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Doctoral Dissertation
Doctoral Program in Bioengineering and Surgical Sciences (38th Cycle)

The rehabilitation of atrophic jaws using short implants with different surface treatment

A multicentred cross-over randomized trial

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I hereby declare that, the contents and organisation of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

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Beatrice Longhi
Turin, October 30, 2025

Summary

Background: The presence of maxillary atrophy can often prevent the use of standard length implants for implant- prosthetic rehabilitation. In these cases, a variety of treatment strategies can be used such as bone implementation techniques or short or extra-short implants. Short implants allow the resolution of cases of edentulism in patients with reduced mandibular and/or maxillary bone level in the posterior sectors and represent an alternative and less invasive approach compared to surgical interventions for bone implementation, also allowing a reduction in treatment times. To improve the biological aspects of the interface between the implant and hard and soft tissues, different implant and prosthetic surface treatments have been proposed, producing contrasting results.
Aim: to evaluate the clinical outcome of short implants with a new design at a macro-structural level in atrophic jaws. also comparing two different surface treatments of the implant collar and transmucosal components.
Materials and Methods: three research centres are involved (Torino, Genova, Foggia). Each centre recruited a minimum number of 10 patients, for a total of 30 patients. Patients who needed to insert at least two short implants (length: 6 mm) contiguous in the posterior sectors of the mandible or maxilla were included. Patients must not present general or local contraindications to the planned surgical and prosthetic intervention and will sign a consent to join the research project. For each patient, the following were recorded: age, sex, smoking habit, cause of tooth loss, presence of parafunctions (clinically assessed on the basis of the presence of wear facets or reported by the patient) and type of antagonist.

Implants will be inserted in healed sites. Definitive transmucosal straight multiunit abutments (MUAs) of height 1 mm, with differentially treated surfaces, were immediately screwed. After 3 months, prosthetic rehabilitation with splinted zirconia crowns screwed to the MUAs was made. Marginal bone levels (MBLs) were evaluated at the time of implant placement (T0), after 3 months (T3), after 6 and 12 months (T6 and T12) through periapical radiographies. Periodontal indexes (probing depth [PD], bleeding on probing [BoP], and plaque index [PlI]) were evaluated at the same time-points, with the maximum follow-up of 12 months

Results: at T3, the mean marginal bone loss was 0.40 ± 0.31 mm in the Test group and 0.42 ± 0.40 mm in the Control group ($p = 0.76$). At T12, these values increased to 0.63 ± 0.41 mm and 0.78 ± 0.43 mm, respectively ($p = 0.94$). Both groups showed physiological probing depths, with mean values ranging from 1.48 mm to 2.10 mm. The Plaque Index (PlI) ranged from 0 to 1 in most cases, while Bleeding on Probing (BoP) was observed sporadically as isolated bleeding spots upon probing, with mean values between 0.20 ± 0.41 and 0.50 ± 0.52. No statistically significant differences were detected between the two groups.

Conclusions: The anodized surface treatment of the implant collar and transmucosal components does not appear to affect marginal bone stability or the condition of periodontal tissues after one year of follow-up. Further long-term studies are required to confirm these findings.

Acknowledgment

I would like to acknowledge Mech&Human S.r.l.(Grisignano di Zocco, Vicenza) as supplier of the implants and the prosthetic components. The biggest acknowledgment goes to my mentor, Prof. Francesco Pera, who carried me by the hand through the three years of my PhD.

To my beloved grandma, Ilde, to my parents and to all the people who supported me through this incredible journey.

Thank you.

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Introduction

1.1 Implant rehabilitations

The history of implantology has a very empirical beginning, with the first clinicians attempting to find solutions for replacing teeth, using devices of varying "creativity." The first attempt of dental implants dates back to the Mayan period, around 600 BC, in Playa de Los Muertos. Shell valves were inserted into mandibular sockets in order to substitute teeth. This is, in fact, the firs example of teeth being replaced with artificial material. In 1978, Dr. Per-Ingvar Brånemark introduced a two-stage, threaded, titanium root-form dental implant system. He developed and tested a design based on pure titanium screws, which he referred to as *fixtures*. These implants were first placed in human patients in 1965 and represented the earliest well-documented and long-term successful dental implants. Brånemark's first patient presented with severe mandibular and chin deformities, congenitally missing teeth, and malocclusion. Four implants were inserted into the mandible, achieving complete integration within six months and remaining functional for the following forty years[1].

Brånemark's discovery was serendipitous. In 1952, while studying blood flow in rabbit femurs, he inserted titanium chambers into the bone and observed that, over time, these chambers became permanently affixed to the surrounding bone tissue[2]. The bone had, in fact, bonded directly to the titanium surface, as any subsequent fracture occurred within the bone itself rather than at the bone–implant interface. This observation was later translated into the field of dentistry, giving rise to the concept of *osseointegration* and paving the way for the inclusion of implantology within dental school curricula.

Brånemark later defined osseointegration as "a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant". The original Brånemark implant was cylindrical in shape, though later designs incorporated a tapered form. Numerous other implant systems were subsequently developed based on Brånemark's foundational work.[3] At the same time, Prof. Schroeder in Bern University (Switzerland) published papers of high scientific relevance describing the osseointegration phenomenon. During the early stages of development, osseointegrated implants were primarily employed in fully edentulous patients to enhance the stability of complete dentures or fixed dental prostheses. Retrospective clinical studies conducted by various research groups reported highly promising outcomes, demonstrating the potential of this innovative treatment approach. Encouraged by these positive results, clinicians gradually expanded the use of osseointegrated implants to partially edentulous patients. The first reports documenting favourable short-term outcomes in such cases began to appear in the late 1980s and early 1990s[4-7].

By the mid-1990s, implant therapy had become an established treatment option for partially edentulous patients presenting with single-tooth gaps, distal extension cases, or larger edentulous spans.[8,9] This clinical indication rapidly gained prominence and has since become the predominant application of implant therapy in contemporary dental practice, particularly in industrialized countries characterized by a high standard of oral healthcare.[10]

Nowadays, dental implants are considered the gold standard treatment for partially and fully edentulous patients. Several factors influence the long term success of dental implants, such as implant characteristics, patient-specific conditions and both surgical and prosthetic techniques.[11-13]

The circumferential anchorage of the implant in bone after completion of bone healing is certainly one of the most important key-factors regarding the surgical aspect.[10] Availability of sufficient bone volume to place the fixture is essential for the success of implant procedures.

1.2 Bone atrophy and bone augmentation

Tooth loss leads to a resorption of the alveolar bone. The physiological changes that occur in the alveolar bone following tooth extraction have been the subject of extensive investigation, particularly in experimental models involving mandibular premolar sites in beagle dogs[14,15]. These studies have provided valuable insight into the biological mechanisms underlying post-extraction bone resorption and remodelling.

The resorptive process begins with the degradation of the bundle bone, a tooth-dependent structure composed of lamellar bone with an average thickness of 0.2–0.4 mm. The initiation of this catabolic phase has been linked to the interruption of the blood supply from the periodontal ligament, which subsequently stimulates significant osteoclastic activity[14,15]. As a direct consequence, the loss of bundle bone results in a vertical reduction of the alveolar ridge height—approximately 2.2 mm on the facial aspect of mandibular premolar sites[14]. In contrast, minimal bone resorption has been observed on the lingual aspect, a discrepancy attributed to the comparatively thinner facial bone plate relative to the lingual or palatal aspects of the socket[14].

Attempts to mitigate these dimensional changes through socket preservation procedures have yielded promising outcomes. Grafting of the extraction socket has been shown to alter the natural remodelling process and to partially counteract the contraction of the marginal ridge typically observed after tooth removal[16]. However, immediate implant placement into a fresh extraction socket does not appear to prevent the physiological remodelling of the socket walls. After a healing period of three months, the residual height of both buccal and lingual walls was found to be similar in sites receiving implants and in naturally healed edentulous ridges. The vertical bone loss remained more pronounced on the buccal aspect, averaging approximately 2.6 mm apical to the sand-blasted and acid-etched implant surface[17].

Experimental evidence also indicates that full preservation of the facial bone wall can be achieved when its initial thickness is at least 2 mm at the time of immediate implant placement[18]. Nevertheless, post-extraction dimensional alterations are influenced by multiple additional factors, including surgical trauma associated with flap elevation, the absence of functional loading on the residual bone walls, and the loss of the periodontal ligament and its associated biological and genetic signalling[19].

In humans, post-extraction dimensional alterations of the alveolar ridge have been well documented. Ridge width reductions of up to 50% have been reported within the first year following tooth loss in premolar and molar sites, with approximately two-thirds of this reduction occurring during the first three months[20]. A systematic review quantified these changes as a loss of 2.6–4.5 mm in ridge width and 0.4–3.9 mm in ridge height after healing[21].

Histological studies based on human biopsies at different post-extraction intervals have elucidated the biological timeline of socket healing[22]. These analyses demonstrated a gradual decline in vascular structures and macrophage density between two and four weeks, a concurrent reduction in osteoclastic activity, and a peak in osteoblastic presence between six and eight weeks, which then stabilized, indicating the transition from resorption to new bone formation.

The degree of post-extraction bone loss is influenced by factors such as facial bone wall thickness, tooth angulation, and anatomical site variation[23]. The thickness of the facial wall is commonly assessed either intraoperatively—1 mm below the alveolar crest[24]—or through cone beam computed tomography (CBCT) at standardized levels[25-27]. In the anterior maxilla, facial bone walls measure less than 1 mm in approximately 90% of cases and less than 0.5 mm in nearly 50%[24-27]. These thin walls, primarily composed of bundle bone, are particularly prone to post-extraction resorption.

A CBCT-based clinical study involving 39 patients demonstrated a progressive resorption pattern in sites with facial bone wall thickness of 1 mm or less, resulting in a median vertical bone loss of 7.5 mm (approximately 62% of the original height) after eight weeks of healing[28]. Conversely, patients with thicker facial walls (>1 mm) exhibited significantly less resorption, with a median loss of only 1.1 mm (9%). In single extraction sites adjacent to healthy dentition, dimensional changes occurred mainly in the central portion of the socket wall, while proximal regions remained largely stable following flapless extraction and eight weeks of healing.[29]

In summary, the dimensional and structural modifications of the alveolar ridge following tooth extraction represent a complex biological process driven by both anatomical and physiological determinants.

It is important to note that, during the 1970s and 1980s, dental implants were predominantly placed in healed jaw sites—areas where tooth extractions had occurred several months or even years earlier. Clinical studies from the 1980s and 1990s demonstrated that osseointegrated implants placed in the absence of a buccal bone wall at the time of insertion exhibited a higher incidence of soft tissue complications and/or a compromised long-term prognosis.[10,30] These studies suggested that implant sites with insufficient bone volume should either be regarded as local contraindications for implant therapy or be subjected to bone augmentation procedures aimed at regenerating the deficient area.

In response to these clinical challenges, several innovative surgical techniques were introduced throughout the 1980s and early 1990s to correct local bone deficiencies within the alveolar ridge. The objective of these approaches was to overcome anatomical limitations that previously restricted implant placement. Published reports described vertical ridge augmentation with autogenous block grafts harvested from the iliac crest in severely atrophied jaws,[31,32] sinus floor elevation procedures in the posterior maxilla,[33,34] lateral ridge augmentation using autogenous onlay grafts,[35,36] and split-crest techniques, including alveolar extension plasty.[37]

Toward the late 1980s, the first experimental investigations involving barrier membranes were published. At the time, these procedures were referred to as Guided Tissue Regeneration (GTR) or the osteopromotion membrane technique.[38] [39,40] Subsequently, the terminology evolved to *Guided Bone Regeneration (GBR)*, which has remained the standard designation ever since.[10]

Building upon these developments, the field of implant dentistry progressively advanced toward the refinement and diversification of bone augmentation techniques. The introduction of new biomaterials and biologically active agents, together with a deeper understanding of bone biology, has led to the establishment of a wide range of regenerative strategies aimed at optimizing the quantity and quality of alveolar bone available for implant placement.

Bone augmentation procedures can be performed either prior to implant placement (two-stage approach) or simultaneously with implant insertion (one-stage approach), employing a range of materials and techniques. When augmentation is carried out before implant placement, an additional surgical intervention is required, followed by a healing period to allow for sufficient bone regeneration before the implant can be inserted.

A wide array of indications, techniques, and biomaterials—often incorporating biologically active agents—are currently available to enhance bone volume. The principal categories of grafting materials include:

Autogenous bone grafts.
Harvested from intraoral or extraoral donor sites within the same patient, autogenous grafts remain the gold standard for bone augmentation[41] due to their superior biocompatibility and osteogenic potential. They provide an optimal scaffold for new bone formation. However, their use entails additional surgery at the donor site, increasing morbidity. Intraoral sources are typically employed for minor defects, while larger graft volumes may be obtained from sites such as the iliac crest. In certain cases, autogenous bone collected during implant site preparation can also be reused via particulate collection systems.

Allografts.
Derived from human donors, allografts are obtained from cadaveric bone and processed through sterilization methods such as freezing or demineralization. They are supplied by certified tissue banks in forms ranging from particulates to solid

blocks. Although resorbable and widely used, concerns persist regarding their complete immunological safety.

Xenografts.

These grafts originate from animal sources, most commonly bovine bone or coral. Through processing, the organic components are completely removed to ensure biocompatibility. While debates have existed concerning the infectious safety of bovine-derived materials, such concerns have largely been addressed [42].

Alloplastic materials.

Synthetic bone substitutes, including calcium phosphates and bioactive glasses, serve as osteoconductive scaffolds facilitating bone ingrowth. They may be used alone or combined with autogenous bone. Depending on their composition, these materials may be fully resorbable, partially resorbable, or non-resorbable.

Barrier membranes for Guided Bone Regeneration (GBR).

This technique employs resorbable or non-resorbable membranes—such as expanded polytetrafluoroethylene, porcine collagen, or polyglactin—to isolate bone defects from soft tissue infiltration. By preventing soft tissue cell migration, the membranes promote undisturbed osteogenesis and facilitate bone regeneration.

Bone morphogenetic proteins (BMPs) and platelet-rich plasma (PRP).

BMPs are naturally occurring proteins that regulate osteogenesis[43]. When incorporated into graft materials, BMPs, along with growth factors and PRP, can significantly enhance bone formation at the defect site.

Several surgical techniques have also been developed to restore bone volume:

Onlay grafting.

Bone grafts are positioned on the surface of the alveolar ridge to increase its height and/or width. The recipient bed is typically perforated to stimulate vascularization, and the graft is stabilized with screws, plates, or occasionally implants[44].

Inlay grafting.

In this method, the alveolar ridge is sectioned, and graft material is interposed between the segments. The Le Fort I osteotomy and interpositional bone graft procedure[45,46]; represent notable applications of this technique.

Ridge expansion.

The alveolar crest is longitudinally split and gradually widened to accommodate implants or graft material. Additional transverse cuts may be performed to control and facilitate expansion.

Distraction osteogenesis.

Originally developed for orthopaedic applications, this technique involves the gradual and controlled mechanical separation of bone segments following a surgical osteotomy[47]. The intervening gap becomes filled with newly formed immature bone, which later matures during a consolidation period. Simultaneous expansion of surrounding soft tissues is an added advantage of this approach.

Each type of graft material can be combined with various surgical approaches, resulting in a broad spectrum of treatment possibilities. Continuous innovation in biomaterials and regenerative agents further enriches the field, though it also introduces complexity in selecting the most appropriate technique. As a result, clinical preference often reflects the surgeon's experience and the perceived success of specific methods or materials.

While numerous surgical and biomaterial-based techniques have been proposed and refined over the past decades, the clinical evidence supporting their comparative efficacy and long-term outcomes remains limited. Several controlled trials have attempted to assess the relative benefits and drawbacks of different augmentation procedures; however, their methodological limitations warrant cautious interpretation of the results. Cochrane's review by Esposito and colleagues from 2009 focused on horizontal and vertical bone augmentation techniques for implant placement. The conclusions they drawn from the available literature must be interpreted with caution, as they are primarily based on a limited number of clinical trials characterized by small or very small sample sizes, relatively short follow-up periods, and, in some cases, a high risk of bias.

Two clinical trials specifically investigated whether vertical augmentation procedures are necessary to enable the placement of longer implants compared with the simpler use of short implants. Vertical augmentation of resorbed mandibles using inlay techniques was associated with a *higher incidence of implant failures (borderline statistical significance), postoperative complications (statistically significant), increased patient discomfort, longer hospitalization, higher costs, and extended overall treatment duration.* Based on the currently available evidence, such invasive procedures cannot be justified solely for the purpose of placing longer implants in resorbed mandibles. Nevertheless, it should be noted that the long-term prognosis of short implants remains insufficiently documented.

Three additional studies examined the relative efficacy of different horizontal bone augmentation techniques.

1. Various augmentation approaches demonstrated the ability to regenerate bone in the horizontal dimension; however, the existing evidence is insufficient to identify a clearly superior technique.
2. Evidence remains inconclusive regarding the potential benefits of biologically active agents, such as platelet-rich plasma (PRP), when used in conjunction with implant therapy.
3. Titanium fixation screws appear to perform more favourably than resorbable poly(D,L-lactide) screws for securing onlay bone blocks, offering superior stability and lower complication rates.

In addition to horizontal ridge augmentation, several investigations have also focused on evaluating vertical bone regeneration procedures. Eight clinical trials have explored the relative efficacy of different techniques for vertical augmentation, providing the following insights:

1. Although various surgical approaches have demonstrated the capacity to increase bone height, the available evidence remains insufficient to determine which specific technique may be considered superior.

2. Bone substitutes, such as deproteinized bovine bone blocks (Bio-Oss), appear to represent a valid and cost-effective alternative to autogenous bone grafts—particularly when compared with grafts harvested from extraoral donor sites—since they are associated with reduced postoperative morbidity.
3. The technique of osteodistraction has been shown to allow for greater vertical bone gain; however, its applicability is limited in cases of severely resorbed or thin alveolar ridges.
4. *Complications were reported with notable frequency across studies and, in some cases, resulted in the complete failure of the augmentation procedure.*
5. Consequently, both clinicians and patients should carefully weigh the potential benefits against the associated risks when considering vertical ridge augmentation, tailoring the therapeutic approach to the specific clinical situation and expected outcomes.[48]

In summary**,** although numerous bone augmentation strategies—both horizontal and vertical—have demonstrated the potential to regenerate alveolar bone, the heterogeneity and limited quality of available studies preclude firm conclusions regarding the superiority of any specific technique or material.

To conclude, such advanced procedures carry serious risks inherent to surgical intervention and severe complications may occur. Besides, bone augmentation techniques requires specific surgical skills and only extremely trained surgeons are to perform them. Furthermore, all these procedures determine a lengthening of the treatment times and an increase in the overall cost of the treatment.[49,50]

1.3 Short Implants

Implants of reduced length have been introduced as an alternative to bone augmentation procedures associated with the placement of standard length implants. Their application has been positively correlated with a reduction in biological complications, overall chair time, and treatment costs, as well as with improved patient-reported outcomes.[51,52] The advantages of short implants can be attributed to their simpler placement procedure, which involves a less invasive surgical approach; to the reduced need for complex bone grafting interventions; and to their suitability in cases where sinus floor elevation surgery is contraindicated due to conditions such as maxillary sinusitis, the presence of maxillary cysts, or other anatomic abnormalities of the sinus cavity.[53] However, due to their reduced length, the surgical preparation of the implant site must be executed with great precision, as it allows minimal room for correction. Additionally, implant-supported restorations in augmented sites often provide superior aesthetic outcomes compared to rehabilitations involving long prosthetic crowns over short implants in atrophic jaws.[54]

The definition of "short implants" has evolved considerably over the past decade, reflecting a gradual trend toward the use of even shorter fixtures. This variability has led to inconsistencies across clinical studies, highlighting the need for standardization to enable meaningful comparison of outcomes. In 2018, Palacios *et al.* proposed defining short implants as those measuring ≤10 mm in length.[55] However, no universally accepted threshold currently exists in the literature, with different authors suggesting limits of ≤6 mm,[56] ≤8 mm,[57] or ≤10 mm.[58] The prevailing contemporary tendency is to categorize implants measuring ≤6 mm as "short" or even "extra-short" implants.[50,59,60]

Recent clinical evidence increasingly supports the use of short and extra-short implants as a reliable alternative to longer implants placed in conjunction with bone augmentation procedures. The umbrella review by Arbildo-Vega et al. (2024) demonstrated that short implants achieve survival and success rates comparable to those of standard-length implants when proper surgical and prosthetic protocols are followed, while offering additional benefits such as reduced biological complications, shorter chair time, and lower treatment costs.[61] Similarly, the meta-analysis by Yu et al. (2021) found no statistically significant differences in implant survival between extra-short implants (≤ 6 mm) and longer implants (≥ 8 mm) with or without bone augmentation at one- and three-year follow-ups. Importantly, the extra-short implant group exhibited fewer biological complications and lower marginal bone loss, indicating reduced morbidity and enhanced clinical efficiency.[62]

Further evidence from the systematic review and meta-analysis by Ravidà et al. (2019) confirmed that short implants (≤ 6 mm) placed in the atrophic posterior maxilla represent a predictable treatment option, showing high survival rates and stable peri-implant bone levels over a three-year period.[63] In line with these findings, Iezzi et al. (2020) compared implants shorter than 7 mm placed in native bone with longer implants inserted in vertically augmented posterior jaws, reporting no significant differences in failure rates between the two groups. Short implants also demonstrated reduced marginal bone loss and fewer postoperative complications, reinforcing their biological and economic advantages.[54] Complementing these short- and medium-term studies, Anitua et al. (2014) provided long-term data on 111 short implants (7.0–8.5 mm) placed in the posterior jaws, followed for an average of more than ten years. The cumulative success rate exceeded 98 %, with minimal marginal bone loss (approximately 1 mm) and no significant influence of implant length, diameter, or crown-to-implant ratio on clinical outcomes. These results offer robust evidence supporting the long-term predictability of short implants under well-controlled clinical conditions.[64] In addition, Sahrmann et al. (2023) conducted a decade-long randomized trial comparing 6 mm and 10 mm implants. Although the survival rate of the 6 mm implants (85.7 %) was lower than that of the 10 mm group (97.1 %), the difference was not statistically significant and marginal bone levels remained stable in both groups, suggesting that with appropriate patient selection and maintenance, ultra-short implants can serve as a viable option when vertical bone is constrained.[65]

Beyond implant length, the platform diameter has been shown to play a decisive role in the mechanical and biological success of short implants. The experimental work by Ivanoff et al. (1997) demonstrated that increasing the implant diameter enhances the bone-to-implant contact area and primary stability, leading to more favourable stress distribution and improved osseointegration compared with narrower implants.[66] This finding provided the biomechanical rationale for the use of wide-platform short implants in clinical practice. Sato et al. (2000) further supported this concept through a finite-element analysis, revealing that wide implant platforms substantially reduced stress concentration at the crestal bone level and improved load distribution in posterior partial edentulism. The authors also showed that an *offset placement* of multiple implants enhances biomechanical performance by dispersing occlusal forces more evenly, thereby reducing overload at the bone–implant interface.[67] Later, the finite-element analysis conducted by Anitua et al. (2010) confirmed that implant diameter has a greater influence on stress distribution than implant length or geometry. The authors concluded that wider implants can more effectively dissipate functional loads and that the combination of reduced length and increased diameter represents a rational and predictable alternative for sites with limited vertical bone height.[68] The retrospective clinical analysis by Anitua et al. (2014) reinforced these biomechanical findings, demonstrating that extra-short implants with wider platforms supporting fixed dentures in posterior jaws achieved excellent long-term outcomes with minimal bone loss and high survival rates.[69]

The concept of a wide-diameter short implant has therefore become a cornerstone of contemporary implant therapy in atrophic posterior jaws. By compensating for reduced length through a broader contact surface and optimized load transfer, wide-platform short implants allow clinicians to achieve high survival rates and excellent prosthetic success while minimizing the need for invasive vertical augmentation. Consequently, modern treatment protocols increasingly combine short or extra-short implants with wider platforms, advanced surface modifications, and digital planning to ensure predictable, minimally invasive, and durable outcomes.

Taken together, these studies consistently demonstrate that short and extra-short implants can achieve clinical outcomes equivalent to those of standard-length implants placed in augmented bone. Their use minimizes the need for invasive grafting procedures, reduces surgical morbidity, treatment duration, and cost, and improves patient satisfaction. Nevertheless, while the short- and long-term data are promising, further prospective studies with standardized methodologies and extended follow-up are necessary to consolidate their role as a standard therapeutic option in the rehabilitation of atrophic jaws.

1.4 Implant surface treatments and coatings

Over the past decades, implant surface engineering has evolved dramatically, moving from machined titanium to grit-blasted, acid-etched, and chemically modified coatings designed to enhance bone-implant contact and secondary stability. This historical evolution, thoroughly described by Abraham (2014), provides the foundation for current research efforts that increasingly focus on the transmucosal region and its critical role in long-term peri-implant tissue health. Early innovations primarily targeted the bone interface, but growing evidence emphasizes that the success of implant therapy also depends on achieving a stable and functional mucosal seal that protects the underlying bone from bacterial infiltration and mechanical stress.[3]

In this context, various studies have explored how nanoscale and physicochemical modifications of titanium surfaces can promote favourable biological responses. Takebe et al. (2014) demonstrated that anodized and hydrothermally treated titanium surfaces enhance epithelial barrier function, suggesting that nano topographic optimization can improve soft-tissue attachment.[70] Similarly, Gulati et al. (2020) showed that anisotropically anodized titanium promoted fibroblast alignment and adhesion, resulting in improved soft-tissue sealing compared with machined surfaces.[71] These findings were later reinforced by Guo et al. (2021), who underlined that while osseointegration remains fundamental, the quality of the peri-implant soft-tissue interface is equally decisive for long-term stability and is profoundly influenced by surface chemistry and topography.[72]

Additional evidence comes from histological and microbiological investigations. Sampatanukul et al. (2018)demonstrated that abutment material and surface characteristics directly influence early inflammatory patterns and the architecture of peri-implant mucosa[73], whereas de Freitas et al. (2021) showed that different abutment materials lead to distinct microbial communities, potentially affecting peri-implant tissue health.[74] Collectively, these studies underscore the importance of engineering the transmucosal surface to favor soft-tissue attachment and to modulate biofilm composition, reducing the risk of peri-implant disease.

Recent experimental research has focused more specifically on anodized surfaces for transgingival components**.** Hadzik et al. (2023) characterized anodized titanium abutment and healing screw surfaces treated at varying voltages, with or without additional plasma modification. Their findings indicated that anodization significantly improved corrosion resistance, while combined anodization and plasma treatment further enhanced fibroblast adhesion and proliferation, suggesting an optimal biological response for soft-tissue integration. [75]Complementary results were obtained by Traver-Méndez et al. (2023)**,** who investigated anodized collar and abutment surfaces and observed enhanced adhesion of keratinocytes and mesenchymal stem cells, along with chemical modifications (notably the incorporation of oxygen, calcium, phosphorus, and sodium) that could foster a more favourable tissue interface.[76]

Taken together, the current body of evidence points toward a paradigm shift: while the optimization of bone-facing implant surfaces has reached maturity, contemporary research is increasingly centred on improving the transmucosal abutment surface to achieve a more stable and functional mucosal seal. Among the available surface modification techniques, anodization stands out as a particularly promising approach due to its ability to alter surface chemistry, nano topography, and biological compatibility in a controlled manner. This growing line of research provides the biological and technological rationale for the present clinical investigation, which aims to assess the clinical performance of anodized abutments in promoting soft-tissue stability and peri-implant health compared with conventional machined surfaces.

Aim of the study

The present clinical study aims to evaluate and compare the peri-implant soft-tissue response to anodized and machined titanium abutments in patients undergoing implant-supported rehabilitation. While surface modifications of the endosseous portion of implants have long been recognized to enhance osseointegration, limited clinical evidence is available regarding the influence of abutment surface characteristics on soft-tissue integration and the stability of the mucosal seal.

Specifically, this study seeks to determine whether anodization of the transmucosal surface promotes improved soft-tissue health, characterized by reduced marginal inflammation, enhanced mucosal stability, and maintenance of peri-implant tissue levels over time, compared with conventional machined abutments. By addressing this gap, the study intends to contribute to the growing body of evidence supporting surface optimization as a key factor in long-term peri-implant tissue preservation and overall implant success.

In addition, the study incorporates a digitally guided approach to implant planning and placement. Pre-surgical evaluation using 3D software is considered essential to achieve optimal implant positioning, even when a flapless guided surgery technique is not employed. The overarching objective is to leverage digital technologies to simplify both surgical and prosthetic protocols while maintaining accuracy and predictability.

Within this framework, the study focuses on two critical aspects of implant rehabilitation:

1. Managing cases with significant vertical bone resorption in a simple and predictable manner.
2. Minimizing patient morbidity through less invasive procedures.

The aim of this randomized clinical trial was to evaluate the performance of short implants (4.3mm in diameter and 6mm in length) with different surface characteristics over time.[77] Particularly comparing implants and transmucosal components with an anodized collar (Test group) to those with a traditionally machined collar (Control group) in terms of marginal bone loss and periodontal indexes.

2.1 Null hypothesis

There are no statistically significant differences in terms of stability, bone resorption and peri-implant indices between implants with anodized collar and transmucosal components and implants with machined collar and transmucosal components.

Materials and Methods

3.1 Type of implant inserted

The INTERCOMPANY ETHICS COMMITTEE of A.O. City of Health and Science of Turin: A.O. Mauriziano Order of Turin: A.S.L. City of Turin, (N°0069632 of 06/06/2023) authorized the research. Recording on ClinicalTrials.gov has been performed, and N°NCT05766878 has been assigned. CONSORT (Consolidated Standards of Reporting Trials) guidelines have been followed in the present trial. The study has been designed as a cross-over randomized trial.

3.2 Patients' recruitment

All patients requiring prosthetic rehabilitation of the posterior maxilla or mandible involving the placement of two adjacent implants were considered for inclusion in the study. The inclusion criteria were as follows: age of 18 years or older; good general health; a minimum of six months elapsed since tooth extraction or loss; insufficient residual ridge height precluding the placement of standard-length implants; and a minimum alveolar ridge width of 7 mm. Exclusion criteria comprised systemic medical conditions contraindicating implant surgery[78]; current or previous antiresorptive therapy; uncontrolled diabetes; pregnancy; and sites that had undergone previous bone regeneration procedures or maxillary sinus augmentation.

The clinical trial was conducted across three academic centres: the University of Genoa (Genoa, Italy), the University of Foggia (Foggia, Italy), and the University of Turin (Turin, Italy).

3.3 Type of implant inserted

Shard Short Implants (Mech&Human S.r.l., Grisignano di Zocco, Vicenza, Italy) have been used, with a platform diameter ranging from 4.3mm to 5 mm and 6mm in lenght.

3.4 Virtual planning

Every surgery was virtually planned in advance using Dtx Software, using which you simulate the insertion of different types of implants, taken from a virtual library, loading the patient's CT Dicom files. This planning served as a model in the surgical phase. (Fig.1)

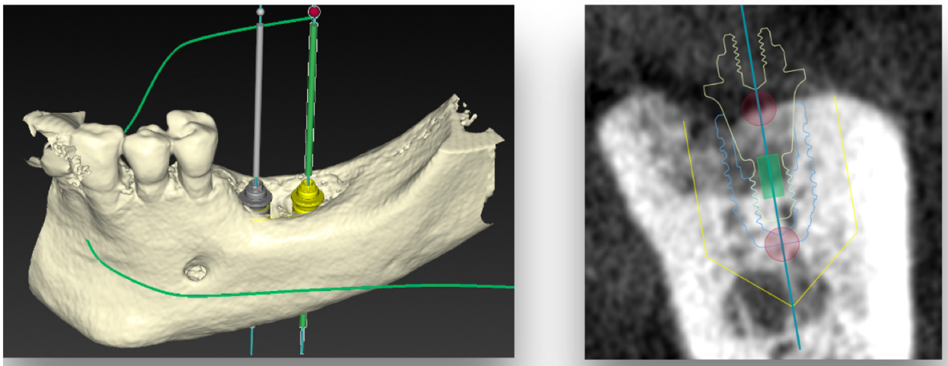


Figure 1: digital implant planning

3.5 Surgical and Prosthetic Protocol

All patients received antibiotic prophylaxis consisting of 2 g of oral amoxicillin administered one hour prior to surgery. Following local anaesthesia, a full-thickness mucoperiosteal flap was elevated.

Implant site preparation was carried out in accordance with the manufacturer’s guidelines. Two adjacent implants, each 6 mm in length and 4.3/5 mm in diameter (Shard Short, Mech&Human, Grisignano di Zocco, Italy), with an average surface roughness of 0.65 µm, were randomly placed within the same quadrant. Both implants featured double acid-etched surfaces, differing only in the surface characteristics of the coronal collar (0.3 mm): the test group implant presented an anodized collar, whereas the control group implant had a conventional machined collar. (Fig.2)

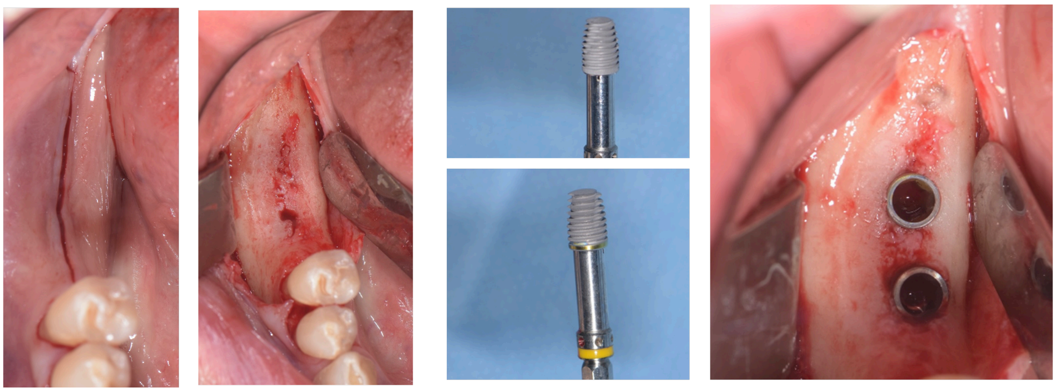


Figure 2: surgical steps

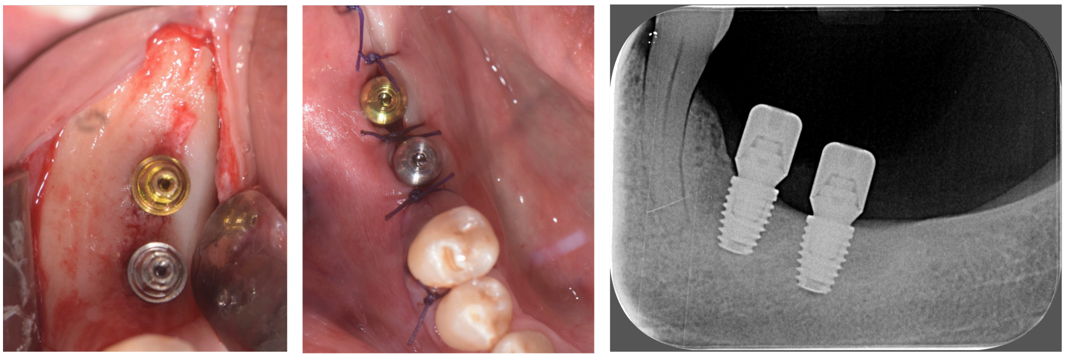


Figure 3: MUAs anodized and machined in place and final x-ray

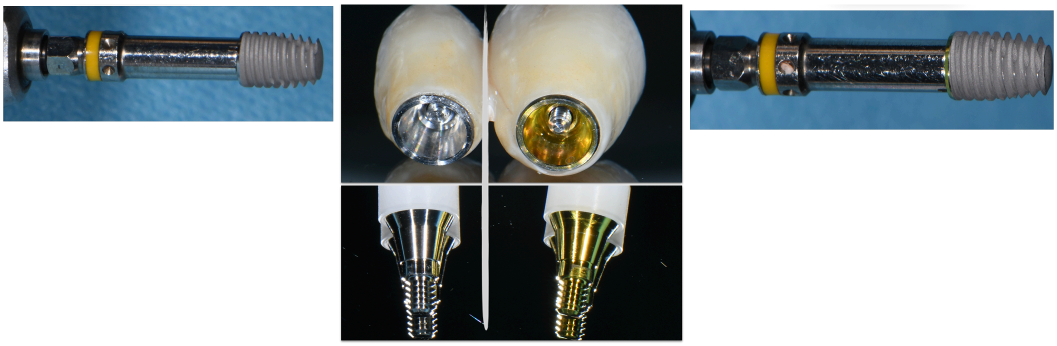


Figure 4: Machined and anodized components

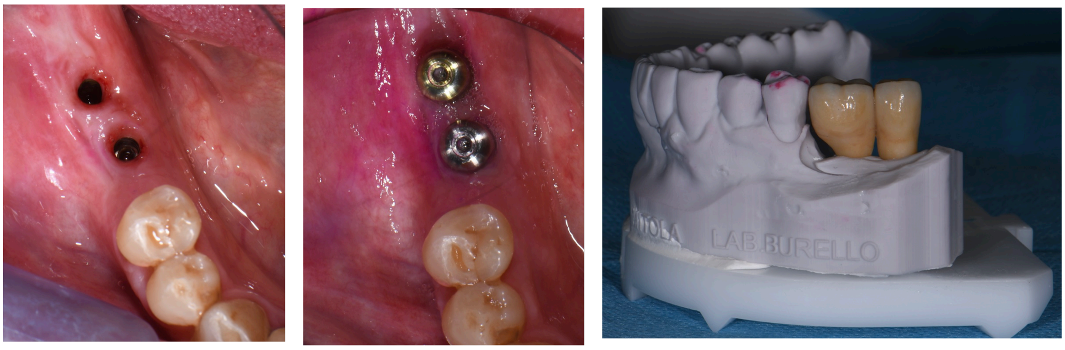


Figure 5: final restoration

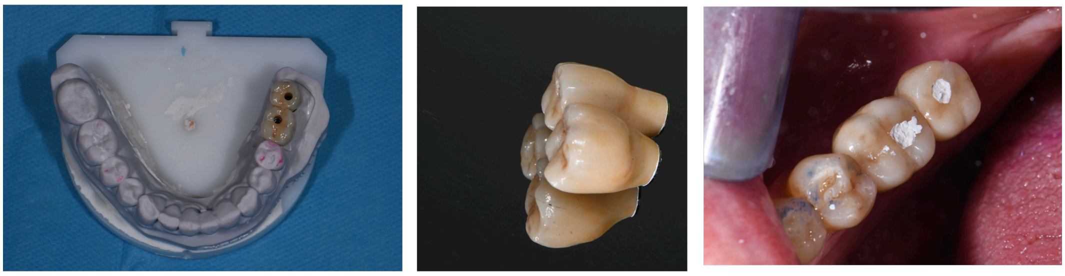


Figure 6: prosthetic phase

Insertion torque (N/cm) and the ISQ values were recorded for each implant during placement. Immediately thereafter, definitive straight transmucosal multi-unit abutments (MUAs) (Mech&Human, Grisignano di Zocco, Italy) with a height of 1 mm were connected according to the *one-abutment one-time* protocol. The test implants received an anodized MUA, while the control implants were fitted with a machined MUA. All abutments were tightened to 25 N/cm as per manufacturer's recommendations. The anodization process for the transmucosal components (implant collars and MUAs) was performed using sodium bicarbonate ($NaHCO_3$) as the electrolyte.

After implant placement, the flap was adapted around the trans-epithelial abutments and secured with a single interrupted suture (Fig.3). Patients were instructed to rinse twice daily with 0.2% chlorhexidine mouthwash and to use analgesics as needed. Sutures were removed 7 days postoperatively, and the surgical sites were allowed to heal in an unsubmerged manner for three months, without the use of temporary prostheses.

After the 3-month healing period, intraoral digital scans were obtained, and the definitive prosthetic rehabilitation was completed with the placement of splinted zirconia screw-retained crowns anchored to the MUAs. Every prosthetic component was either machined or anodized depending on the randomization and the respective implant collar.(Figg.4-5)

3.6 Outcome meausures

3.6.1 Radiographic measurements

Primary outcome of the study was the marginal bone loss over time. To assess marginal bone levels and evaluate peri-implant bone remodelling over time, standardized periapical radiographs were obtained immediately after surgery (baseline) and at 3, 6, and 12 months of follow-up. All radiographs were performed using a Rinn XCP® paralleling device under standardized exposure parameters (0.25 s, 63 kV, 8 mA). Given the anatomical limitations of the edentulous areas, which prevented the fabrication of a reusable silicone bite registration device once the implants were restored with crowns, radiographic standardization relied exclusively on the parallel beam technique to minimize angular distortion between time points.

Radiographic analysis was carried out using ImageJ® (National Institutes of Health, Bethesda, MD, USA), an open-source software widely employed in medical and dental research for linear and area measurements. Calibration was performed using the known implant length as a reference to convert pixel dimensions into millimetres.

The marginal bone level (MBL) was determined by measuring the distance from the implant shoulder to the first visible bone-to-implant contact point, both at the mesial and distal aspects of each implant. Marginal bone loss (MBL change)was then calculated as the difference between baseline and subsequent follow-up measurements (3, 6, and 12 months).

Previous validation studies have confirmed the reliability of ImageJ for radiographic bone measurements. In particular, Peñarrocha-Oltra et al. at the University of Valencia compared ImageJ and Adobe Photoshop® against a high-precision 3D DicomViewer® reference, demonstrating that both tools provide accurate and reproducible measurements of marginal bone loss, with ImageJ showing slightly higher precision (within hundredths of a millimetre). These findings justify its use in the present study as a robust method for quantifying peri-implant bone changes over time.[79-81]

The measurement protocol followed the same principles described by Gheisari et al. (2017) in their comparative study of one-stage and two-stage implant placement. For each radiograph, the implant outline and crestal bone profile were delineated, and the vertical distance between the implant shoulder and the marginal bone level was recorded at both mesial and distal aspects. These values were then compared with the known implant length for calibration, and bone-level changes were assessed by comparing the subsequent radiographs to the baseline (T0) images.

This approach allowed for precise evaluation of marginal bone stability and bone remodelling dynamics throughout the first year of functional loading, ensuring consistency and reproducibility of radiographic data across all time points.

3.6.2 Evaluation of periodontal indexes

Probing Depth (PD):
The probing depth was measured as the linear distance, expressed in millimetres, from the gingival margin to the base of the gingival sulcus or peri-implant pocket. Measurements were performed at six sites per implant using a calibrated periodontal probe to ensure accuracy and reproducibility.

Plaque Index (PlI):
The presence of dental plaque was assessed according to the Silness and Löe Index[82], which scores plaque accumulation on a scale from 0 to 3, where *0* represents the absence of plaque and *3* denotes abundant soft deposits within the gingival sulcus and/or on the prosthetic and marginal surfaces. The PlI

was recorded at four surfaces per implant (mesial, distal, buccal, and palatal/lingual) at each time point. The mean PlI value per implant was subsequently calculated and used for statistical analysis.

Bleeding on Probing (BoP):
Peri-implant bleeding tendency was evaluated using the Revised Papillary Bleeding Index[83], recorded circumferentially around each implant. The score ranges from 0 to 4, where *0* indicates the absence of bleeding and *4* represents spontaneous or profuse bleeding occurring without probing or upon minimal tissue manipulation.

3.7 Sample size and Randomization

The sample size was determined using an online statistical tool (https://app.sampsize.org.uk). The effect size was estimated based on a clinically relevant difference in marginal bone loss (MBL) of 0.25 mm at six months following placement of 6-mm short implants, assuming a population standard deviation of 0.21 mm as reported in previous literature. Considering the cross-over study design, the most conservative assumption was applied by setting the intrasubject correlation coefficient (ρ) to zero, which yields the largest required sample size[84].

Based on these parameters, a minimum of 22 patients (44 implants) was required to detect a statistically significant difference with a two-tailed α level of 1% and a statistical power of 90%. To compensate for possible dropouts estimated at 20%, the final planned sample size was increased to 30 patients (60 implants).

3.8 Statistical analysis

All statistical analyses were conducted by an independent examiner using STATA software, version 16.0 (StataCorp LLC, College Station, TX, USA). Descriptive statistics were presented as absolute and relative frequencies for categorical variables and as means ± standard deviations (SD) for continuous variables.

The distribution of continuous data at each observation time point was verified using the Shapiro–Wilk test to assess normality. Depending on data distribution, comparisons between the Test and Control groups were performed using the Student's *t*-test for normally distributed variables or the two-sample Wilcoxon rank-sum test for non-normally distributed variables. Differences in categorical variables were analysed using the Chi-square (χ^2) test.

To further explore the influence of implant position (maxilla vs. mandible) on marginal bone loss (MBL) across different follow-up intervals, multivariate linear regression models were developed. The level of statistical significance was set at $p < 0.05$ for all tests.

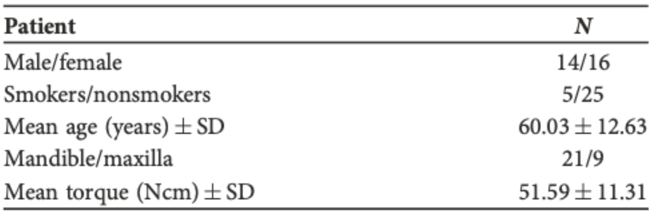
Results

Recruitment and clinical interventions were conducted across three experimental centres: the dental clinics of the University of Genoa (Genoa, Italy), the University of Foggia (Foggia, Italy), and the University of Turin (Turin, Italy). After the inclusion of 30 patients—ten per centre, as determined by the sample size calculation—patient enrolment was concluded.

All enrolled participants successfully completed the full treatment protocol and the scheduled follow-up visits. The age of the patients ranged from 24 to 82 years, with a mean age of 60.03 ± 12.63 years. The sample was balanced by sex, comprising 14 male and 16 female participants.

Each subject received two adjacent implants, resulting in a total of 60 implants placed: 18 in the posterior maxilla and 42 in the posterior mandible. All surgical and prosthetic procedures were completed without intraoperative or postoperative complications, and every implant reached the prosthetic loading phase as planned (Table 1).

Table 1: general characteristics of the sample



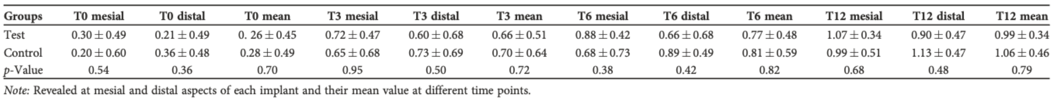
Patient	*N*
Male/female	14/16
Smokers/nonsmokers	5/25
Mean age (years) ± SD	60.03 ± 12.63
Mandible/maxilla	21/9
Mean torque (Ncm) ± SD	51.59 ± 11.31

4.1 Primary outcomes

At T3, all implants demonstrated successful osseointegration, with no biological complications reported or recorded. Following prosthetic rehabilitation, a total of 56 implants remained fully functional throughout the subsequent follow-up periods (T6 and T12). Four implants—two placed in the maxilla and two in the mandible—experienced a prosthetic complication related to the loosening of the abutment screw. This event occurred equally in implants featuring an anodized collar and those with an untreated machined collar. No additional biological or mechanical complications were observed during the entire study period.

Marginal Bone Levels (MBLs) were compared between groups using the two-sample Wilcoxon rank-sum test, revealing no statistically significant differences at any of the examined time points (Table 2).

Table 2: Marginal bone level expressed in millimetres



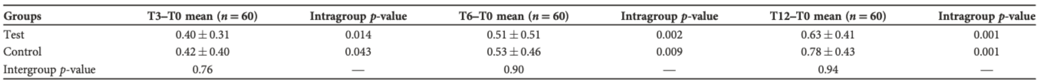
Groups	T0 mesial	T0 distal	T0 mean	T3 mesial	T3 distal	T3 mean	T6 mesial	T6 distal	T6 mean	T12 mesial	T12 distal	T12 mean
Test	0.30 ± 0.49	0.21 ± 0.49	0. 26 ± 0.45	0.72 ± 0.47	0.60 ± 0.68	0.66 ± 0.51	0.88 ± 0.42	0.66 ± 0.68	0.77 ± 0.48	1.07 ± 0.34	0.90 ± 0.47	0.99 ± 0.34
Control	0.20 ± 0.60	0.36 ± 0.48	0.28 ± 0.49	0.65 ± 0.68	0.73 ± 0.69	0.70 ± 0.64	0.68 ± 0.73	0.89 ± 0.49	0.81 ± 0.59	0.99 ± 0.51	1.13 ± 0.47	1.06 ± 0.46
p-Value	0.54	0.36	0.70	0.95	0.50	0.72	0.38	0.42	0.82	0.68	0.48	0.79

Note: Revealed at mesial and distal aspects of each implant and their mean value at different time points.

Between T0 and T3, the mean marginal bone loss (MBL change) was 0.40 ± 0.31 mm in the Test group and 0.42 ± 0.40 mm in the Control group (*p* = 0.76). Bone remodelling continued slightly over time, with MBL values increasing to 0.51 ± 0.51 mm at T6 and 0.63 ± 0.41 mm at T12 in the Test group, and to 0.53 ± 0.46 mm at T6 and 0.78 ± 0.43 mm at T12 in the Control group. The differences between the two groups remained statistically nonsignificant, with *p* = 0.90 and *p* = 0.94 at T6 and T12, respectively.

In contrast, intragroup comparisons revealed statistically significant differences in MBL values at T3**,** T6, and T12 compared to baseline, indicating a gradual but measurable pattern of bone remodelling over time within both the Test and Control groups (Table 3).

Table 3: mean marginal bone loss (mm) around each implant at different time points



Groups	T3–T0 mean ($n = 60$)	Intragroup p-value	T6–T0 mean ($n = 60$)	Intragroup p-value	T12–T0 mean ($n = 60$)	Intragroup p-value
Test	0.40 ± 0.31	0.014	0.51 ± 0.51	0.002	0.63 ± 0.41	0.001
Control	0.42 ± 0.40	0.043	0.53 ± 0.46	0.009	0.78 ± 0.43	0.001
Intergroup p-value	0.76	—	0.90	—	0.94	—

No significant differences in the primary outcomes were observed between implants placed in the maxilla and those in the mandible, at any of the recorded time points (*p* = 0.829 at T3, *p* = 0.747 at T6, *p* = 0.434 at T12).

4.2 Secondary outcomes

Periodontal indices indicated overall healthy peri-implant conditions at all evaluation time points. The Plaque Index (PlI)values generally ranged between 0 and 1, demonstrating low levels of plaque accumulation. At T3, the mean PlI was 0.45 ± 0.44 in the Test group and 0.51 ± 0.42 in the Control group (*p* = 0.54). At T6, mean values were 0.64 ± 0.47 and 0.58 ± 0.51, respectively (*p* = 0.65), while at T12, PlI averaged 0.57 ± 0.47 in the Test group and 0.52 ± 0.50 in the Control group (*p* = 0.78).

Probing Depth (PD) measurements remained within physiological limits throughout the study. Mean PD values for the Test and Control groups were 1.48 ± 0.80 mm and 1.56 ± 0.56 mm at T3 (*p* = 0.49), 1.88 ± 0.83 mm and 2.10 ± 0.78 mm at T6 (*p* = 0.37), and 2.14 ± 0.80 mm and 2.01 ± 0.85 mm at T12, respectively. Only one patient exhibited an increased PD value of 5 mm on multiple implant surfaces.

No cases of spontaneous bleeding or suppuration were recorded during the observation period. Bleeding on Probing (BoP) was observed around 12 implants at T3**,** 13 implants at T6, and 10 implants at T12, presenting as isolated bleeding points upon gentle probing of the gingival margin.

No statistically significant differences were found between the Test and Control groups for any of the evaluated periodontal parameters (Table 4). Similarly, when comparing outcomes between implants placed in the maxilla and mandible, no significant variations were detected (*p* = 0.829 at T3, *p* = 0.747 at T6, *p* = 0.434 at T12).

Discussion

The present clinical investigation aimed to compare the performance of short dental implants featuring two different collar surface treatments—anodized versus traditionally machined collars—with respect to marginal bone loss (MBL) and periodontal health. The split-mouth cross-over design minimized inter-individual variability by allowing each patient to serve as both the Test and Control, thereby controlling for confounding biological factors.

The findings demonstrated that both implant types performed comparably throughout the observation period, showing no statistically significant differences in MBL or peri-implant clinical parameters. Specifically, the Test implants exhibited mean MBL values of 0.40 mm at 3 months, 0.51 mm at 6 months, and 0.63 mm at 12 months, whereas the Control implants presented similar measurements, with differences between groups being nonsignificant ($p = 0.76$; $p = 0.90$; $p = 0.94$). These values are consistent with those reported in previous studies on bone remodelling around dental implants and fall well within the range of physiological bone remodelling typically observed following implant placement and prosthetic loading[85].

Historically, early reports described acceptable marginal bone loss values of 1.5–2.0 mm during the first year of functional loading[86-88]; however, more recent evidence suggests that early crestal bone loss should ideally remain below 0.5–1.0 mm to minimize the long-term risk of peri-implantitis[89,90]. In light of this, the results of the present study can be considered encouraging, although long-term follow-up is required to confirm the stability of these outcomes.

The stability of marginal bone levels is particularly relevant in the context of short implants, where limited bone–implant contact height might theoretically predispose to higher stress concentrations. Nevertheless, current evidence indicates that short implants perform similarly to conventional-length implants in terms of MBL, probing depth (PD), and even survival rate[91,92]. Moreover, in atrophic jaws, short implants have shown comparable clinical success to longer implants placed in augmented bone following sinus floor elevation or vertical ridge augmentation. Multiple long-term studies have reported similar survival, bone stability, and complication rates between these treatment modalities[93].

In particular, the meta-analysis by Ravidà et al.[63] compared clinical and patient-reported outcomes between short (≤ 6 mm) and long (≥ 10 mm) implants, demonstrating lower biological complication rates, reduced MBL, and shorter treatment times for short implants, albeit with a slightly higher incidence of prosthetic complications after three years.

Concerning surface modifications, existing literature suggests that implants with anodized surfaces may present a slightly lower survival rate compared with sandblasted, large-grit, acid-etched (SLA) implants[94]. Nonetheless, marginal bone loss values between these surface types appear similar at short-term evaluation, with some studies showing a mild increase in MBL for anodized implants over longer follow-up periods (up to 5 years). Interestingly, several studies included in that systematic review reported higher MBL values than those observed in the present study, with Åstrand et al.[95] documenting 2.0 mm of bone loss and Eliasson et al. reporting 1.54 mm after one year, whereas other authors found MBL < 1 mm at one-year follow-up[96-98].

In contrast to those studies, the implants in the current trial differed only in the surface treatment of the collar rather than the entire implant body. This distinction is clinically relevant, since modifying the collar alone is intended primarily to reduce bacterial adhesion at the transmucosal level without altering the osseointegration process along the implant surface.

Regarding collar-specific surface modifications, previous research has compared machined**,** rough**,** microthreaded, and laser-microtextured collar designs. Some evidence indicates that machined collars may be associated with greater early bone resorption and higher early failure rates, while microthreading and laser texturing have not shown a consistent benefit in preserving marginal bone[99]. Several animal histologic studies have examined whether the surface characteristics of transmucosal components influence soft-tissue attachment and stability; however, the findings remain inconclusive, as highlighted in the systematic review and meta-analysis by Canullo et al. [100].

Specific data on anodized transmucosal components remain limited. A split-mouth clinical study assessing anodized abutment collars found no statistically significant differences in PD, plaque accumulation, or bleeding compared with non-anodized abutments[101]. In the present investigation, the findings align with those results: no significant differences were detected between groups in Plaque Index (PlI), Probing Depth (PD), or Bleeding on Probing (BoP**)**, and both groups maintained excellent peri-implant soft-tissue health throughout the 12-month follow-up.

It is likely that patient-related factors—including oral hygiene**,** daily habits, and salivary composition—had a more substantial impact on periodontal conditions than the minor physicochemical variations introduced by the anodization process. Given that the recorded PlI values were consistently low, effective plaque control by patients probably contributed to the overall maintenance of healthy peri-implant tissues in both groups. Moreover, anodization with sodium bicarbonate ($NaHCO_3$) may have produced nanotopographical modifications too subtle to elicit a measurable biological or microbiological effect under clinical conditions.

The present study also considered the potential influence of soft-tissue quality, including the width of keratinized mucosa, on peri-implant health. However, since the two implants (Test and Control) were placed adjacent to one another, they shared comparable soft-tissue anatomy, making this parameter non-discriminatory. Consistently, a recent meta-analysis[11] reported that the presence or width of keratinized mucosa exerts minimal influence on PD and MBL, though it may affect plaque accumulation. This suggests that soft-tissue preservation in atrophic jaws remains clinically relevant for facilitating hygiene and long-term maintenance.

Despite the promising results, several limitations should be acknowledged. First, the follow-up period was limited to one year, which restricts the ability to detect potential long-term differences between anodized and machined collars. Longer observation is needed to assess the durability of osseointegration and the risk of late biological or mechanical complications. Second, the study design involved the placement of two adjacent implants per patient. Although a minimum 3 mm inter-implant distance was consistently maintained, proximity and splinted restorations may have influenced stress distribution and peri-implant responses. Finally, the relatively modest sample size limits the generalizability of the results and precludes subgroup analyses (e.g., smoking status, implant site, or bone quality).

Within these limitations, the present findings suggest that short implants with anodized collars perform comparably to those with machined collars in terms of marginal bone stability and peri-implant soft-tissue health after one year of function. Further long-term, multicenter, randomized controlled trials with larger sample sizes are needed to confirm these results and clarify the potential clinical advantages of anodized transmucosal surfaces in implant dentistry.

Conclusion

Within the limitations of the present clinical study, anodization of the implant collar and transmucosal components did not appear to influence marginal bone stability or peri-implant soft-tissue health after one year of functional loading. Both surface configurations—anodized and machined—demonstrated comparable clinical and radiographic performance, supporting the predictability of short implants in posterior sites.

Nevertheless, to substantiate these preliminary findings**,** further investigations with larger patient cohorts, extended follow-up periods, and standardized evaluation protocols are required. Such studies will help to clarify the potential long-term biological and mechanical implications of collar surface modifications in short dental implants and to define their role in optimizing peri-implant tissue preservation.

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