n = 20 2. Pink anodization, n = 20	CIELab spectrophotometry
Martínez-Rus F et al[31]	2017	6 months and 3 weeks	20 abutments (Core3dcentres Core Custom Abutments) 3. Control, n = 5 4. Pink anodized, n = 5 5. Gold anodized, n = 5 6. Zirconia, n = 5	1. Gingival biotype distribution 2. CIELab spectrophotometry

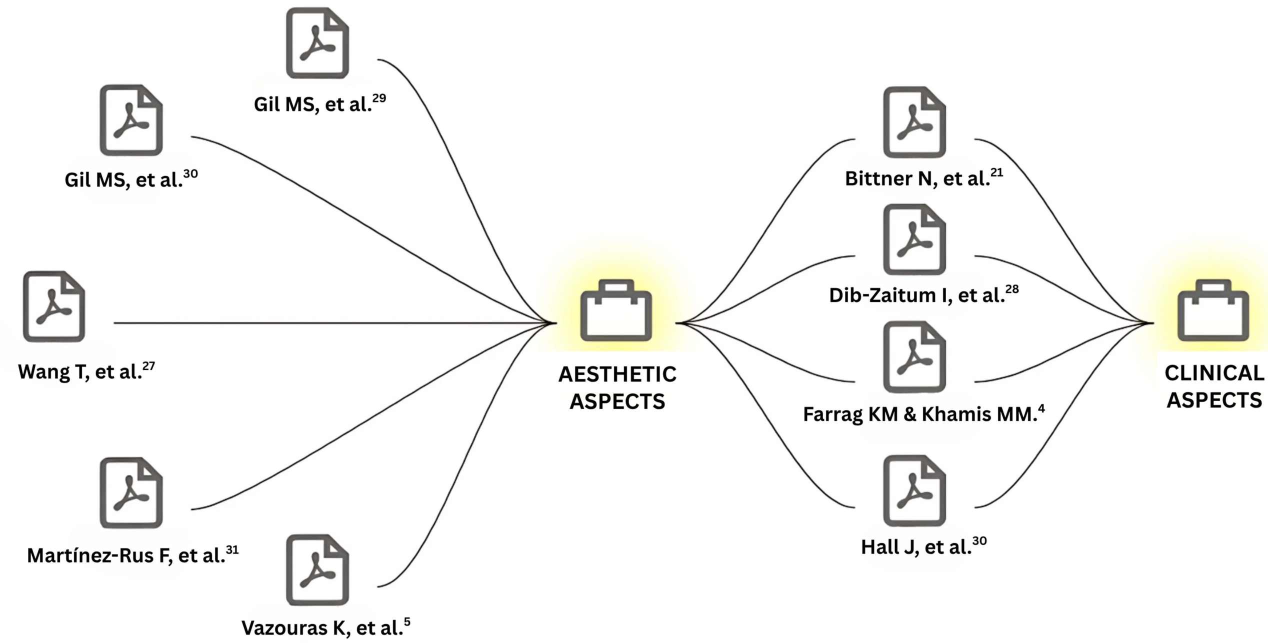

Figure 2 Visual categorization of included studies into aesthetic and clinical outcomes.

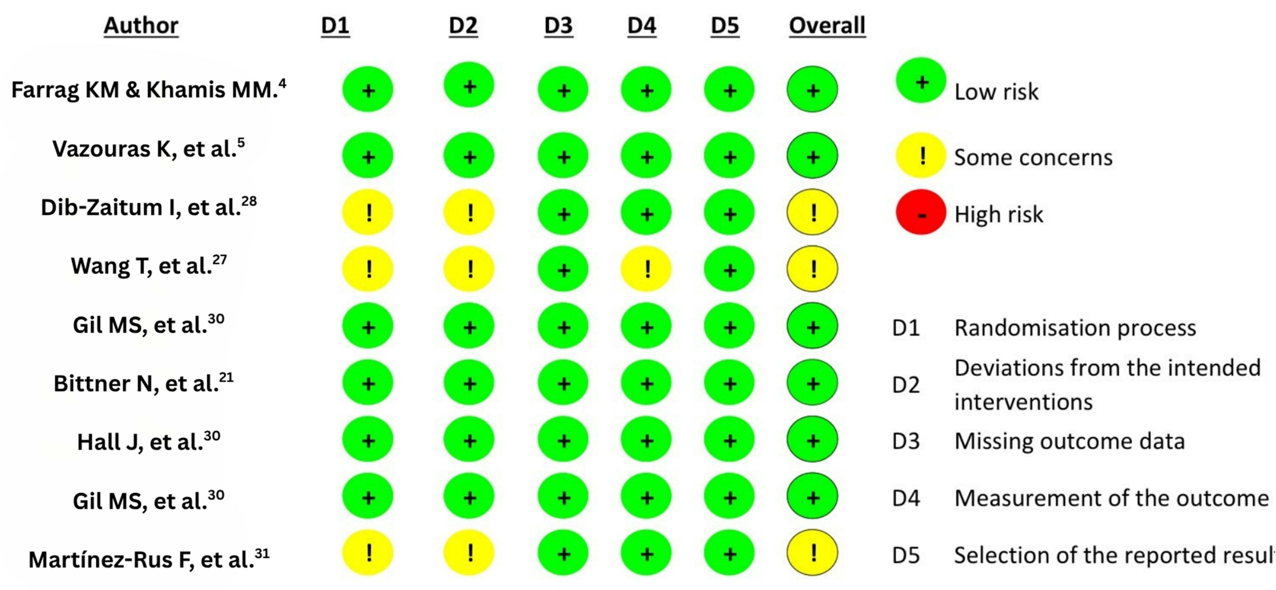

Figure 3 Risk of bias summary for all included studies using RoB 2.0 assessment tool.

indicators have provided varying conclusions regarding the effects of anodized abutments on peri-implant soft tissue health.

CIELab Spectrophotometry Measurements

Several studies assessing peri-implant soft tissue colour using CIELab spectrophotometry consistently reported improved aesthetic outcomes with anodized abutments. Notably, Vazouras et al (2022), Bittner et al (2020), and Wang et al (2021) found that pink anodized abutments produced lower ΔE values (ranging from 6.2 to 9.90) compared to non-anodized

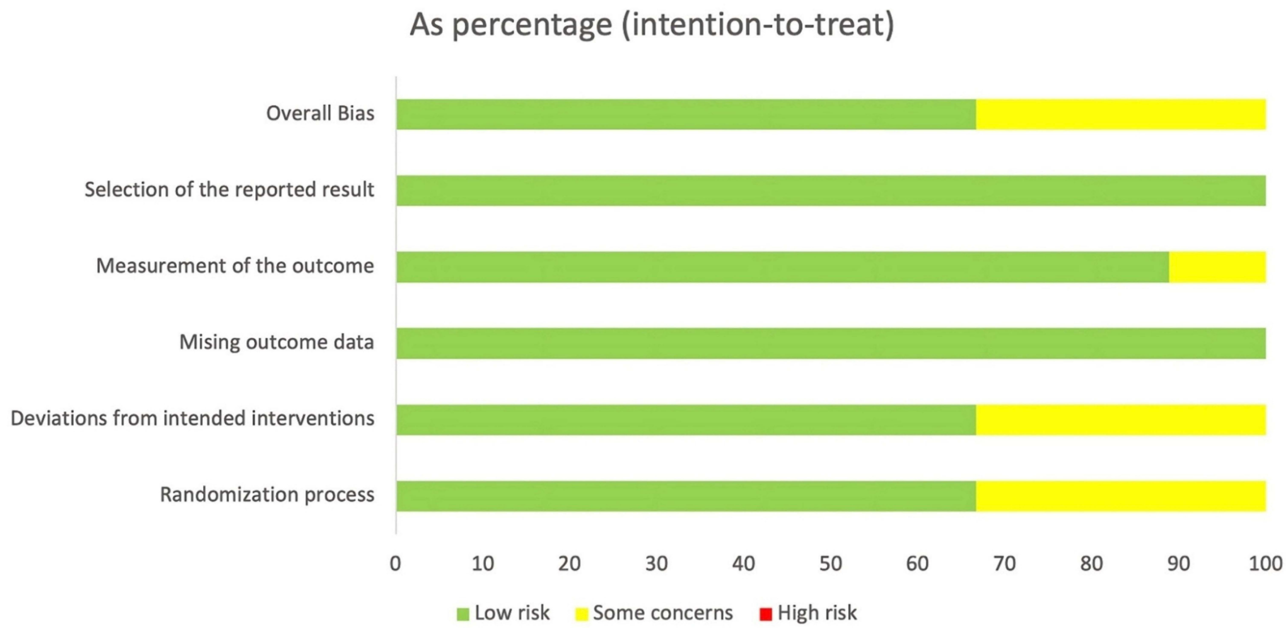

Figure 4 Percentage distribution of bias judgments across all RoB 2.0 domains.

titanium (ΔE = 6.14 to 11.25). While all reported improvements were within ranges generally considered perceptible to the human eye ($\Delta E > 3.7$), many values still exceeded the threshold for ideal clinical indistinguishability.[9,26,33]

These findings were most pronounced in patients with thin gingival biotypes, suggesting that soft tissue thickness is a critical moderating factor. However, variation in spectrophotometric devices and lack of uniform tissue thickness control across studies may affect cross-study comparability. Only one study (Wang et al, 2021) reported statistical significance ($p < 0.05$), highlighting the need for standardized outcome reporting in future trials.[9,26,33]

Martínez-Rus et al (2017) and Gil et al (2019) also confirmed the aesthetic benefits of pink anodization over gold anodization or untreated titanium, highlighting the role of soft-tissue thickness in determining effectiveness.[36,37] Gil et al (2017, 2019) further demonstrated that anodized pink abutments reduced colour discrepancies between peri-implant soft tissue and natural gingiva, especially in the *red spectrum (Δa*)*improving aesthetic blending. However, Gil et al (2017) emphasized that subjective patient perception has a significant influence on the evaluation of outcomes.[35,36]

Pink Esthetic Score (PES)

The Pink Esthetic Score (PES) was utilized in several studies to assess the visual integration of anodized abutments with surrounding peri-implant tissues. Vazouras et al (2022) reported significantly higher PES values for pink-anodized abutments (mean = 10.12 ± 1.13) compared to non-anodized titanium abutments (mean = 9.68 ± 1.41), indicating enhanced soft tissue esthetics in the test group. These findings suggest that anodized surfaces may improve gingival architecture, papilla fill, and overall mucosal appearance.[9]

However, Farrag and Khamis (2023) found no significant long-term differences in PES between anodized and control groups after 18 months, raising questions about the durability of these aesthetic improvements. Other studies, such as Martínez-Rus et al (2017), supported these results with moderate PES enhancements in thin biotypes, although no study reported PES scores approaching the theoretical maximum of 14. The outcome variation may be attributed to differences in follow-up duration, measurement timing, patient-specific factors, and subjective elements of PES scoring. Overall, while anodization appears to offer short-term aesthetic gains as reflected in PES values, its long-term impact on soft tissue esthetics remains inconclusive.[8,37]

Table 3 Evaluation of Aesthetic Indicator Measurements

Aesthetic Indicators	Authors	Abutment Surface Treatment	
		Anodized	Control
CIELab spectrophotometry measurements	Vazouras K et al.[5]	ΔE = 9.90 ± 2.51	ΔE = 11.25 ± 2.98*
	Bittner N et al.[21]	Thick biotype: ΔL = 4.97 Δa = 0.27 Δb = 3.10 ΔE = 8.42 Thin biotype: ΔL = 3.87 Δa = 1.44 Δb = 3.17 ΔE = 6.2	Thick biotype: ΔL = 4.48 Δa = 2.33 Δb = 3.36 ΔE = 7.96 Thin biotype: ΔL = 5.09 Δa = 1.52 b = 2.32 ΔE = 6.14
	Gil MS et al.[30]	ΔL = −5.23 ± 4.33 Δa = −2.19 ± 4.76 Δb = −3.34 ± 3.58	ΔL = −4.84 ± 3.99 Δa = −3.11 ± 4.37* Δb = −3.34 ± 3.25
	Martínez-Rus F et al.[31]	Pink:Middle, ΔE = 10.68 ± 4.2 Incisal, ΔE = 8.6 ± 6.1 Gold: Middle, ΔE = 8.96 ± 3.1 Incisal, ΔE = 9.16 ± 6.5	Middle, ΔE = 11.56 ± 3.4* Incisal, ΔE = 10.42 ± 6.3*
	Gil MS et al.[29]	Cervical: L = 46.27 ± 4.39 a = 16.98 ± 4.33* b = 11.32 ± 2.77 ΔE = 4.69 Middle: L = 46.92 ± 4.16 a = 16.51 ± 3.84* b = 11.12 ± 2.82 ΔE = 4.47 Incisal: L = 47.97 ± 4.80 a = 14.43 ± 3.72 b = 11.13 ± 2.70 ΔE = 3.84	Cervical: L = 46.97 ± 4.04 a = 15.51 ± 3.60* b = 11.27 ± 2.34 ΔE = 3.86 Middle: L = 47.29 ± 3.07 a = 15.55 ± 2.91* b = 11.24 ± 2.04 ΔE = 3.74 Incisal: L = 47.89 ± 4.24 a = 14.75 ± 4.27 b = 11.19 ± 3.00 ΔE = 4.17
	Wang T et al.[27]	Pink:ΔL = 3.68 ± 2.09 Δa = 2.85 ± 2.87* Δb = 4.44 ± 4.10 ΔE = 7.63 ± 3.46* Gold: ΔL = 4.10 ± 2.13 Δa = 2.91 ± 3.54* Δb = 3.89 ± 4.37 ΔE = 7.90 ± 3.67*	ΔL = 4.26 ± 2.83 Δa = 3.97 ± 3.46 Δb = 4.81 ± 3.94 ΔE = 8.74 ± 3.46

(*Continued*)

Table 3 (Continued).

Aesthetic Indicators	Authors	Abutment Surface Treatment	
		Anodized	Control
Pink Esthetic Score & Modified Pink Esthetic Score	Vazouras K et al.[5]	10.12 ± 1.13	9.68 ± 1.41
	Farrag KM & Khamis MM.[4]	Initial: 7.32 ± 1.04 Final: 7.64 ±1.01	Initial: 7.32 ± 0.76Final: 7.64 ± 0.67
Peri-implant Tissue Thickness	Farrag KM & Khamis MM.[4]	2.30 ± 0.67 mm	2.38 ± 0.83 mm
	Wang T et al.[27]	Thick: 2.72 ± 0.13 (n = 7) Thin: 1.85 ± 0.29 (n = 4)	
	Martínez-Rus F et al.[31]	Thick: 2.43 ± 0.1 (n = 3) Thin: 1.46 ± 0.2 (n = 17)	
	Vazouras K et al.[5]	Thick: 3.05 ± 0.95 (n = 8) Thin: 1.79 ± 0.22 (n = 17)	
Peri-implant Tissue Width	Farrag KM & Khamis MM.[4]	2.39 ± 0.61 mm	2.46 ± 0.68 mm
	Hall J et al.[30]	Initial: 2.31 ± 1.39 mm Final: 2.37 ± 1.10 mm	Initial: 1.80 ± 1.48 mm Final: 1.98 ± 1.20 mm
	Dib-Zaitum I et al.[28]	Initial: 5.2 ± 3.9 mm Final: 4.8 ± 3.2 mm	Initial: 5.2 ± 1.6 mm Final: 3.8 ± 2.2 mm

Notes: *Statistically significant (p < 0.05).

Table 4 Evaluation of Clinical Indicator Measurements

Clinical Indicator	Author	Abutment Surface Treatment	
		Anodized	Control
Mucosa recession	Bittner N et al.[21]	Thin biotype: 1.37 ± 1.05 mm Thick biotype: 1.28 ± 0.79 mm	Thin biotype: 1.99 ± 0.42 mm Thick biotype: 1.13 ± 0.88 mm
	Farrag KM & Khamis MM.[4]	Initial: 0.21 ± 0.42 mm Final: 0.27 ± 0.52 mm	Initial: 0.20 ± 0.39 mm Final: 0.27 ± 0.44 mm
Probing depth	Farrag KM & Khamis MM.[4]	Initial: 2.65 ± 0.48 mm Final: 2.60 ± 0.40 mm	Initial: 2.71 ± 0.53 mm Final: 2.65 ± 0.46 mm
	Hall J et al.[30]	Initial: 2.22 ± 0.78 mm Final: 2.52 ± 0.97 mm	Initial: 2.33 ± 0.80 mm Final: 2.60 ± 1.16mm
	Dib-Zaitum I et al.[28]	Initial: 1 ± 2.21 mm Final: 1.5 ± 1.4 mm	Initial: 1.55 ± 1.46 mm Final: 1.5 ± 1.4 mm
Plaque Index & Modified Plaque Index	Farrag KM & Khamis MM.[4]	Initial: 0.24 ± 0.42 mm Final: 3 ± 1.6 mm	Initial: 0.22 ± 0.39 mm Final: 0.25 ± 0.44 mm
	Hall J et al.[30]	Initial score 0: 84.4% score 1: 15.6% score 2: 0% Final Score 0: 88.5% score 1: 3.8% score 2: 7.7%	Initial score 0: 81.3% score 1: 15.6% score 2: 3.1% Final score 0: 88.5% score 1: 3.8% score 2: 7.7%

(*Continued*)

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Table 4 (Continued).

Clinical Indicator	Author	Abutment Surface Treatment	
		Anodized	Control
Gingival Index & Modified Gingival Index	Farrag KM & Khamis MM.[4]	Initial: 0.24 ± 0.42 Final: 0.11 ± 0.31	Initial: 0.22 ± 0.39 Final: 0.11 ± 0.28
	Hall J et al.[30]	Initial score 0: 90.6% score 1: 9.4% Final score 0: 92.3% score 1: 7.7%	Initial score 0: 90.6% score 1: 9.4% Final score 0: 88% score 1: 12%
Bleeding on Probing	Hall J et al.[30]	Initial: 0.556 ± 0.684 Final: 0.519 ± 0.640	Initial: 0.722 ± 0.712 Final: 0.654 ± 0.629
	Farrag KM & Khamis MM.[4]	Initial: 0.14 ± 0.36 Final: 0.14 ± 0.36	Initial: 0.11 ± 0.31 Final: 0.14 ± 0.36

Peri-Implant Tissue Thickness and Width

Several studies investigated the influence of anodized titanium abutments on peri-implant soft tissue thickness and width to determine whether surface modifications affect structural tissue volume. Clinical findings consistently indicated that while anodized abutments contributed to improved esthetic outcomes, they did not significantly change soft tissue dimensions. Wang et al (2020), Martínez-Rus et al (2017), and Vazouras et al (2022) all reported a positive correlation between increased peri-implant tissue thickness and improved esthetic integration (eg, lower ΔE values and higher PES scores). However, in each case, anodization did not produce measurable increases in soft tissue thickness or width compared to control abutments. These outcomes suggest that the visual benefits associated with anodized surfaces are attributable primarily to color modulation rather than volumetric soft tissue enhancement.[9,33,37]

Farrag and Khamis (2023) similarly found no statistically significant differences in peri-implant tissue dimensions between pink-anodized and standard titanium abutments after 18 months. This reinforces the conclusion that anodization has minimal to no direct impact on tissue remodeling or volume gain.[8] Overall, the evidence indicates that anodization improves esthetic blending without altering the physical thickness or width of the peri-implant soft tissues. These findings underscore the significance of pre-existing tissue volume in achieving optimal visual outcomes and suggest that adjunctive surgical or regenerative procedures (eg, soft tissue grafting) may be necessary in cases of insufficient gingival thickness, regardless of the abutment surface color or treatment approach.

Mucosal Recession & Probing Depth

Multiple clinical trials have evaluated the influence of anodized abutments on peri-implant tissue health indicators, including mucosal recession and probing depth. Farrag & Khamis (2023) observed no statistically significant differences between pink-anodized and standard titanium abutments in mucosal recession (mean = 0.27 mm for both) or probing depth (2.60 mm vs 2.65 mm, $p > 0.05$) after 18 months of follow-up. Similarly, Hall et al (2019) reported nearly identical final probing depths (2.52 mm for the anodized group vs 2.60 mm for the control group), with no significant progression noted over time. These findings suggest that while anodized surfaces may enhance aesthetic integration, they do not confer measurable improvements in soft tissue stability or inflammatory response. Notably, few studies controlled for confounding factors, such as baseline tissue thickness, oral hygiene habits, or implant location, which limits the generalizability of these results. Moreover, most trials lacked long-term follow-up beyond two years, leaving questions about the durability of any biological advantages.[8,19,34]

Plaque Index & Gingival Index

Several clinical studies assessed the influence of anodized titanium abutments on plaque accumulation and gingival inflammation using Plaque Index (PI) and Gingival Index (GI) scores. Overall, the findings indicate negligible differences between anodized and non-anodized abutments, suggesting that surface coloration and modification do not significantly impact microbial colonization or the risk of inflammation. Farrag & Khamis (2023) observed similar plaque levels between pink-anodized and control titanium abutments after 18 months of follow-up, with no statistically significant differences in PI values. Hall et al (2019) likewise reported comparable plaque accumulation between groups, reinforcing the conclusion that anodization does not substantially alter surface affinity for bacterial adherence in a clinical setting. Regarding the gingival index, a slight increase in the absence of inflammatory markers in the anodized group, from 90.6% to 92.3%, while the control group saw a reduction from 88%, indicating marginally better soft tissue behavior around anodized surfaces. Despite this trend, the differences did not reach statistical significance, and the overall variation remained within clinically acceptable limits.[8,19]

These findings suggest that while anodized abutments may exhibit favorable biological surface characteristics in vitro (eg, fibroblast adhesion and lower bacterial load), such advantages do not consistently translate into reduced plaque retention or improved gingival inflammation markers in vivo. Oral hygiene habits, prosthetic design, and patient compliance are the predominant factors influencing implant therapy, plaque, and gingival health outcomes.

Bleeding on Probing

Multiple studies investigated the effect of anodized titanium abutments on bleeding on probing (BoP), a clinical indicator of peri-implant mucosal inflammation. Hall et al (2019) noted that anodized abutments showed a marginally lower bleeding index (0.519) compared to non-anodized controls (0.654), suggesting a potential benefit of anodization. However, this difference did not reach statistical significance, indicating that the observed trends may not be clinically meaningful. Similarly, Farrag and Khamis (2023) reported comparable BoP levels between pink-anodized and conventional titanium abutments at 18 months, reinforcing the notion that anodization does not substantially reduce soft tissue inflammation in the long term. The authors attributed the lack of significant variation to consistent oral hygiene measures and regular follow-up, which can help mitigate inflammation regardless of the type of abutment.[8,19]

While specific studies hint at a slight advantage for anodized surfaces regarding BoP, the current evidence remains inconclusive. No investigations documented increased bleeding or other adverse inflammatory effects associated with anodization. Thus, although anodized abutments may exhibit favorable surface properties in vitro, such as reduced bacterial colonization, these benefits do not consistently translate into a statistically significant decrease in BoP in vivo.

Discussion

Achieving optimal peri-implant esthetics and maintaining long-term tissue health are critical considerations in modern implant dentistry. Aesthetic outcomes are crucial for patient satisfaction, particularly in visible zones, where achieving a natural colour harmony between peri-implant mucosa and surrounding gingiva plays a significant role. Equally important is preserving peri-implant tissue health, which ensures the long-term stability and functionality of the implant through factors such as maintaining keratinized mucosa height, controlling inflammation, and promoting bacterial resistance. This discussion will explore these two interrelated aspects in detail, emphasizing their clinical relevance and the role of anodized titanium abutments in addressing both domains. Integrating aesthetic and clinical considerations provides a comprehensive framework for optimizing implant outcomes and advancing patient-centered care.

Peri-Implant Soft Tissue Esthetics and Color Harmony

Objective CIELab spectrophotometry and PES measurements have consistently demonstrated that anodized titanium abutments significantly enhance peri-implant esthetic integration compared to conventional titanium, reducing ΔE values and thus diminishing the visible grayish shine-through effect, particularly noticeable in thin gingival biotypes. By creating an oxide layer of controlled thickness, anodization produces warm-toned abutment surfaces (commonly pink or gold) that better blend with the surrounding gingiva. Vazouras et al (2022), Bittner et al (2020), Wang et al (2020), and

Martínez-Rus et al (2017) have consistently documented that anodized abutments exhibit lower ΔE values compared to untreated titanium, though slightly higher compared to zirconia abutments. In a similar crossover study, changing from a gray to a pink anodized abutment resulted in a significant increase in the red component of the peri-implant mucosa (a* value), indicating that the soft tissue appeared more pink and closer in hue to the adjacent natural gum tissue. Notably, this improvement was most pronounced in patients with a thin gingival phenotype.[9,26,33,38] Gil et al (2019) likewise found that using a pink-neck implant and abutment system can visibly shift the peri-implant tissue color toward a more natural gingival appearance, contributing positively to the overall esthetic outcome in the anterior zone.[35,36] These findings confirm that anodized abutments play a valuable role in enhancing peri-implant esthetics by masking the underlying metal hue and achieving better color harmony with the soft tissue.

Ioannidis et al (2016) further validated these observations, showing that gold-anodized abutments outperformed pink-anodized titanium in reducing mucosal discoloration, particularly in thin biotype scenarios.[39] In vitro findings by Farrag et al (2022) and Wadhwani et al (2016) emphasize the critical role of anodization in enhancing peri-implant esthetics through improved abutment color integration. Farrag et al demonstrated that anodized titanium abutments exhibit significantly lower color discrepancies (ΔE values), with higher chroma and warmth (higher L*a*b*and C*lower h*) compared to conventional titanium, particularly beneath thin lithium disilicate ceramic restorations. These improvements are especially beneficial in thin gingival biotypes, where the subgingival abutment color has a significant influence on esthetic outcomes.[20,40,41]

Patient-centered outcomes highlight the esthetic benefits of anodization. Vazouras et al's trial showed higher satisfaction with pink-anodized, or zirconia, abutments compared to gray titanium. After one-year, pink anodized abutments-maintained satisfaction levels comparable to those of zirconia. While anodization improves esthetics, it does not eliminate mismatch, with differences often noticeable (ΔE ~7-8).[5] Anodization adds a warm hue that better mimics natural tissue color, enhancing esthetics in the visible zone. However, the long-term benefits remain unclear due to the limited study periods (3–18 months), necessitating further research on the enduring effectiveness and clinical significance of anodization.

Influence of Abutment Color and Gingival Biotype on Esthetic Outcomes

The esthetic impact of anodized abutments is closely tied to the thickness and quality of the patient's gingiva. Gingival biotype (thin vs thick) plays a pivotal role in how much the abutment color shows through the soft tissue. In cases of a thin biotype (<2 mm of tissue thickness), the choice of abutment color becomes critical for optimal esthetics. Thin, translucent gingiva cannot mask underlying materials, so a gray titanium abutment can impart a dull grayish-blue hue to the tissue. Anodizing the abutment to a pink or gold shade mitigates this effect by providing a warm underlying tone. Clinical trials support this approach: patients with thin gingiva experienced a significant improvement in soft tissue color match when using pink-colored abutments instead of gray. Pink anodized abutments consistently reduce Δa* values, improving the red-green balance and creating a more harmonious integration between the peri-implant mucosa and natural gingiva. By imparting a rose or gingiva-colored tone to the transgingival portion of the abutment, anodization minimizes the grayish show-through of metal underneath thin mucosa. Recent clinical studies confirm that anodized pink abutments can significantly reduce visible color mismatch between implant sites and adjacent natural gingiva.[9,26,35,42]

Different anodization colors (typically pink versus gold or yellow) may be selected based on the clinical scenario, and each has its advantages. Pink anodization is intended to emulate the redness of healthy gingiva, whereas gold (yellowish) anodization offers a warm, neutral background. Interestingly, research by Martínez-Rus et al suggests that gold-anodized titanium abutments can be as effective as or even more effective than pink anodization in certain situations. In a spectrophotometric analysis predominantly involving thin peri-implant tissues, gold-hued anodized abutments produced soft tissue color outcomes nearly equivalent to those of zirconia abutments, and superior to standard gray titanium and pink-anodized titanium. The authors noted that in their thin-biotype cohort, pink-anodized abutments did not perform as well as gold in minimizing color mismatch. In contrast, gold anodization made the gingival color closer to the surrounding natural gingiva. This could be due to differences in how pink vs yellow hues interact with various gingiva skin tones or the thin tissue's optical properties.[34,37–39] Conversely, when the soft tissue biotype is thick (>2 mm), the influence of abutment color on outward gingival appearance is far less pronounced. A thicker connective tissue layer can obscure the abutment's color, leading to similar esthetic outcomes regardless of whether the abutment is gray, pink, or gold. In such cases, the natural tissue mass provides its masking effect, and anodization becomes more of an "insurance policy" against any unexpected transparency.

These findings imply that clinicians should consider the gingival biotype when choosing abutment colors. For patients with thin or scalloped gingiva in the smile zone, opting for a pink or gold anodized abutment (or even a ceramic abutment) is prudent to ensure the implant restoration does not appear dark. Pink anodized abutments have been widely adopted for this purpose, and gold-anodized abutments serve as an alternative that can impart a warm underlying hue. The selection may also be tailored to the individual's gingival pigmentation; for instance, a gold anodized abutment might better support a lighter, yellowish-pink gingival tone, whereas a deeper pink anodization might suit a patient with more vascular or reddish gingiva. Ultimately, both colors have demonstrated the ability to improve esthetic integration compared to silver-gray titanium. The key is that the abutment should not be one-size-fits-all: matching the abutment hue to the clinical context (biotype and tissue color) is essential for achieving the best possible peri-implant esthetics.

Biological Responses and Clinical Outcomes

Beyond aesthetics, anodized titanium abutments demonstrate favorable biological interactions with peri-implant soft tissues. Research indicates that the anodic oxidation process can yield a nanotextured titanium oxide surface that is highly biocompatible, thereby promoting cell adhesion and connective tissue attachment. In a recent trial assessing various abutment surface treatments, anodized abutments tended to develop a denser collagen fiber network at the soft tissue interface compared to machined titanium (smooth) abutments. Anodization significantly influences the biological interactions between peri-implant soft tissues and titanium abutments. Anodized surfaces markedly enhance the adhesion, proliferation, extracellular matrix secretion, and directional growth of gingival fibroblasts. The research conducted by Gulati et al (2020) and the systematic review by Crenn et al (2021) emphasized these benefits, demonstrating that anodized titanium surfaces with anisotropic nanoporous characteristics effectively augment fibroblast activity, thereby potentially offering a more robust biological barrier against microbial infiltration compared to conventional titanium surfaces.[18,43,44]

Clinically, anodization has shown nuanced functional advantages. Hall et al (2018) identified significant biological benefits associated with anodized abutments, notably including a marked reduction in bleeding during abutment removal and an increase in the height of keratinized mucosa for up to two years. Furthermore, Golalipour et al (2025) found that anodization significantly reduced bacterial adhesion without negatively affecting surface roughness, thereby providing indirect support for anodization as a preventive measure against peri-implant diseases.[19,45]

However, alternative clinical studies present a more cautious viewpoint. While assessing mucosal recession, Bittner et al (2020) underscored that those values fluctuated according to gingival biotype and predominantly focused on aesthetic rather than functional clinical outcomes. Their research revealed that, although anodization enhanced visual color matching with natural gingiva, it did not produce significant disparities in peri-implant health parameters such as probing depths, bleeding on probing, or plaque levels, thereby underscoring the critical influence of oral hygiene on peri-implant health. Likewise, Farrag and Khamis (2023), in an 18-month split-mouth study, found no notable clinical differences in probing depths, bleeding scores, plaque levels, or gingival indices between pink-anodized and standard titanium abutments, indicating that anodization does not adversely affect soft tissue health or elicit additional inflammation over time.[8,26]

The current evidence suggests that anodization of titanium abutments has a positive influence on gingival fibroblast and epithelial responses, thereby enhancing biological integration at the peri-implant soft tissue interface without increasing inflammation. Histological evidence reveals robust connective tissue integration, characterized by high collagen density, adjacent to anodized surfaces.[18,27,43,46–49] These biological enhancements do not consistently translate into significant clinical improvements in peri-implant health indicators. Further rigorous, methodologically robust, and long-term clinical studies are needed to clarify the definitive clinical advantages of anodization, ensuring that enhancements in aesthetics and soft-tissue biology do not compromise biological stability but reinforce long-term peri-implant health.

https://doi.org/10.2147/CCIDE.S535430

The risk of bias assessment demonstrated robust internal validity, as most RCTs were conducted in controlled environments, such as university dental hospitals, which minimized variability and enhanced reliability. All studies had a low risk of missing outcome data and selective reporting, ensuring transparency.[8,9,19,26,33–37] However, 30% expressed concerns about randomization due to unclear allocation concealment, 20% due to intervention deviations, and 10% due to limitations in outcome measurement, likely related to blinding issues. Only three studies included a priori sample size calculations, raising concerns about statistical power.[8,19,34] Notably, 70% of the assessments were classified as low risk, while 30% were identified as moderate risk. Importantly, no articles were categorized as high risk, which underscores the methodological robustness of the study. Future research should prioritize rigorous randomization, adequate justification of sample size, and standardized methodologies to enhance clinical outcomes.

Conclusion

This systematic review demonstrates that anodized titanium abutments enhance aesthetic outcomes by improving color harmony with natural gingiva, particularly in patients with thin gingival biotypes. Objective evaluations, such as CIELab spectrophotometry and the Pink Esthetic Score (PES), consistently report reduced color discrepancies (ΔE values) in anodized abutments compared to standard titanium, with pink anodized abutments achieving ΔE values that approach the performance of zirconia abutments. Studies also indicated that patients with thin gingiva showed the most noticeable aesthetic improvement due to reduced grayish show-through. However, the review also revealed that these aesthetic gains did not consistently translate into substantial clinical improvements. Key clinical parameters such as probing depth, plaque index, gingival index, and bleeding on probing showed minimal or statistically insignificant differences between anodized and non-anodized abutments.

The study's limitations include significant heterogeneity across included trials, especially regarding abutment materials, surface treatment protocols, follow-up periods, and assessment methodologies. Differences in spectrophotometric devices, lack of standardized control over soft tissue thickness, and limited long-term follow-up durations further complicate data synthesis and limit generalizability. Only a minority of studies incorporated a priori sample size calculations, raising concerns about statistical power and the estimation of effect sizes.

In summary, anodization of titanium abutments represents a promising strategy to enhance peri-implant soft tissue esthetics, particularly in patients with thin gingival biotypes. Although its impact on clinical tissue health parameters remains unclear, existing evidence suggests that it has no harmful effects. Overall, anodized abutments are a safe option with proven esthetic benefits, while their functional advantages should continue to be explored through future research.

Clinical Implications & Future Directions

Anodized titanium abutments offer clear aesthetic advantages in implant-supported restorations, particularly for patients with thin gingival biotypes where soft tissue translucency poses challenges. Pink and gold anodized abutments help minimize grayish show-through by enhancing color harmony with the surrounding gingiva. This makes them especially suitable for restorations in the anterior maxilla or esthetically demanding zones. In contrast, using gold anodized abutments may be more appropriate in thicker gingival biotypes or posterior regions where mechanical strength and tissue masking are prioritized over precise color blending.

However, the clinical implications must be interpreted cautiously. Although improvements in soft tissue esthetics are well-documented, the review found no significant or consistent differences in clinical parameters, such as plaque accumulation, probing depth, mucosal recession, or bleeding on probing, when comparing anodized to non-anodized abutments. This suggests that while anodization enhances visual outcomes, it may not directly translate to measurable improvements in peri-implant tissue health.

To facilitate the interpretation of this systematic review into clinical practice, particularly regarding the selection of abutments based on gingival biotype, we present a practical decision tree (Figure 5). This diagram is designed to help clinicians make informed decisions between anodized and non-anodized abutments, considering the patient's gingival biotype characteristics and the aesthetic requirements of each case. Specifically, for cases involving thin gingival biotypes, the use of anodized titanium abutments in pink or gold is recommended to minimize the potential transparency of gingival tissues that could compromise aesthetic outcomes. Conversely, for thick gingival biotypes, the selection of

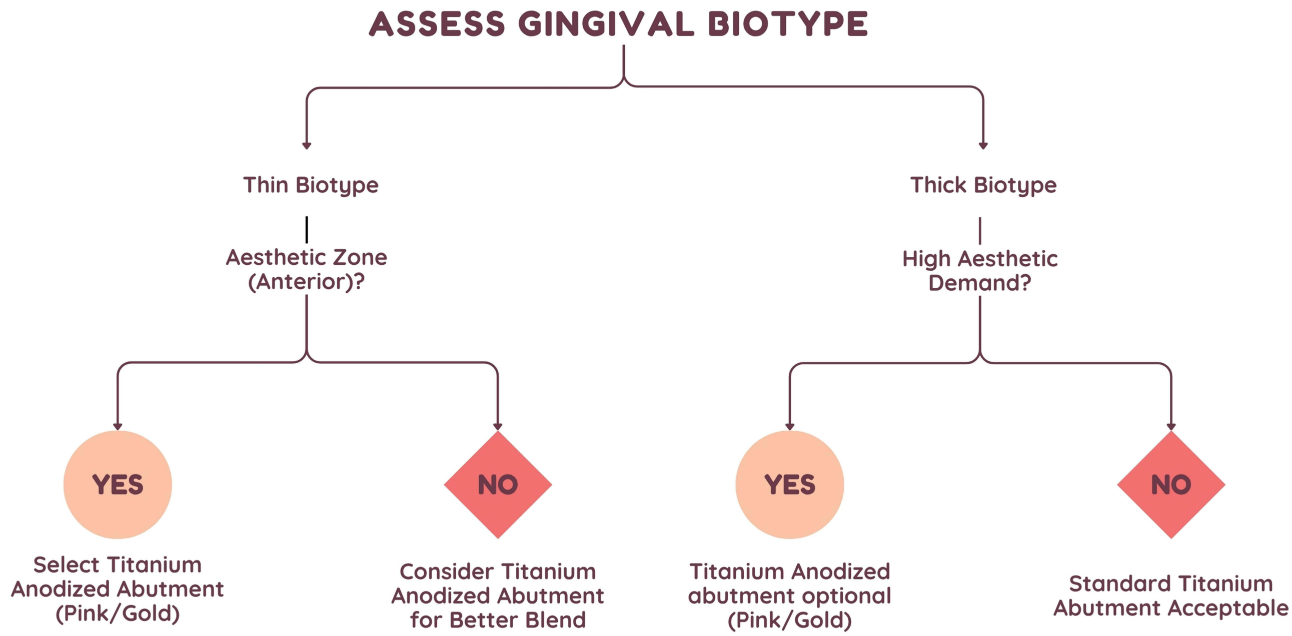

Figure 5 Clinical decision tree for selecting titanium abutments based on gingival biotype and esthetic needs.

anodized or non-anodized abutments offers greater flexibility and can be tailored according to the patient's specific aesthetic requirements.

Anodization can be used in conjunction with adjunctive procedures, such as soft tissue grafting or highly translucent ceramics, to enhance clinical performance and maximize aesthetic outcomes. Additionally, strict oral hygiene protocols and regular maintenance remain crucial in preventing bacterial colonization, regardless of the abutment surface treatment.

Future research should prioritize long-term, randomized controlled trials with standardized methodologies, larger sample sizes, and well-defined patient biotypes. Studies should also aim to control for peri-implant tissue thickness and utilize consistent spectrophotometric tools to evaluate color outcomes. A promising approach involves integrating anodized surfaces with bioactive coatings, such as antimicrobial peptides or hydroxyapatite, to enhance tissue integration and resistance to microbial adhesion. Nanostructured anodization and biologically active surface modifications may represent the next frontier in optimizing the aesthetic and functional longevity of dental implant restorations.

Abbreviation

Ti, Titanium; TiO_2, Titanium dioxide; PES, Pink Esthetic Score; MPES, Modified Pink Esthetic Score; ΔE, Color difference (from CIELab); PI, Plaque Index; mPI, Modified Plaque Index; GI, Gingival Index; mGI, Modified Gingival Index; BoP, Bleeding on Probing; RCT, Randomized Controlled Trial; DBBM, Deproteinized Bovine Bone Mineral; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; CIELab, International Commission on Illumination color space (L*a*b* values); SLM, Selective Laser Melting; nm, Nanometer.

Acknowledgments

The authors gratefully acknowledge the Oral Biomaterials Study Center (*Pusat Studi Oral Biomaterial*), Universitas Padjadjaran, for providing access to scientific literature, interdisciplinary expert consultation, and technical guidance that supported the development and completion of this study.

Funding

This research was supported by the Internal Research Grant of Universitas Padjadjaran (Hibah Riset Internal Unpad) under grant number 2203/UN6.3.1/PT.00/2022, funded through the Doctoral Dissertation Research scheme (Riset Disertasi Doktor Unpad – RDDU).

Disclosure

The authors report no conflicts of interest in this work.

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