EGAS MONIZ SCHOOL of HEALTH & SCIENCE | INSTITUTO UNIVERSITÁRIO EGAS MONIZ

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MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

DENSIFYING THE FUTURE: A CRITICAL REVIEW OF OSSEODENSIFICATION AND IMPLANT DENTISTRY

Trabalho submetido por

RAFAEL GUIZZO GONZALEZ ORTIZ

para a obtenção do grau de Mestre em Medicina Dentária

Junho de 2025

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Trabalho orientado por

Prof. Doutor Paulo Mascarenhas

e coorientado por

Prof. Doutor Paulo Maurício

Junho de 2025

Dedication

To my family, my unwavering source of love and support throughout this journey.

To my father, Rafael, and my mother, Maria Rita, for teaching me the value of effort, perseverance, and integrity.

To my siblings, Diego and Fernanda, who, with affection and companionship, always gave me the strength to move forward.

To my advisor, Professor Paulo Mascarenhas, and my co-advisor, Professor Paulo Maurício, for their rigorous guidance, intellectual generosity, and example of academic excellence that guided the construction of this work.

And, with special emotion, to my wife Mariana, for believing in me, encouraging me to dream bigger, and walking with me on a new path outside our country.

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I would like to thank the Egas Moniz University Institute for the infrastructure and academic environment that provided the ideal conditions for the development of this research.

To my family, especially my father Rafael, my mother Maria Rita, and my siblings Diego and Fernanda, for their unconditional love, continuous support, and motivation to keep going, even in the most challenging moments.

And, in a very special way, to my wife Mariana, for believing in me, encouraging me to dream bigger and walking with me on a new path outside our country. Your presence, understanding and love were essential for this goal to be achieved.

To all, my sincere thanks.

ABSTRACT

Osseodensification has established itself as an innovative surgical approach in implantology, permitting bone compaction without the removal of tissue and thereby diverging from the principles of conventional subtractive drilling techniques (Huwais & Meyer, 2016). By employing specially designed burs in reverse rotation, the method preserves autogenous bone particles, increases insertion torque and enhances primary implant stability. The technique fosters the formation of new bone and elicits a more efficient biological response—factors that are critical for predictable osseointegration, particularly in anatomically challenging regions such as the posterior maxilla (Cardozo et al., 2018).

Evidence suggests that osseodensification allows the adoption of immediate-loading protocols with greater safety, improves local vascularisation and accelerates healing through the induction of controlled micro-fractures (Macari et al., 2024). Diagnostic tools such as computed tomography facilitate precise surgical planning and thereby reduce operative risks. The technique is further associated with increased peri-implant bone density and a reduced risk of mechanical and biological complications (Lahens et al., 2016).

Notwithstanding these advantages, limitations remain regarding the learning curve, variability in operative parameters and the influence of systemic factors such as smokings and osteoporosis. Standardising the technique therefore continues to represent a significant challenge. Comparative studies report success rates comparable with traditional methods, albeit with demonstrable advantages in initial stability (Stacchi et al., 2022). Nonetheless, uncertainty persists concerning the long-term maintenance of these gains.

In this context, osseodensification stands out as a promising technique in contemporary clinical practice; however, further multicentre and longitudinal investigations are required to achieve definitive validation of its protocols and benefits.

Keywords: Osseodensification, Dental Implants, Bone Densification, Implantology.

GENERAL INDEX

LIST OF ABBREVIATIONS

3D – Three Dimensions (Modelling/Planning)

BAFO – Bone Area Fraction Occupancy

BIC – Bone–Implant Contact

BMP-2 – Bone Morphogenetic Protein-2

CAD/CAM – Computer-Aided Design/Computer-Aided Manufacturing

CBCT – Cone-Beam Computed Tomography

CCW – Counter-Clockwise Rotation

CD - Conventional Drilling

CI – Confidence Interval

CT – Conventional (Subtractive) Drilling Technique

CW – Clockwise Rotation

D1–D4 – Misch Bone-Density Classification

e-PTFE – Expanded-Polytetrafluoroethylene Membrane

FOV – Field Of View (In CBCT)

GBR – Guided Bone Regeneration (≡ ROG)

IDR – Immediate Dento-Alveolar Restoration

ISO – International Organization For Standardization

ISQ – Implant Stability Quotient

IT – Insertion Torque

µCT – Micro-Computed Tomography

OD – Osseodensification

OHIP-14 – Oral Health Impact Profile-14

PCF – Pounds Per Cubic Foot (Density Of Polyurethane Blocks)

PIS – Primary Implant Stability

PRF – Platelet-Rich Fibrin

PRP – Platelet-Rich Plasma

RCT – Randomised Controlled Clinical Trial

RFA – Resonance-Frequency Analysis

ROI – Region Of Interest

ROG – Guided Bone Regeneration (≡ GBR)

rpm – Revolutions Per Minute

SD – Subtractive Drilling

SMI – Structural Model Index

Tb.N – Trabecular Number

Tb.Sp – Trabecular Spacing

Tb.Th – Trabecular Thickness

TCCB – Cone-Beam Computed Tomography

VOI – Volume Of Interest

ZICZ – Zygomatic Implant Critical Zone

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Osseodensification has been gaining ground as an emerging and unique surgical technique for preparing the bone bed for dental implants. Unlike traditional approaches, this method is based on preserving bone structure and controlled densification through specific biomechanical mechanisms. Its application is particularly advantageous in areas where bone density is reduced, such as in the posterior region of the maxilla, contributing to greater implant stability from the moment of insertion (Pai et al., 2018; Ibrahim and Sherif, 2020; Andrade, 2023).

This technique breaks with the subtractive logic of conventional drilling, which involves the removal of tissue during osteotomy. Instead, rotary instruments designed to perform bone compaction by reverse rotation are used, namely Densah drills. By acting on the bone tissue, these drills promote progressive plastic deformation of the trabeculae, favoring compaction in the radial and apical directions. As a result, the autogenous bone material is not removed and remains at the site of the intervention, which favors bone neoformation and enhances the regeneration process (Witek et al., 2019; Oliveira et al., 2018).

Results obtained in different investigations indicate that this approach significantly improves both the initial and subsequent stability of implants, especially in bone types considered challenging, such as D3 and D4 classifications. In these situations, the failure rate of traditional methods tends to be higher. On the other hand, systematic reviews of the literature point to consistent improvements in the density of the surrounding bone tissue and a significant reduction in the time required for healing. These factors converge to achieve faster, more effective, and more reliable osseointegration, giving the procedure greater clinical predictability (Yu et al., 2022a; Yu et al., 2022b; Macari et al., 2024).

OD has also proven to be highly effective in immediate loading protocols, allowing for greater initial stability, shortening the interval until prosthetic rehabilitation and providing greater predictability in situations of severe bone resorption (Macari et al., 2024; Ferreira Amancio & Hipólito da Silva, 2024). As it is a minimally invasive technique aimed at bone conservation, it is of particular interest in complex rehabilitation, as evidenced by recent clinical reports (Andrade, 2023).

In the context of contemporary implantology, osseodensification (OD) is not merely a technical innovation, but rather a true paradigm shift. This approach is aligned with the current principles of modern implantology, which value clinical predictability, tissue preservation, acceleration of healing processes, and integration with digital and guided technologies (Bonfante et al., 2017). In this context, OD has established itself as a therapeutic strategy of choice, especially in patients with challenging bone conditions.

The history of bone drilling techniques in implantology is intrinsically linked to the development of the concept of osseointegration. The first records date back to the 1940s, when Bothe et al. identified the ability of titanium to integrate biologically with bone. Later, in 1951, Leventhal formally classified titanium as a biocompatible material, laying the foundations for its clinical application (Bonfante et al., 2017). However, it was Brånemark's discovery in the 1960s, when he observed the irreversible integration of titanium optical chambers into bone tissue, that gave rise to the modern concept of osseointegration. Subsequently, Albrektsson et al. (1981) systematized the essential criteria that define success in implantology (Lahens et al., 2018).

For several decades, implant bed preparation remained focused on a subtractive model, based on the use of rotary drills that remove bone tissue to create space for the implant. Although effective, this approach has limitations, particularly in situations of low bone density, compromising primary stability and reducing local regenerative potential by removing viable bone particles (Macari et al., 2024).

In order to overcome these limitations, techniques that promote structural bone preservation began to be introduced. A relevant milestone was the transcrestal maxillary sinus elevation technique, described by Summers in 1994, which uses progressive osteotomes to compact the bone and elevate the sinus floor in a minimally invasive manner. This technique is considered a precursor to the philosophy of OD, as it uses bone compaction as a mechanism to reinforce the initial stability of the implant (Rodrigues et al., 2023).

Alongside this development, bone expansion techniques also emerged, such as manual expanders and modified drills, whose aim was to condition the cortical and trabecular bone by controlled compression, avoiding excessive tissue removal. However, these solutions proved to be limited in terms of biomechanical control and clinical predictability (Cardozo et al., 2022).

It was against this backdrop that OD emerged as a new surgical paradigm. Introduced by Huwais in 2013, this additive technique uses multifaceted drills in reverse rotation, promoting bone compaction and redistribution of autogenous particles along the osteotomy walls (Pai et al., 2018; Lopez et al., 2017). This procedure preserves the structural integrity of the bone, increases local density and favors osseointegration.

Comparative studies have shown that osseodensification provides significant clinical advantages, namely greater insertion torque, greater bone-implant contact, and more effective biomechanical performance, especially in areas with low bone density (Lahens et al., 2016; Oliveira et al., 2018). Recent clinical cases reinforce its applicability in complex rehabilitations, such as in the posterior region of the maxilla, where therapeutic predictability remains a significant clinical challenge (Andrade, 2023).

In this context, osseodensification represents a substantial technical advance, in line with contemporary principles of implantology, which favor minimally invasive, evidence-based approaches with regenerative potential. Its incorporation into clinical practice is the result of decades of technical and scientific progress and emerges as an efficient response to the current demands of oral rehabilitation.

Modern implantology has evolved significantly, driven by the continuous search for more predictable, less invasive methods that can be adapted to different clinical realities. In this scenario, OD stands out as an innovation of recognized practical and scientific value, with a direct impact on clinical results and growing validation in the specialized literature.

Recent contributions from authors such as Macari et al. (2024) demonstrate that OD favors superior primary stability, accelerates healing processes, and promotes effective bone compaction during osteotomy. This compaction phenomenon induces a positive biological response, resulting in the formation of a denser and metabolically active bone bed, conducive to osseointegration and the long-term success of dental implants.

Clinical studies, such as that by Bergamo et al. (2022), reinforce this data by reporting higher insertion torque and stability quotient (ISQ) values in implants placed with OD, compared to conventional drilling, in various anatomical locations and implant types.

In addition to initial stability, recent evidence indicates that OD positively influences peri-implant bone microarchitecture. Bittar et al. (2024) documented greater bone volume, increased trabecular thickness and better trabecular interconnection -

essential parameters for long-term clinical success, especially in cases of resorption or low bone density.

Clinically, osseodensification (OD) offers a safe and predictable alternative in complex scenarios, notably in rehabilitating the atrophic posterior maxilla. Its capacity to preserve bone volume and enhance primary stability helps avoid invasive procedures such as grafting (Andrade, 2023). The growing number of systematic reviews and meta-analyses, like that by Gaikwad et al. (2022), underscores OD's increasing scientific relevance. Their findings indicate notable gains in primary stability, bone-implant contact, and bone volume in animal models, supported by robust histomorphometric data.

Given these developments, this review consolidates current technical and scientific knowledge on OD, aiming to elucidate its biomechanical rationale, clinical advantages, and inherent limitations. It also encourages evidence-based practice and further research to refine surgical protocols in contemporary implantology.

The primary objective is to identify OD’s advances and benefits, particularly its role in enhancing implant stability, conserving bone during osteotomy, and promoting favourable osseointegration (Macari et al., 2024; Ibrahim & Sherif, 2020). Benefits include higher insertion torque, increased peri-implant density, improved bone microarchitecture, and reduced healing periods—contributing to greater predictability and success (Bittar et al., 2024; Gaikwad et al., 2022).

Secondary aims involve examining OD’s clinical use across various contexts: posterior maxilla rehabilitation, transcrestal sinus lifts, immediate loading, and low-density bone sites (Andrade, 2023; Bergamo et al., 2022; Ibrahim & Sherif, 2020). Finally, this review addresses reported limitations such as patient-specific bone variability, the need for technical proficiency, lack of protocol standardization, and limited long-term data (Pai et al., 2018; Bonfante et al., 2017).

II. DEVELOPMENT

2. METHODOLOGY

This literature review was developed with the aim of gathering and critically analysing the most relevant scientific literature related to the osseodensification technique in modern implantology. The methodological design followed a structured and rigorous path, organized into the stages described below.

2.1 Sources of information

The literature was collected from leading international databases, namely PubMed, Scopus, Web of Science, ScienceDirect, SciELO, LILACS, DOAJ, and Elsevier. The search covered literature published between 2014 and 2024 to ensure the timeliness and relevance of the evidence compiled in both Portuguese and English, as well as Spanish.

2.2 Search strategy

The search strategy was based on specific descriptors related to the central theme, including: “Osseodensification”, “Dental Implants”, “Bone Densification”, and “Implantology”. These terms were combined using Boolean operators (AND, OR, NOT) to refine the results and optimise the retrieval of relevant studies. An example of a combination used was: (“Osseodensification” AND “Dental Implants”) OR (“Bone Densification” AND “Implantology”).

2.3 Inclusion criteria

This review included primary and secondary studies with an explicit methodological design, such as randomized clinical trials, cohort studies, case-control studies, cross-sectional studies, systematic reviews and meta-analyses. Only articles published in peer-reviewed scientific journals and written in Portuguese, English or Spanish were considered. The selection included studies focusing on osseodensification or techniques associated with preparing the implant bed. Studies conducted on humans or large animal models (excluding rodents) were also considered as long as they analysed relevant variables such as peri-implant bone density, insertion torque, primary and/or secondary stability, success rate, and implant longevity.

2.4 Exclusion criteria

All studies that did not provide the full text or had insufficient data for critical analysis were excluded from this review. Similarly, articles based exclusively on small animal models, specifically rodents, were excluded because they did not accurately reflect human clinical conditions. Also excluded were publications that superficially addressed osseodensification, without methodological articulation, discussion of results, or a direct connection to implantology practice.

2.5 Selection of studies

The selection of studies was carried out in three distinct phases. In the first stage, the titles and abstracts were reviewed to eliminate publications that were clearly outside the scope of the review. This was followed by a comprehensive analysis of potentially eligible texts based on the previously defined inclusion and exclusion criteria. In the final phase, the selected studies were organised, systematised, and subjected to a qualitative critical analysis.

2.6 Methodological foundation

The methodological structure of this review was inspired by models widely used in recent systematic reviews and in academic dissertations recognized in the field (Gaspar et al., 2024; Yu et al., 2022a). In addition, the guidelines of the PRISMA statement were followed in order to guarantee transparency, reproducibility and rigour in the bibliographic selection process.

The systematisation of the evidence gathered aims to provide a solid foundation of knowledge on the advances, applications, and limitations of osseodensification in contemporary implantology, offering methodological and scientific support for the analyses presented in the following chapters.

3. SCIENTIFIC FOUNDATIONS

3.1 Applied Bone Biology

Understanding the principles of bone biology is crucial for comprehending the physiological mechanisms that underpin the osseodensification technique in the context of modern implantology. Bone tissue is characterised as dynamic, metabolically active, and highly specialised, composed of a mineralised extracellular matrix, differentiated cells (osteoblasts, osteocytes, and osteoclasts), and an intricate vascular network that ensures the nutrition, oxygenation, and transport of osteoprogenitor cells (Huwais & Meyer, 2016).

From a morphological point of view, there are two main types of bone: cortical bone, which is compact and responsible for structural strength, and trabecular bone, which is more porous, vascularized and metabolically active, predominantly in regions such as the posterior jaw and the epiphyses of long bones (Pai et al., 2018). Such structural distribution can be visualised in figure 1.

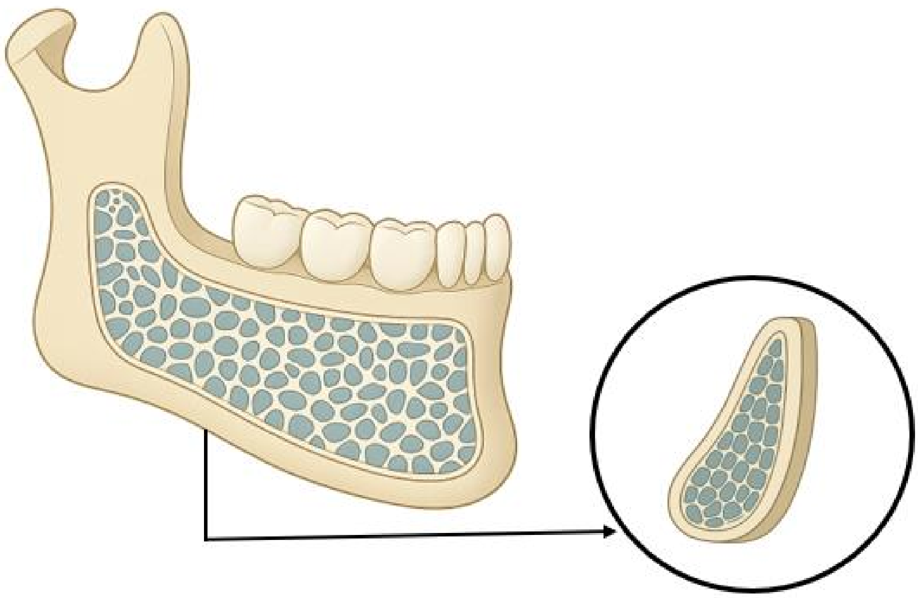

Figure 1 – Schematic representation of the human mandible in the sagittal section, highlighting the internal bone structure. The distinction between the compact, dense cortical bone (outer layer) and the porous, highly vascularised trabecular bone (inner region) is evident. The transverse-section inset enlarges the internal architecture of the posterior alveolar bone, a zone of particular relevance in implantology. In these sites, the osseodensification technique

acts by compacting the trabeculae, thereby promoting osseointegration and increasing the primary stability of implants placed in low-density bone.

Osseodensification, described by Huwais and Meyer (2016), introduces an innovative surgical approach to bone bed preparation, diverging from conventional subtractive techniques. Instead of removing tissue, this technique compacts it laterally against the walls of the osteotomy, redirecting the trabeculae and retaining autogenous bone particles inside the cavity. This process favours the formation of a dense and viable bone matrix, which acts as an osteoconductive and potentially osteoinductive substrate, promoting bone regeneration (Machado et al., 2018; Bonfante et al., 2019).

While conventional drills exert a cutting action, removing tissue and potentially causing thermal necrosis or microfractures, osseodensification drills, such as the Densah Burs, act in reverse rotation (counterclockwise). This movement leverages the viscoelasticity of the bone to compact the trabeculae, rather than destroying them, thereby preserving the structural integrity of the bed (Slete et al., 2018).

From a histological point of view, the application of bone densification promotes a significant reorganization of bone trabeculae, resulting in the formation of a denser and more homogeneous peri-implant zone. Comparative studies reveal a higher proportion of viable bone, less necrotic tissue, and broader contact between the implant surface and the adjacent bone. According to Oliveira et al. (2018), these structural changes favor faster and more effective osseointegration, with positive repercussions on both primary and secondary implant stability. Histomorphometric data obtained in sheep models show that the bone densification technique provides an absolute increase of approximately 15% in the bone-to-implant contact (BIC) rate and 11% in the bone area fraction occupancy (BAFO) when compared to conventional drilling (Lahens, 2016; Oliveira, 2018). These results indicate that trabecular bone compaction significantly increases the extent of bone contact and the volume of new bone formation around the implant. A graphical representation of these gains can be seen in figure 2.

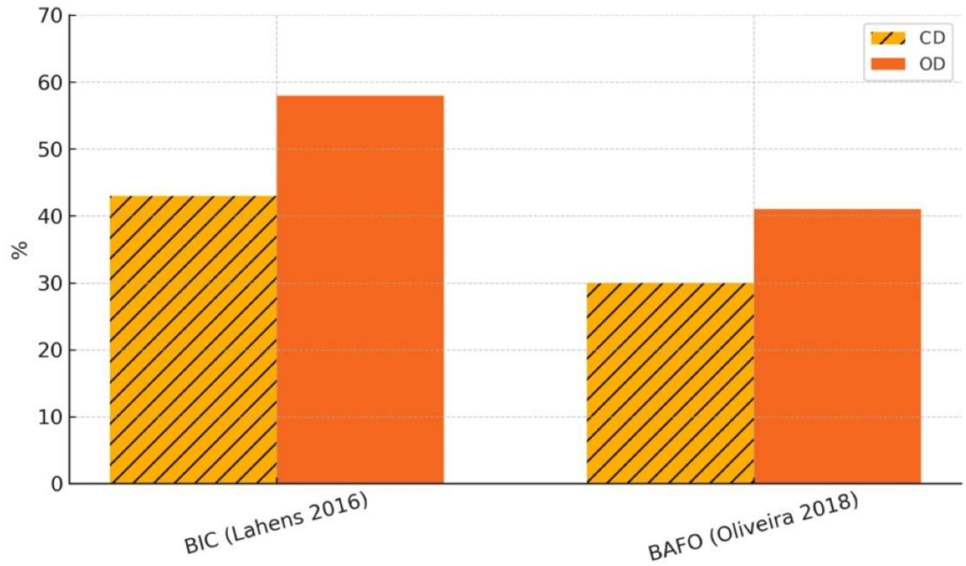

Figure 2. Histomorphometric gains with osseodensification (OD) versus the conventional technique (CT).

The concept of osseointegration, understood as the functional and structural connection between living bone and the implant, depends directly on the bone remodelling cycle, which comprises three phases: resorption, inversion and formation. In the first phase, osteoclasts remove damaged tissue; in the inversion phase, the bed is prepared to receive new cells; finally, osteoblasts deposit a new mineralised matrix. Techniques that preserve cell viability and bone architecture tend to enhance this cycle, promoting more efficient osseointegration (Bonfante et al., 2019; Witek et al., 2019). Figure 3 illustrates the different bone-density types according to the Misch classification.

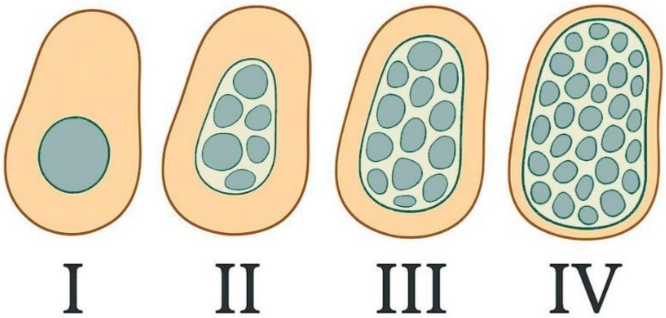

Figure 3 – Schematic representation of the four bone-density types according to the Misch classification.
Type I: predominantly cortical structure
Type II: thick cortex with medium trabeculae
Type III: thin cortex with moderate trabeculae
Type IV: very thin cortex with sparse, widely spaced trabeculae
The osseodensification technique is particularly effective in types III and IV, where low bone density compromises the primary stability that can be achieved with conventional methods.

In this scenario, osseodensification stands out for preserving both the mineralized structure and the cellular components of the bone. The bone debris compacted along the osteotomy acts as a particulate graft in situ, facilitating bone neoformation and increasing the initial stability of the implant (Huwais & Meyer, 2016). This capacity for immediate autografting sets OD apart from conventional approaches, which eliminate potentially regenerative tissue.

In a study using high-resolution micro-computed tomography, Bittar et al. (2024) showed that osteotomies performed with OD provide a significant increase in peri-implant bone volume (32.01 ± 5.75 mm³ with OD vs. 23.17 ± 3.39 mm³ with the conventional technique), as well as greater trabecular thickness, smaller spacing between trabeculae and increased bone interconnectivity. These changes favour the biomechanical distribution of masticatory loads, contributing to long-term stability. These alterations favour the biomechanical distribution of masticatory loads and contribute to long-term stability. These structural differences are illustrated in Figure 4.

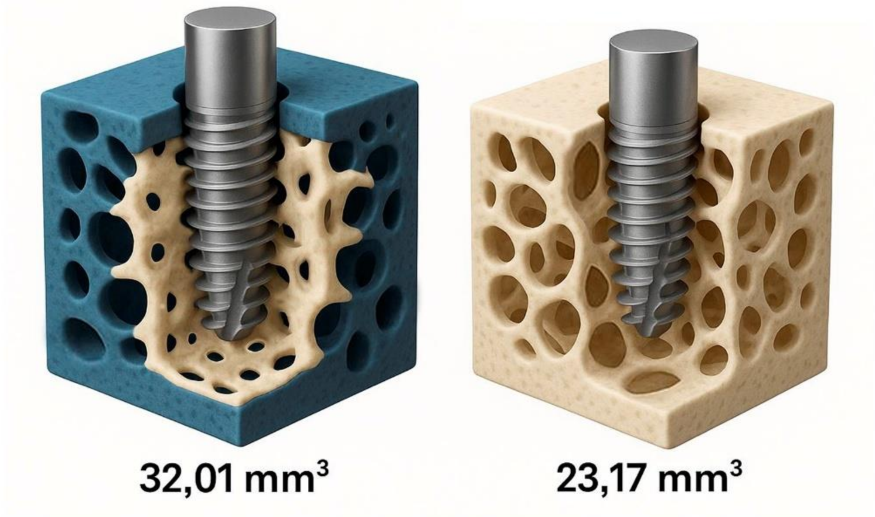

Figure 4 – Three-dimensional comparative representation of peri-implant bone micro-architecture following osseodensification (OD) and the conventional technique (CT). OD reveals a more compact structure, with thicker, closely packed and more numerous trabeculae, associated with a greater bone volume (32.01 mm³). CT shows wider, more widely spaced and irregular trabeculae, reflecting the lower bone density (23.17 mm³) characteristic of type IV bone.

From a clinical point of view, Oliveira et al. (2018) and Torroni et al. (2020) have shown that OD increases insertion torque and resistance to implant removal, even in regions of low bone density. These results are associated with more favourable histological responses, marked by the absence of compression necrosis, preservation of vascularisation, and the early presence of osteoid tissue—indicators of active healing and early osseointegration.

The clinical application of OD has been particularly effective in patients with bone atrophy, especially in the posterior maxilla. The possibility of expanding the bone simultaneously with the osteotomy, without the need for additional grafts, represents a significant advance. On the other hand, greater primary stability favours immediate loading protocols, thereby minimising the risk of micro-movements in the early stages (Tretto et al., 2018).

An additional aspect to consider is the reduction of bone microdamage and the prevention of structural fatigue. Literature based on Frost's model (1964, as cited in Huwais & Meyer, 2016) suggests that preserving trabecular architecture reduces the risk of fatigue fractures, contributing to the longevity of implant-supported rehabilitations. Although more studies are still needed in this area, current data points to a more physiological mechanical response.

Local vascularization also seems to benefit from OD. Controlled compaction reorganizes the bone marrow without obstructing Havers' canals, maintaining nutrition and facilitating angiogenesis. This active microenvironment favours the deposition of osteoid matrix and its subsequent mineralization (Witek et al., 2019).

From a biomechanical point of view, the technique respects Frost's model, according to which bone responds to mechanical stimuli within a “formation window”. By densifying the peri-implant tissue without exceeding the physiological limits of deformation, OD ensures that the induced micromovements remain within the ideal range for osteogenesis. This balance is decisive for successful osseointegration, especially in immediate or early loading protocols (Bonfante et al., 2019).

In summary, osseodensification is a significant advance in the preparation of implant beds. Its biological foundations, combined with the benefits demonstrated in bone architecture, trabecular density, vascularization, and initial stability, result in more efficient, rapid, and predictable osseointegration. Unlike subtractive techniques, which involve the removal of potentially useful tissue, OD preserves and enhances existing biological resources, promoting more physiological integration with the recipient bone.

Its adoption in clinical practice, especially in patients with compromised bone density, reflects a paradigm shift in contemporary implantology. By combining the principles of bone biology with technological innovation, OD is positioned as a minimally invasive, effective solution in line with the principles of regenerative medicine.

3.2. Biomechanical Principles

The biomechanics of dental implants constitute a decisive foundation for clinical predictability in implantology, particularly where the quality of the host bone is compromised. Among the numerous factors that influence the performance of the bone–

implant complex, bone density, the distribution of masticatory loads, insertion torque, and primary stability are pre-eminent. In this context, osseodensification (OD) has emerged as a technical innovation that transforms the management of these parameters by replacing tissue removal—characteristic of conventional techniques (CT)—with controlled bone compaction during osteotomy.

The density of the recipient bone is one of the principal determinants of initial implant anchorage. In regions such as the posterior maxilla—typified by type IV bone with sparse trabeculation and a thin cortical plate—achieving primary stability represents a significant clinical challenge. By compacting trabeculae and preserving autogenous bone debris, OD substantially increases local density, thereby improving the biomechanical environment for implant fixation. Bittar *et al.* (2024) demonstrated that OD yielded a significantly higher insertion torque (CT: 7.67 ± 2.44 N cm; OD: 19.78 ± 5.26 N cm; $p = 0.0005$) together with notable enhancements in peri-implant microarchitecture, including greater bone volume, thicker trabeculae, a higher trabecular count and reduced inter-trabecular separation. Figure 5 illustrates the comparative biomechanical parameters between OD and the conventional technique.

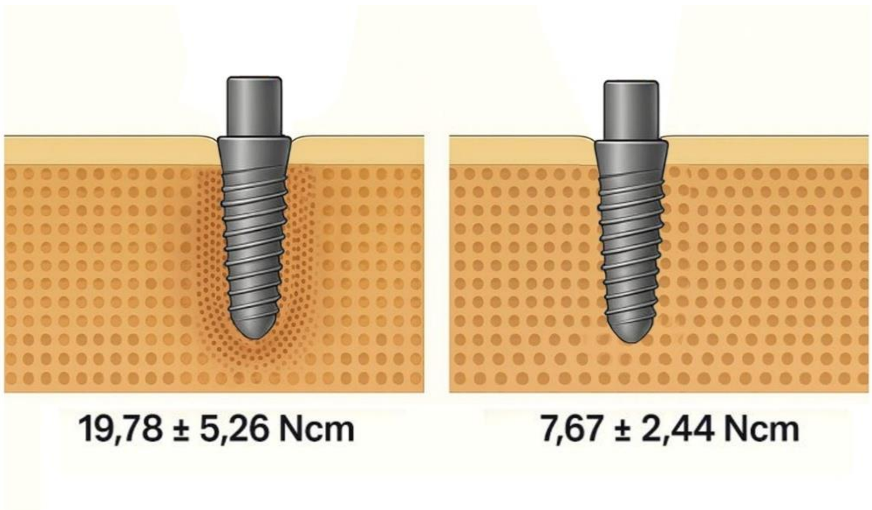

Figure 5 – Biomechanical comparison between osseodensification and the conventional technique. The osseodensification approach demonstrates a higher insertion torque, more compact trabeculae and a densified peri-implant zone, promoting uniform dissipation of masticatory loads and minimising the risk of micro-movements. The conventional technique, by contrast, exhibits a less dense bone structure, increased stress concentration and reduced primary stability.

Beyond merely increasing peri-implant bone density, OD optimises stress distribution at the bone-implant interface. By creating a denser and more structured osteotomy bed, the implant gains a more resilient foundation capable of supporting early functional loads, thereby minimising micromovement and facilitating osseointegration. The preservation of trabecular integrity allows occlusal forces to be dissipated more homogeneously, reducing localised stress peaks that could otherwise precipitate marginal bone resorption or implant failure (Bonfante *et al.*, 2019).

OD also contributes to the formation of a high-strength osseous interface. Huwais and Meyer (2016) reported that the procedure produces a layer of densified bone around the osteotomised site, increasing local mineral density and promoting intimate contact between the implant and host bone. This effect is partly attributable to the *spring-back* phenomenon, in which bone, once compacted, partially recovers its shape through viscoelastic elasticity, resulting in a firmer and more adaptive implant fit.

A systematic analysis by Gaikwad *et al.* (2022) reinforced these observations, showing significant improvements in biomechanical parameters associated with OD. The weighted mean insertion torque was 2.27 N cm higher than with the conventional technique, accompanied by increases in bone-to-implant contact (BIC) and bone area fraction occupancy (BAFO)—both reference histomorphometric indicators of osseous integration.

Clinically, these advantages translate directly into greater predictability, particularly in immediate-loading protocols. Tretto *et al.* (2018) observed that OD drills provide higher insertion torque and less loss of bone density during implant-bed preparation. This combination produces a biomechanically more stable interface capable of resisting early masticatory loads without compromising wound healing.

Moreover, OD is effective for controlled bone expansion and is especially valuable in narrow alveolar ridges. Tian *et al.* (2018), comparing OD with osteotomes, found that OD affords superior bone contact and greater stability without the side effects frequently associated with osteotomes, such as irregular trabecular fractures. This application is particularly beneficial in atrophic zones where bed expansion is required, allowing more invasive grafting techniques to be avoided.

Similarly, Lopez *et al.* (2017), working in spinal orthopaedics, showed that bone compaction induced by OD significantly enhances the anchorage of endosseous devices, increasing extraction strength and effective bone contact. Although conducted in a different context, the biomechanical principles observed are entirely applicable to implantology, where initial implant stability depends on the efficiency of the physical bond with the bone.

OD also affords greater control over bone deformation during osteotomy. Andrade (2023) describes how densifying drills with non-cutting edges generate a compression wave that displaces trabeculae in a controlled manner, raising local density without inducing microcracks, thermal necrosis or excessive compression. This biomechanical control favours primary stability and renders the technique particularly effective in type IV bone.

The influence of operative variables on OD efficacy has likewise been demonstrated. Cardozo *et al.* (2022) demonstrated that drill type and rotational speed significantly impact the outcomes achieved. In their study, Maximus drills operated at 600 rpm promoted greater bone expansion and higher insertion torque in models simulating type IV bone than Neodent drills, underscoring the importance of standardising clinical protocols to ensure biomechanical predictability.

Finally, the synergistic interaction between primary and secondary stability warrants emphasis. Primary stability, mechanical in nature, is achieved at implant placement; secondary stability, biological in nature, arises from new bone formation and remodelling. OD enhances both phases: by reducing initial micro-movement, it establishes optimal conditions for mineralisation while simultaneously stimulating cellular activity and bone remodelling, thereby accelerating osseointegration. The superiority of the stability curve achieved through osseodensification is evident in figure 6.

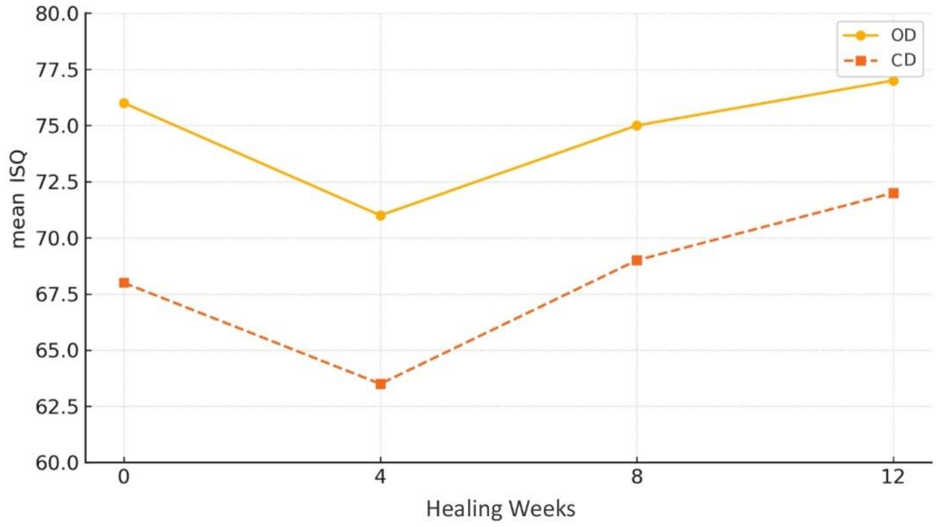

Figure 6. Evolution of implant stability (ISQ) during the healing period. Line chart illustrating the mean implant stability quotient (ISQ) values recorded in the clinical trials of Bergamo et al. (2022; multicentre study, n = 75) and Ibrahim et al. (2020; prospective study, n = 30) for implants placed using osseodensification (OD) and conventional drilling (CT). The OD group begins with an ISQ of approximately 76 ± 3, shows a slight reduction at week 4 (remodelling phase) and recovers to values above 75 by week 12. The CT group starts with an ISQ of about 68 ± 3, reaches a minimum of roughly 64 at week 4 and exceeds 70 only after 12 weeks. OD therefore maintains mean values above the critical stability threshold (ISQ ≥ 70) throughout the entire early-healing period.

Bone-fatigue resistance offers an additional benefit. Bonfante *et al.* (2019) report that densified bone being less prone to microcrack formation under repetitive loading, reduces the risk of structural failure—particularly in immediate-loading cases where initial stability is critical to therapeutic success.

In summary, osseodensification represents a conceptual transformation in the biomechanical approach to implantology. By reorganising and conserving bone rather than removing it, the technique creates a denser, more resilient and functionally efficient bed, promoting not only osseointegration but also the longevity of implant-supported rehabilitation. Gains in bone density, insertion torque, bone-implant contact and extraction resistance are interdependent components of an optimised biomechanical response that contributes to clinical success from the moment the implant is placed.

3.3. Comparison with Traditional Techniques

The evolution of surgical strategies for preparing the bony bed in implantology has, over recent decades, marked an inflexion point in the refinement of clinical protocols. Traditionally, osteotomy is performed using subtractive techniques, in which clockwise-rotating drills progressively remove bone until the desired implant diameter is achieved. Although well-established, this approach presents considerable limitations, particularly in anatomical sites with reduced bone density, such as the posterior maxilla. In this context, osseodensification (OD), as proposed by Huwais and Meyer (2016), has emerged as a biomechanically advantageous alternative by prioritising compaction and preservation of bone tissue during drilling. This non-subtractive method has proved effective in enhancing primary stability, maintaining the structural integrity of the osteotomy, and reinforcing bone-implant contact.

The principal distinction between the techniques lies in their action on the recipient's bone. Conventional drilling (CT), employing aggressively cutting drills in a clockwise direction, removes a substantial portion of the trabecular framework, thereby reducing the peri-implant bone volume and density. Such loss of bone mass compromises initial implant anchorage, especially in type III and IV substrates (Bonfante et al., 2019). By contrast, OD utilises non-cutting-edge drills that rotate anti-clockwise, inducing lateral compression of the bone and realigning trabeculae along the osteotomy. The outcome is the formation of a halo of densified bone around the implant bed, which significantly improves both mechanical and biological support (Huwais & Meyer, 2016). Figure 7 illustrates the comparison between conventional osteotomy (bone removal) and osseodensification osteotomy (lateral compaction of trabecular bone), highlighting the preservation of the bone matrix.

Figure 7. Schematic comparative representation of the two osteotomy techniques. On the left is the conventional drilling (subtractive technique), characterised by the removal of trabecular bone tissue and consequent rarefaction of the peri-implant bone matrix. On the right is the osseodensification osteotomy (additive technique), in which the reverse-rotating bur induces lateral compaction of the bone, preserving the trabeculae and forming a densified halo around the osteotomy site. This approach enhances primary stability and improves the biomechanical and biological conditions for osseointegration.

The scientific literature corroborates the biomechanical superiority of OD. In an ex-vivo study, Bittar et al. (2024) recorded a markedly higher insertion torque with OD (19.78 ± 5.26 N cm) than with conventional drilling (7.67 ± 2.44 N cm). A concomitant increase in peri-implant bone volume was observed (OD: 32.01 ± 5.75 mm^3; CT: 23.17 ± 3.39 mm^3), together with clear histomorphometric improvements—namely greater trabecular thickness, a higher number of trabeculae and reduced trabecular separation. These findings attest to a denser, more stable and functionally competent bone microenvironment.

Similar results were reported by Tretto et al. (2018) in a systematic review comparing traditional drills with OD drills in low-density bone models. OD yielded consistent improvements in primary stability indices—insertion torque, removal resistance and bone-implant contact—thus validating its clinical applicability in scenarios of bone resorption.

The benefits of OD extend beyond dental implantology. In a study by Lopez et al. (2017) involving spinal implants in sheep, greater anchorage strength and improved bone–device contact was observed with OD compared with conventional drilling. Although an orthopaedic model was employed, the biomechanical principles are analogous, reinforcing the utility of bone compaction as a universal strategy for structural reinforcement.

Another differentiating aspect concerns the viscoelastic behaviour of bone and the geometry of the osteotomy. Pai et al. (2018) demonstrated that OD generates a functionally reduced osteotomy owing to the spring-back effect—the bone's capacity partially to recover its volume after compression. This phenomenon promotes a firmer, more adaptive implant fit compared to the broader and less stable cavity resulting from the subtractive technique.

Histologically, OD is also noteworthy. Andrade (2023) reports that the bone deformation induced by OD occurs in a controlled manner via a compression wave that preserves trabecular viability, avoids irregular fractures and maintains the integrity of vascular channels. Such an environment favours osteoconduction and angiogenesis, thereby facilitating more rapid and predictable osseointegration.

From a technical-operative perspective, Cardozo et al. (2022) demonstrated that variables such as drill design and rotational speed influence OD outcomes. In models simulating type IV bone, Maximus drills operated at 600 rpm produced higher insertion torque and greater bone expansion than conventional Neodent drills. This finding indicates that, even within the OD protocol, standardising instruments and operative parameters can optimise results—something difficult to achieve with the inherently destructive subtractive technique.

Complementarily, the review by Gaikwad et al. (2022) showed that OD promoted higher bone-to-implant contact (BIC) and bone area fraction occupancy (BAFO) indices than the conventional technique. The histological and biomechanical gains observed stem from controlled bone compaction, which is absent in subtractive drilling, as it removes potentially viable tissue.

In a comparative study of alternative osteotomy preparations—including piezo-surgery, osteotomes and under-drilling—Yu et al. (2022b) concluded that only OD and under-drilling consistently enhanced primary stability. Among these, OD stood out for the predictability of its outcomes and its capacity to provide effective anchorage even in complex scenarios, such as atrophic maxillae.

Clinically, these differences have tangible implications. OD allows graft omission in cases of mild-to-moderate defects, facilitates earlier loading protocols with greater safety, and improves prognosis in regions of cancellous bone. Additionally, it is associated with reduced operative trauma, accelerated healing and better postoperative acceptance (Andrade, 2023).

Conversely, conventional drilling still has a role in sites with favourable anatomy and adequate bone density, remaining the method of choice in several protocols. Nonetheless, it bears significant drawbacks: greater heat generation, the need for intensive irrigation, lower insertion torque in type IV bone, and a higher likelihood of requiring adjunctive techniques such as grafting or bone expansion. The removal of viable bone may also delay remodelling and compromise osseointegration.

Conceptually, subtractive drilling aims to create a geometric space for implant placement, whereas OD proposes active modulation of the recipient bed, optimising both biomechanical and biological responses. As Bonfante et al. (2019) emphasise, this represents a shift from a passive geometric fit to an active functional linkage based on bone densification.

In summary, osseodensification constitutes a genuine paradigm in contemporary implantology. By combining tissue preservation, structural reinforcement and biological stimulation, the technique proves particularly effective in low-density bone where primary stability is critical. The robustness of current evidence points to the progressive consolidation of OD as the preferred technique in challenging clinical contexts, offering a more consistent biomechanical and histological response than traditional subtractive methods.

4. TECHNOLOGICAL ADVANCES AND PROCEDURES

4.1 Innovative Instruments

Osseodensification has established itself as one of the most impactful technological advances in contemporary implant practice, not merely for reconfiguring the classical principles of osteotomy preparation but, above all, for introducing dedicated surgical instruments that have set a new paradigm for primary stability and osteointegration. Among these innovations, the Densah® burs (Versah®), developed by Salah Huwais, are notable, having been designed to compact and preserve bone during osteotomy, thereby challenging the subtractive logic of conventional drills (Andrade, 2023).

The drills used in osseodensification have a multifaceted design, with blunt cutting edges and concave geometry, which allows for lateral and centrifugal displacement of trabecular bone. This configuration promotes controlled viscoelastic deformation and radial compaction of the tissue, without bone removal. Counterclockwise rotation at low controlled speeds (between 800 and 1,200 rpm) generates a compression wave that reorganizes the bone microarchitecture and improves the biomechanical properties of the implant bed. As a result, there is an increase in peri-implant bone density and insertion torque, factors that play a key role in achieving primary stability (Bittar et al., 2024; Andrade, 2023).

Laboratory and pre-clinical studies have validated the efficacy of Densah burs in preparing implant sites in low-density bone (types III and IV). Bittar et al. (2024) observed that, when compared with conventional drilling, osseodensification burs significantly increased the insertion torque (19.78 ± 5.26 N·cm versus 7.67 ± 2.44 N·cm) and promoted higher trabecular density, an increased number of trabeculae and reduced inter-trabecular spacing. Despite these favourable structural alterations, no significant differences were recorded in the implant stability quotient (ISQ), demonstrating that the technique enhances mechanical support without compromising functional integrity.

Additionally, Cardozo et al. (2018) compared different drilling systems—Maximus and Neodent—used in conjunction with the osseodensification technique. Maximus burs, operated at 600 rpm in a counter-clockwise direction, exhibited superior performance in insertion torque and bone expansion in models simulating type IV bone, surpassing the results obtained with Neodent burs. These data reinforce that biomechanical performance depends not exclusively on the technique but also on bur design and the operative parameters employed.

The applicability of osseodensification is not limited to dental implantology. López et al. (2017) demonstrated the technique's efficacy in the orthopaedic fixation of metallic devices in ovine cervical vertebrae, where an increase in pull-out strength and percentage bone-implant contact (%BIC) was recorded. These findings underline the potential of bone compaction as a biomechanical strategy in diverse clinical contexts.

Within the field of implant materials, the synergy between osseodensification and grade IV titanium or Ti6Al4V alloys has been investigated. Lahens et al. (2018) evaluated the impact of the technique on implants with machined and sand-blasted/acid-etched surfaces, concluding that, regardless of topography, OD increased bone-implant contact and the percentage of the newly formed bone area (%BAFO) without prejudice to initial stability. The presence of densified bone surrounding the implant thus appears to enhance osteointegration, even in scenarios with compromised bone density.

An additional relevant mechanism involves the formation of bone healing chambers induced by bone compaction, which occurs without significant removal of autogenous particles. Mello-Machado et al. (2021) demonstrated that these chambers favour the deposition of immature osteoid matrix and allow the placement of wider-diameter implants, accelerating regeneration and reinforcing secondary stability.

Corroborating these data, Gaikwad et al. (2022) demonstrated significant improvements in insertion torque and peri-implant bone occupancy indices in a meta-analysis involving animal models, suggesting that drilling with Densah burs can expedite and optimise the osteointegration process with sustainable long-term gains.

The clinical versatility of OD has been explored in various situations, including immediate post-extraction placement, rehabilitation of maxillae with moderate horizontal atrophy, transcrestal sinus floor elevation, and immediate-loading protocols. In these contexts, trabecular bone compaction enables the attainment of ideal insertion torque values without the need for grafts or invasive approaches, broadening the indications of the technique in daily practice.

Despite the demonstrated benefits, the safe use of OD requires rigorous technical mastery. The correct drilling sequence, axial force control, and rotational management are essential to avoid microfractures, overcompression, or implant misalignment.

Accordingly, specific training involving simulations, synthetic models and supervised clinical practice is recommended to ensure effective learning and safe application of the technique.

It is equally necessary to consider the limitations of OD. In patients with a thick cortical plate (type I bone), compaction may generate excessive resistance to insertion, compromising vascular perfusion and increasing the risk of overload. Conversely, in extremely porous or very thin bone, the scarcity of trabeculae may diminish the densifying effect, necessitating a combination with other approaches, such as guided bone regeneration or implants with expansive macro-geometry.

Finally, Macari et al. (2024) emphasise that, despite the promising results, the clinical benefits attributed to OD—such as reduced healing time, improved peri-implant bone quality and the feasibility of immediate loading—still require robust validation through randomised clinical trials with prolonged follow-up. Most evidence derives from pre-clinical studies, in vitro trials or clinical case series without control groups, which limits the extrapolation of the results to general practice.

In summary, the instruments associated with osseodensification, particularly the Densah burs, represent a significant advance in bone preparation for implant placement. The combination of technological innovation, biomechanical enhancement and versatile clinical application positions this approach as one of the most promising in contemporary implantology, especially in patients with severe atrophy or compromised bone quality.

4.2. Clinical Protocol

Osseodensification, as an innovative technique for preparing the bone bed in implantology, requires a careful reassessment of established clinical protocols. Unlike traditional subtractive drilling, which aims to remove tissue to allow implant insertion, osseodensification values the compaction and preservation of native bone, promoting controlled plastic deformation and three-dimensional reorganization of the trabeculae. This approach requires the clinician to master specific maneuvers, use appropriate instrumentation, and adapt the operating parameters to the patient's bone density, anatomical morphology, and treatment plan.

The protocol begins with a thorough assessment of bone density, based on the Misch scale (D1–D4) or Hounsfield unit values obtained by cone beam computed tomography. This analysis guides the choice of drills, the drilling sequence, the rotations, and the axial force to be applied. The procedure usually begins with a conventional pilot drill to define the axis and depth of the implant, followed by the introduction of densifying drills in reverse rotation, under continuous irrigation, with progressive diameter until the desired osteotomy caliber is reached. The ideal insertion torque range for each bone density class (D1 to D4) is illustrated in Figure 8.

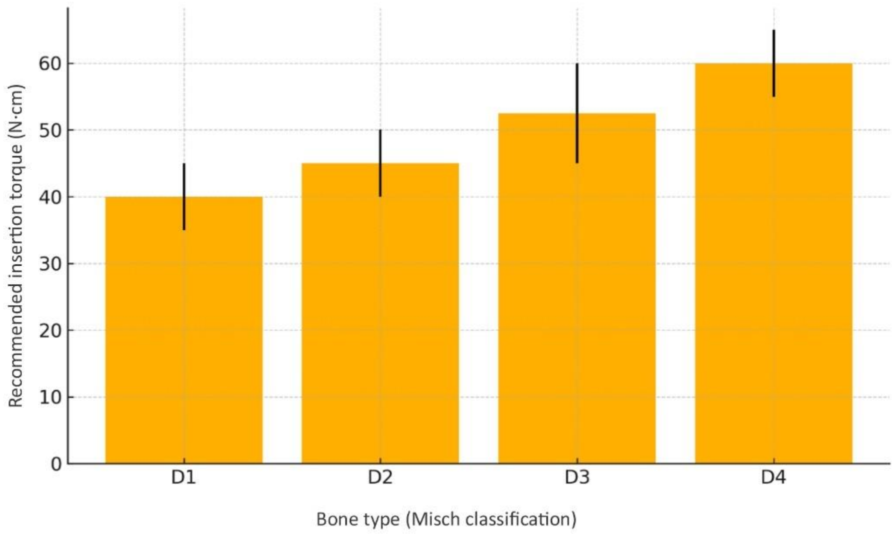

Figure 8. Recommended torque range for bone densification as a function of bone density (Misch classification). The bar chart shows, for each bone type (D1 to D4), the average recommended insertion torque value (bar) and the range of variation allowed (vertical error line), based on clinical consensus (Versah®, Maximus®) and data from Bergamo et al. (2022), Ibrahim et al. (2020), Cardozo et al. (2022), and Macari et al. (2024). An upward trend is observed: torque values increase as bone density decreases. D1 bone has an average torque of about 40 N·cm, while D4 bone approaches 60 N·cm, with greater permissible variation, reflecting the need for greater compaction in low-density substrates.

In the clinical case described by Andrade (2023), bone densification was performed according to the Maximus protocol for posterior maxillary rehabilitation. Drilling began with Maximus drills at 800 rpm in reverse rotation, followed by densification at 400 rpm in the same direction. This strategy allowed for efficient compaction of type IV bone, characterized by low trabecular density, ensuring high primary stability. The residual space was filled with particulate biomaterial, reinforcing three-dimensional support and stimulating bone regeneration. This case highlights the importance of adjusting the protocol to the local anatomy, even when following the manufacturer's guidelines.

In posterior maxillary regions, where the presence of cancellous bone and sinus pneumatization limit the available bone height, osseodensification can be incorporated into minimally invasive sinus-elevation protocols. Baron and Venkatraman (2017) described a transcrestal technique using Densah burs in which, after drilling to 1 mm short of the sinus membrane with a pilot drill, subsequent 2 mm and 3 mm burs are employed in reverse rotation to fracture the sinus floor in a controlled fashion and to elevate the membrane by injecting a paste-like biomaterial, thereby enabling immediate implant placement without perforating the membrane.

The combination of osseodensification with minimally invasive transcrestal sinus-elevation techniques has proven effective in cases with a residual bone height of 4 mm to 6 mm. Baron and Venkatraman (2017) described a transcrestal approach whereby the osteotomy is carried out to approximately 1 mm from the sinus membrane with a pilot drill, followed by a sequence of Densah® burs in reverse rotation to effect controlled fracture of the sinus floor and elevation of the membrane without perforation. This method not only densifies the local bone but also permits immediate implant insertion with adequate primary stability.

Complementarily, Elsaid et al. (2022) reported a clinical case series in which OD was applied together with transcrestal sinus elevation, followed by simultaneous implant placement. All patients, each with a residual bone height of less than 6 mm, achieved complete clinical success and a mean vertical gain of 3.5 mm. These data reinforce the efficacy of the combined technique in atrophic posterior sectors, particularly when the aim is to avoid more invasive lateral approaches.

The benefits observed include not only an increase in peri-implant bone density and insertion torque (Bittar et al., 2024) but also a more favourable histological response, with reduced tissue trauma and the potential for accelerated osteointegration (Gaikwad et al., 2022). These results support the integration of OD with transcrestal strategies as a viable biomechanical solution in cases of moderate vertical resorption of the posterior maxilla.

The geometry of the burs and the operative parameters employed directly influence clinical outcomes. Cardozo et al. (2022) compared Maximus and Neodent burs in blocks simulating type IV bone. They found that, when operated at 600 rpm in clockwise rotation, Maximus burs produced higher insertion torque and greater bone expansion. This finding highlights the importance of calibrating the protocol according to the drilling system and the manufacturer's recommendations.

In a comparative study, Bittar et al. (2024) analysed two groups—one subjected to conventional subtractive drilling and the other to osseodensification with Versah burs operated in reverse rotation under continuous irrigation. The OD group exhibited greater peri-implant bone density, higher insertion torque and clear micro-architectural improvements, validating the technique's efficacy, particularly in low-density bone such as type IV.

The clinical effectiveness of osseodensification was likewise confirmed in the case series by Elsaid et al. (2022), in which a standardised protocol of transcrestal sinus elevation with simultaneous implant placement was employed. In patients with residual bone height between 4 mm and 6 mm, drilling with Densah burs to 1 mm from the membrane, followed by biomaterial injection and implant placement, resulted in 100% clinical success, an average bone height gain of 3.5 mm, and satisfactory initial stability.

Consistent results were reported by Mello-Machado et al. (2021) in a double-blind, randomised clinical trial that compared OD with the traditional undersized drilling technique. The authors noted that the OD group achieved higher insertion-torque values, the development of healing chambers conducive to bone formation by intramembranous osteogenesis, and greater initial stability without an increase in post-operative complications. These findings reinforce the technique's efficacy from both biomechanical and biological perspectives.

According to Macari et al. (2024), the OD protocol should be considered flexible and adjustable to the individual characteristics of each clinical case. In situations such as bone resorption, severe atrophy or immediate-loading implants, OD is advantageous because it increases local bone density and often obviates the need for additional reconstructive procedures. Ideally, its implementation should be preceded by precise digital planning, employing three-dimensional simulations, customised guides and computer-assisted navigation.

During the execution of the technique, rigorous control of the rotational speed—generally between 800 and 1,200 rpm—and the axial force applied is essential. Movements should be progressive and well irrigated to avoid thermal necrosis. The tactile perception of resistance to compaction, which differs from the sensation experienced with conventional cutting drills, constitutes a useful intra-operative indicator. For this reason, prior training with synthetic models and direct clinical supervision is recommended.

Table 1 shows the technical parameters usually recommended for each bone type, based on the widely used clinical classification of bone density (D1 to D4). Included are the initial pilot drills, the suggested densification sequence, the corresponding rotational speeds, the expected insertion torques, and clinical observations relevant to surgical practice.

Table 1 – Clinical parameters for osseodensification according to Misch bone type

Misch bone type	Typical cortical/ trabecular aspect	Pilot drill ø (mm)	Osseodensifying bur sequence*	Densification speed (rpm, counterclockwise)	Target insertion torque (n·cm)	Axial pressure & irrigation / clinical remarks
D1 (dense cortical) anterior mandible	Cortical ≥ 2 mm, scant medullary bone	2.0	2.5 → 3.0 (optional) - avoid oversizing	600 – 800	35 – 45	Light pressure: abundant irrigation prefer minimal under-preparation; risk of overcompression/ thermal necrosis.
D2 (thick cortical, medium trabeculae)	Cortical 1–2 mm	2.0	2.5 → 3.5	800 – 1,000	40 – 50	Light to moderate pressure; “pumping” 2 s/2 s constant flushing; pause every 3 mm to dissipate heat.
D3 (thin cortical, moderate trabeculae)	Cortical ≤ 1 mm	1.8	2.0 → 3.0 → 4.0	1,000 – 1,300	45 – 60	Moderate pressure, pumping 3 s/2 s allows ridge expansion of 1–2 mm without microfractures; ideal for posterior maxilla.
D4 (thin cortical, sparse trabeculae)	Cortical < 0.5 mm	1.8	2.0 → 2.8 → 3.8 (implant Ø 4.2)	1,300 – 1,500	55 – 65	Firm, controlled pressure; dual-pass recommended use prolonged reverse rotation (4 s) to maximise compaction; facilitates immediate loading.

Note. Details, for each Misch bone density category (D1–D4), the recommended pilot drill, the progression of diameters, the reverse rotational speed, the target insertion torque and ideal axial pressure during osseodensification, as well as specific clinical alerts. It is evident that less dense bones (D3–D4) require higher rotational speeds (≈ 1 000–1 500 rpm), a more extended compaction sequence and permit insertion torques in the range of 55–65 N·cm, whereas in D1 bone minimal under-preparation and moderate torque (35–45 N·cm) are advised to avoid thermal and mechanical overcompression.

Customisation of the osseodensification protocol also extends to the selection of implant type, which is particularly pertinent in situations with low bone density. In such cases, the use of implants with a more aggressive macro-geometry combined with treated surfaces helps to optimise primary stability and favour early osseointegration (Bittar et al., 2024; Gaikwad et al., 2022). This strategy often permits immediate placement and, in favourable clinical conditions, the adoption of early functional-loading protocols, thereby reducing overall treatment time (Andrade, 2023; Macari et al., 2024).

OD is likewise compatible with guided bone regeneration (GBR) techniques, mainly when used with resorbable membranes and osteoconductive biomaterials. In post-extraction sockets or regions compromised by fenestrations or partial bone defects, the technique can be combined with particulate grafts or ceramic bone substitutes, promoting volumetric maintenance of the alveolar crest and integrity of the implant site (Elsaid et al., 2022; Andrade, 2023).

In summary, the clinical protocol of osseodensification is marked by its high versatility, predictable outcomes and adaptability to diverse anatomical and therapeutic scenarios. Its effective application requires mastery of the underlying biomechanical principles, refined operative competence and meticulous pre-operative assessment. The ongoing evolution of densifying burs, together with advances in digital tools such as 3-D planning, guided navigation and customised guides, consolidates osseodensification as one of the most promising surgical strategies in modern implantology—particularly in cases where bone preservation constitutes a decisive criterion for rehabilitative success.

4.3. Innovations in Diagnosis and Planning

The convergence between digital technologies and surgical practice has profoundly transformed the therapeutic approach in implantology, particularly with regard to bone bed preparation through bone densification. Advances in imaging techniques, combined with the development of three-dimensional planning software and 3D printing of customized surgical guides, have contributed significantly to increasing the accuracy, predictability, and safety of implant procedures (Macari et al., 2024; Andrade, 2023). These digital tools allow not only a more detailed diagnosis, but also preoperative simulation of the implant trajectory and monitoring of clinical results.

As a technique that promotes the compaction and reorganization of trabecular bone, osseodensification requires meticulous planning based on reliable three-dimensional data. This process involves volumetric analysis of bone anatomy, assessment of cortical and cancellous tissue density, and precise definition of the axis and depth of the osteotomy. Cone beam computed tomography (CBCT) plays a central role in this context, as it allows the identification of critical structures such as the maxillary sinuses and mandibular canal, in addition to enabling the accurate measurement of residual bone thickness and available angulation (Andrade, 2023).

The importance of imaging extends to the post-operative phase. In the study by Elsaid et al. (2022), which evaluated the application of OD combined with transcrestal sinus elevation and immediate implant placement, CBCT was employed both immediately post-operatively and after six months. This methodology enabled the quantification of vertical bone gain, verification of sinus-membrane integrity and tracking of mineralisation around the implants, providing objective indicators of surgical efficacy and the progress of osseointegration.

The integration of osseodensification with digital resources—such as three-dimensional planning, customised surgical guides and CBCT imaging analysis—has enhanced procedural precision and predictability, especially in anatomically critical regions such as the posterior maxilla. This interplay between technology and biology positions OD as a technique fully compatible with guided implantology.

In the experimental setting, digital imaging has allowed rigorous quantification of the effects of OD. Cardozo et al. (2022) conducted an in vitro study using polyurethane blocks simulating type IV bone, comparing two densifying-bur systems:

Maximus and Neodent. Pre- and post-drilling tomographic scans enabled precise measurement of the bone expansion produced by each system. The results showed that Maximus burs generated higher insertion torque and greater bone expansion, underscoring the essential role of imaging in the controlled evaluation of biomechanical performance.

In more complex areas of oral rehabilitation, such as the placement of zygomatic implants, three-dimensional analysis is equally indispensable. Aparicio et al. (2021), in proposing the anatomical approach for implants in the zygomatic region, introduced the concept of the ‘zygomatic implant critical zone’ (ZICZ), the definition of which requires detailed volumetric analysis by CBCT. Although the study does not directly involve OD, the principles of densitometric assessment and precise planning apply across the board and are particularly relevant when interventions are contemplated in atrophic maxillae or posterior regions with limited anatomy.

The importance of imaging assessment is likewise evident in the clinical study by Mello-Machado et al. (2021), which evaluated the efficacy of OD in the primary stability of implants placed in low-density bone. Although the authors did not report the use of surgical guides, they emphasised the prior densitometric analysis by CBCT, which guided the choice of drilling sequence, osteotomy depth, and the need for biomaterials. This approach ensured safe planning tailored to the individual osseous characteristics.

In cutting-edge research, Bittar et al. (2024) employed micro-computed tomography (μCT) to evaluate bone microarchitecture after the conventional and OD techniques. This high-resolution technology enabled the examination of parameters such as trabecular thickness, mineral-matrix porosity, and inter-trabecular distance. The results indicated that OD promotes better structural preservation and a more favourable osteogenic response. Although μCT is not yet feasible in daily clinical practice, it represents an advance that heralds the future of bone imaging, expanding the boundaries of morphofunctional assessment.

In complementary research, Mello-Machado et al. (2021) explored the concept of bone-healing chambers induced by osseodensification in greater depth, emphasising their role in promoting organised tissue regeneration. The configuration of these structures depends directly on imaging analysis of the alveolar ridge and available bone thickness. Even when not explicitly mentioned, digital imaging constitutes the invisible foundation upon which many clinical decisions related to ocular disease (OD) rest.

This perspective is reinforced by the review conducted by Macari et al. (2024), which highlights the importance of radiographic examinations—such as panoramic radiographs, tomographies and three-dimensional digital models—in the appropriate selection of cases. Imaging guides not only the choice of the most suitable surgical technique but also the definition of optimised trajectories to preserve native bone tissue. In this process, surgical guides emerge as key elements in ensuring the faithful execution of the plan.

Likewise, the multicentre study by Bergamo et al. (2021) confirms that variables such as bone density, osteotomy depth and three-dimensional implant positioning are directly associated with primary stability. These parameters, in turn, can be assessed reliably only through high-resolution pre-operative imaging, underscoring the value of digital planning in cases indicated for OD.

Complementarily, the systematic review by Tretto et al. (2018) maintains that the choice of implant-site preparation instrument—whether conventional, osteotomic or densifying—should be guided by anatomical and densitometric criteria previously assessed by advanced imaging methods.

In summary, three-dimensional planning supported by digital imaging, along with the use of customised guides, constitutes a fundamental pillar of contemporary implantology. Osseodensification, as a technique based on the controlled modulation of osseous tissue, benefits significantly from this technological ecosystem. Imaging provides not only detailed diagnostic analysis but also precise execution and objective monitoring of outcomes. In this context, excellence in the clinical application of OD is intrinsically linked to mastery of digital diagnostic and planning tools, consolidating its status as a technical and scientific reference in modern implant practice.

5. CLINICAL APPLICATIONS

5.1. Implantology

Primary stability of dental implants is a fundamental cornerstone for the success of oral rehabilitations employing osseointegrable fixtures. This initial stability, understood as the “mechanical lock” obtained immediately after insertion of the implant into the osseous bed, is a reliable indicator of osseointegration viability and long-term clinical predictability. It is typically assessed by insertion torque and the Implant Stability Quotient (ISQ) value and is closely linked to the prevention of micromovements and the creation of an environment conducive to new bone formation (Bergamo et al., 2021). Comparative results from the principal clinical trials are presented in Table 2.

Table 2 – Synthesis of clinical studies on osseodensification: insertion torque, stability, success rates and pertinent observations

No.	Study (year / design)	n (implants)	Anatomical region / Bone type	Mean torque (N·cm)	Initial ISQ (OD / CT)	1-year success (OD / CT)	Key observations
1	Bergamo et al. (2022) – multicentre controlled	75	Maxilla & mandible • D3–D4	50 ± 12	78 / 69	98.7 % / 96.0 %	Significant gain in primary and secondary stability
2	Koutouzis & Huwais (2019) – retrospective	56	Posterior maxilla • ridge ≤ 3 mm	61 ± 14	77 / NR	92.8 % / —	Mean ridge expansion of 2.8 mm without grafts
3	Elsaid et al. (2022) – RCT transcrestal sinus	20	Posterior maxilla • height 4–6 mm	45 ± 10	61 → 80	100 % / —	Zero membrane perforations; bone gain +3.5 mm
4	Ibrahim & Sherif (2020) – clinical trial	30	Maxilla & mandible • D3–D4	47 ± 7 / 35 ± 6	74 / 67	100 % / 95 %	ΔTorque +34 % with OD

							(*p* < 0.01)
5	Gaspar et al. (2024) – RCT sinus floor	60	Posterior maxilla • D4	48 ± 11	75 / 70	96.7 % / 94.5 %	Lower self-reported pain in OD group
6	Salgar (2021) – case series	25	Posterior maxilla • height ≤ 1.5 mm	50	NR	96 % / —	Vertical gain 10–14 mm (crestal OD)
7	Stacchi et al. (2023) – RCT (OD vs piezosurgery)	60	Various • D2–D4	40 ± 9 / 38 ± 8	70 / 72	98.3 % / 98.3 %	Only 1 failure (OD) within 90 days
8	Mello-Machado et al. (2021) – double-blind RCT	30	Posterior mandible • D3–D4	46 ± 8 / 33 ± 7	73 / 65	100 % / —	Healing chambers enhance BAFO↑

Note. Synthesis of pertinent clinical investigations into osseodensification. A comparative overview of eight clinical studies evaluating insertion torque, primary stability (implant stability quotient, ISQ), 12-month success rates and additional specific observations in implants placed using osseodensification (OD) versus conventional drilling (CT). The dataset encompasses prospective and retrospective cohorts as well as randomised clinical trials (RCTs), across various anatomical sites and Misch bone density classifications. Findings consistently indicate enhanced stability and success rates in OD groups, alongside clinical benefits such as peri-implant bone gain, reduced postoperative pain and fewer associated complications.

Osseointegration is a multifactorial process in which the quality and quantity of the host bone, the implant’s macro- and micro-geometry, the surgical technique employed and the patient’s systemic conditions all interact (Ibrahim et al., 2020). Even so, it is primary stability—resulting from the intimate adaptation between the implant threads and the bone tissue—that initiates healing, provoking a controlled inflammatory response that culminates in the deposition of mineralised bone tissue in direct contact with the implant surface (Mello-Machado et al., 2021).

As healing progresses, stability comes to depend on bone remodelling around the implant, thereby acquiring a biological nature. This secondary phase involves the replacement and progressive maturation of the newly formed bone and is all the more effective when the initial stability is robust (Andrade & Valiense, 2023; Cardoso et al., 2022).

In anatomically unfavourable regions such as the posterior maxilla—characterised by type IV bone that is highly trabecular and of low density—achieving primary stability is more challenging. In such cases, conventional drilling techniques can prove insufficient, and alternative approaches, such as osseodensification, have been successfully incorporated into immediate loading protocols (Ibrahim et al., 2020).

Osseodensification differs in that it compacts and redirects bone tissue during osteotomy rather than removing it. Using burs with non-cutting edges in a counter-clockwise rotation, the technique induces controlled plastic deformation of the trabeculae, thereby densifying the implant bed and enhancing local mechanical resistance (Huwais & Meyer, 2016; Lahens et al., 2016). This process results in higher insertion torque and the creation of a biologically active substrate that favours osseointegration (Bergamo & Zahoui, 2021).

Multicentre studies report significantly higher insertion-torque and ISQ values in the early postoperative stages with OD compared with conventional drilling (Mello-Machado et al., 2021; Ibrahim et al., 2020). This advantage stems partly from the preservation and redistribution of autogenous bone particles during osteotomy preparation, which acts as an autograft, providing structure and a stimulus for the recruitment of osteoprogenitor cells (Huwais & Meyer, 2016; Lahens et al., 2016).

Trabecular compaction associated with OD also stimulates angiogenesis and preserves the integrity of vascular channels—elements essential for an effective osteogenic response. This feature is especially relevant in elderly patients and in sites with limited vascularisation, such as the cancellous bone of the posterior maxilla (Slete et al., 2018; Ferreira Amancio & Hipólito da Silva, 2024).

Within immediate-loading protocols, OD facilitates treatment by ensuring torque levels compatible with early prosthetic installation, thereby shortening overall treatment time and enhancing satisfaction for both patient and clinician (Bergamo et al., 2021; Ibrahim et al., 2020). Nonetheless, procedural success also depends on implant macro-geometry; models with an aggressive tread design, pronounced taper, and treated surfaces that encourage cellular adhesion are preferred (Mello-Machado et al., 2021).

Pre-operative planning is pivotal. Cone-beam computed tomography (CBCT) enables the precise evaluation of bone density, available volume, and adjacent anatomical structures, guiding implant selection and the drilling protocol (Samir et al., 2024; Gaspar et al., 2023). By integrating these data with the biomechanical benefits of osseodensification, clinicians enhance the likelihood of achieving optimal stability while reducing complications.

Correct execution of the technique requires specific training. OD demands careful control of rotational speed, axial pressure and drilling sequence; improper bur use can lead to overheating, under-preparation or implant misalignment. Training on synthetic models and supervised clinical practice in a controlled environment are therefore recommended (Huwais & Meyer, 2016; Kanathila & Pangi, 2018).

Postoperative follow-up also has a direct impact on clinical outcomes. Proper maintenance and strict control of factors such as bruxism and oral hygiene are essential to ensure the longevity of implants and prevent complications, particularly peri-implantitis (Bergamo et al., 2021).

Clinical studies demonstrate that even in regions with type IV bone, OD can equal the survival rates observed in denser bone by reducing initial bone loss and promoting more efficient remodelling patterns (Ibrahim et al., 2020). This benefit allows, for example, the use of short implants in areas of limited bone height, thereby avoiding more invasive grafting procedures (Mello-Machado et al., 2021).

Biologically, bone compaction induced by OD has an osteogenic effect: it stimulates mesenchymal cells and promotes the retention and activation of local morphogenetic proteins, accelerating the formation of mineralised tissue and contributing to long-term stability (Huwais & Meyer, 2016; Lahens et al., 2016; Mello-Machado et al., 2021).

Table 3 – Histomorphometric and biomechanical gains achieved with osseodensification (OD) versus conventional drilling (CT) in major preclinical studies (2016–2024).

No.	Study / Model	Primary Metric	OD (mean ± SD)	CT (mean ± SD)	Δ OD vs. CT
1	Lahens 2016 – ovine, 6 weeks	BIC (%)	58 ± 6	43 ± 7	+35 %
2	Oliveira 2018 – ovine, 12 weeks	BAFO (%)	41 ± 5	30 ± 4	+37 %
3	Alifarag 2018 – ovine, 3 & 6 wks	Pull-out torque (N·cm)	76 ± 9	54 ± 8	+41 %
4	Trisi 2016 – ovine, 8 weeks	Peri-implant bone density (g/cm³)	0.82 ± 0.07	0.62 ± 0.05	+32 %
5	Witek 2019 – ovine, 4 weeks	Trabecular thickness (mm)	0.23 ± 0.02	0.17 ± 0.02	+35 %
6	Bittar 2024 – porcine ex vivo	Peri-implant bone volume 3 mm (mm³)	32.0 ± 5.8	23.2 ± 3.4	+38 %

Note. This table summarises preclinical investigations (ovine and porcine models) that quantify the benefits of osseodensification (OD) in comparison with conventional drilling (CD). Assessed parameters include histomorphometric metrics—bone-to-implant contact (BIC), bone area fraction occupancy (BAFO), trabecular density and thickness—and biomechanical performance (removal torque). Consistent improvements of +30 % to +40 % were observed, thereby substantiating the biological rationale of the technique (Trisi 2016; Lahens 2016; Oliveira 2018; Alifarag 2018; Witek 2019; Bittar 2024).

In immediate-loading protocols, achieving high insertion torque is a sine qua non. OD fulfils this requirement, restoring masticatory function in a shorter time with superior comfort and predictability (Pai et al., 2018; Bergamo et al., 2021). Nevertheless, factors such as the extent of edentulism, parafunctional habits and occlusal conditions must be carefully assessed before opting for immediate loading (Ibrahim et al., 2020).

Medium-term success rates confirm the favourable performance of osseodensification, particularly in challenging regions. Although studies with follow-up exceeding ten years are still awaited, current data support its inclusion in contemporary implantology protocols (Mello-Machado et al., 2021; Bergamo et al., 2022; Gaspar et al., 2023).

By combining reduced surgical trauma, lower vibration and preservation of bone structure, OD meets the requirements of minimally invasive implantology. It is especially indicated for systemically compromised patients or those anxious about extensive surgery, as it offers more conservative and less painful rehabilitations (Kanathila & Pangi, 2018; Macari et al., 2024; Samir et al., 2024).

Ongoing research into the technical parameters of OD—such as speed, torque, irrigation, bur design and bone morphology—reflects the scientific community's commitment to refining the technique and adapting it to diverse clinical scenarios (Bergamo et al., 2021).

In sum, primary stability is essential for implant success, particularly in immediate-loading situations and in low-density bone. Osseodensification stands out as a modern and effective technique that combines tissue preservation with biological stimulation, fostering an environment conducive to osseointegration and long-term functional durability (Lahens et al., 2016; Mello-Machado et al., 2021; Bergamo et al., 2022). Its integration into clinical practice, underpinned by continuous training and digital planning, broadens therapeutic possibilities and sets a new standard of excellence in oral rehabilitation with osseointegrable implants.

5.2. Bone Regeneration

Bone regeneration is one of the foundational pillars of implant-supported rehabilitation, particularly when there are significant deficiencies in the height or width of the alveolar ridge. In such scenarios, augmenting the osseous volume through grafts and guided bone regeneration (GBR) procedures is crucial for permitting implant placement and ensuring satisfactory primary stability. Surgical advances over the past decade have considerably expanded the therapeutic armamentarium of modern implantology. Among these innovations, osseodensification stands out for its ability to compact rather than remove bone tissue (Mello-Machado et al., 2021).

The posterior maxilla frequently poses an anatomical challenge for implant placement owing to its low bone density—typically classified as type III or IV, according to Misch—and the progressive pneumatisation of the maxillary sinus after tooth loss (Yu et al., 2022a). This condition often results in inadequate bone height and width for receiving conventional implants. Traditionally, bone grafts and sinus-lift techniques, whether via a lateral or a transcrestal approach, have been employed. These procedures, however, are associated with greater morbidity, longer surgical duration and a higher risk of sinus-membrane perforation (Salgar, 2021).

Osseodensification, as a non-subtractive osteotomy technique, seeks to overcome those limitations. Using specially designed burs operated in reverse rotation, bone tissue is compacted against the walls of the implant bed, thereby redistributing autogenous particles and promoting new bone formation (Ferreira Amancio & Hipólito da Silva, 2024; Huwais & Meyer, 2016; Lahens et al., 2016). This process—often referred to as the 'autograft effect'—increases local density and creates an environment more conducive to primary stability.

In the context of volumetric augmentation, osseodensification may be applied either in isolation or in combination with other regenerative strategies. In cases of moderate horizontal atrophy, bone compaction enables expansion of the alveolar crest without the need for large graft volumes (Mello-Machado et al., 2021). When coupled with meticulous surgical planning, the technique maximises the contact area between the implant and the recipient bed, thus facilitating anchorage in substrates of lower density (Yu et al., 2022a).

Transcrestal sinus elevation assisted by osseodensification represents a promising clinical application. The densifying bur is used to traverse the ridge, gently displacing the sinus membrane and creating a sub-antral space that can be filled with biomaterials or left to stabilise with a blood clot, depending on the therapeutic plan (Samir et al., 2024; Salgar, 2021). Clinical studies have reported lower morbidity, reduced perforation risk, and shorter operative times compared with the lateral window technique (Samir et al., 2024).

Combining osseodensification with guided bone regeneration (GBR) has proven advantageous in treating fenestrations, dehiscences, and volumetric deficiencies. Bone compaction provides a more stable foundation for the biomaterial, thereby increasing graft success (Rodrigues et al., 2023). Ongoing multicentre trials indicate superior outcomes for patients with low-density bone when osseodensification is employed (Yu et al., 2022b).

Moreover, the reduced surgical trauma associated with the technique has been linked to shorter healing periods. The retention of autogenous fragments and the osteogenic stimulus provided by bone compaction contribute to rapid osseous consolidation, facilitating immediate loading (Andrade, 2023; Ferreira Amancio & Hipólito da Silva, 2024).

Nevertheless, osseodensification does not of itself, replace traditional reconstructive procedures. In cases of severe atrophy or extensive pneumatisation, block grafts or other complementary approaches may still be required to obtain adequate bone volume (Samir et al., 2024). In such situations, the technique serves as an adjunct, reducing micromovements and enhancing initial stability (Rodrigues et al., 2023).

When applied to other low-density regions, such as the posterior mandible, osseodensification has been shown to increase insertion torque and reduce failure rates (Andrade, 2023). Although its learning curve does not differ markedly from that of conventional drilling, strict adherence to protocols governing speed, rotation (800–1,500 rpm, reverse), and irrigation is essential (Ferreira Amancio & Hipólito da Silva, 2024).

Imaging technologies, such as CBCT, combined with 3D planning software, enable the precise assessment of cortical thickness, trabecular density, and local anatomy, thereby enhancing procedural safety and predictability (Macari et al., 2024; Samir et al., 2024).

Although long-term studies are still awaited, histological evidence shows increased bone-to-implant contact (BIC) and trabecular formation with osseodensification (Mello-Machado et al., 2021). Patient experience also tends to be positive, with less pain and oedema, provided that clinical indications are respected (Rodrigues et al., 2023; Yu et al., 2022b).

In conclusion, osseodensification is a versatile and promising regenerative technique that expands therapeutic options in implantology, particularly in anatomically compromised regions. Its judicious application, supported by well-defined protocols and digital imaging, promotes safer, more stable and reproducible outcomes. Consolidation of the technique as a routine adjunct will depend on protocol standardisation and the accumulation of robust long-term clinical evidence.

5.3. Periodontology and Orthodontics

Osseodensification has been steadily consolidating its position as an innovative technique in contemporary dentistry, with expanding applications not only in implantology but also in disciplines such as periodontology and orthodontics. Founded on the principle of compacting rather than removing bone tissue, this approach creates an environment conducive to the regeneration and adaptation of alveolar bone in various clinical contexts (Huwais & Meyer, 2017). For this reason, it has captured the interest of researchers and clinicians who perceive the technique as having significant potential to optimise the initial stability of implants and increase bone density in compromised regions (Macari et al., 2024).

The notion that bone can be condensed and sculpted—rather than merely removed—represents a paradigm shift in procedures involving osseous drilling. In periodontology, the challenges posed by extensive bone defects, common in patients with advanced periodontal disease, demand strategies that favour the preservation and volumetric augmentation of the alveolar ridge. Through osseodensification, tissue is displaced laterally into adjacent trabeculae, filling microstructural spaces and increasing local density (Mello-Machado et al., 2021). This process helps create a surgical bed richer in osteoprogenitor cells and growth factors, thereby promoting tissue regeneration.

Clot stability and the integrity of the osseous framework are critical determinants of success in periodontal regenerative interventions. During guided bone regeneration procedures—such as the placement of expanded polytetrafluoroethylene (e-PTFE) membranes or resorbable collagen barriers—the increased bone density achieved with osseodensification bolsters the physical support for these structures, enhancing graft predictability (Bergamo et al., 2021). Furthermore, by maintaining ridge architecture after tooth extraction, the technique aids in preserving the alveolar crest—an aspect essential for future rehabilitation, especially in patients with a history of bone loss associated with chronic inflammation (Ferreira Amancio & Hipólito da Silva, 2024).

Within orthodontics, osseodensification has been proposed as a valuable adjunct for stabilising mini-implants, particularly in areas of low bone density, such as the posterior maxilla. These devices, essential for absolute anchorage and for performing complex tooth movements without relying on adjacent teeth, exhibit a higher failure risk in sparse bone. Although most current studies focus on conventional implants, applying the principle of bone densification shows the potential to increase insertion torque and initial stability, potentially reducing mechanical failure rates in mini-implants (Huwais & Meyer, 2016; Bergamo et al., 2022).

Beyond anchorage, the biological effects of osseodensification on bone adjacent to mini-implants are equally relevant. Compaction stimulates the release of osteogenic mediators and fosters a micro-environment favourable to new bone formation and local vascularisation (Huwais & Meyer, 2016; Lahens et al., 2016). This milieu promotes trabecular maturation and reduces implant micromobility, contributing to long-term functionality (Mello-Machado et al., 2021). In more complex surgical scenarios—such as transverse maxillary expansion—combining osseodensification with ancillary techniques yields more substantial dimensional gains with a lower incidence of cortical fractures or perforations (Ferreira Amancio & Hipólito da Silva, 2024).

Preserving bone volume, whether in periodontology or orthodontics, is a cornerstone of therapeutic planning. In dental extractions associated with periodontal disease, maintaining the alveolar ridge is crucial to avoid a structural collapse that could compromise subsequent implant placement or orthodontic movement. By preventing bone removal and promoting more organised healing, osseodensification provides improved conditions for medium- and long-term rehabilitation (Ferreira Amancio & Hipólito da Silva, 2024).

From a biomechanical standpoint, the technique produces a zone of compacted bone with higher peri-implant density, offering greater resistance to functional loads and enhancing stability at the bone-implant interface (Huwais & Meyer, 2016; Mello-Machado et al., 2021). This densification not only supports the maintenance of primary stability but may also limit the formation of micro-gaps susceptible to early bacterial infiltration—an especially pertinent consideration in rehabilitation for patients with periodontal compromise or in orthodontic applications.

Technically, osseodensification requires specialised burs that operate in reverse (counter-clockwise) rotation under copious irrigation, with strict control of speed and torque to avoid thermal necrosis and microfractures (Huwais & Meyer, 2017). Although the learning curve is slightly steeper than that of conventional techniques, proper application yields consistent clinical benefits, including greater predictability in mini-implant insertion, reduced healing time, and higher success rates (Ferreira Amancio & Hipólito da Silva, 2024).

In regenerative surgeries—particularly in post-extraction sockets or deep defects in periodontal patients—osseodensification has been proposed as an adjunct tool, helping to create a denser osteoconductive matrix compatible with grafts and potentially reducing the need for more invasive procedures. Experimental studies have demonstrated greater volumes of newly formed bone and less resorption when the technique is employed (Macari et al., 2024; Tian et al., 2018; Lahens et al., 2016). Nonetheless, larger and longer-term clinical trials are still required to consolidate this evidence.

The combination of bone densification with biomaterials from different sources, such as allogeneic, xenogeneic, or synthetic substitutes, has shown promising results, increasing the receptivity of the surgical bed and promoting graft stability, especially in maxillary sinus elevation procedures (Lopez et al., 2017; Baron & Venkatraman, 2017). Although the literature is still limited, it is suggested that the creation of densified zones may, in the future, benefit complex orthodontic movements, especially in areas of low bone density.

Despite the reported advantages, the clinical application of bone densification requires careful planning. In patients with active inflammation or infection, the prognosis may be negatively influenced, and it is essential to ensure a healthy bone environment before performing the technique (Ferreira Amancio & Hipólito da Silva, 2024; Huwais & Meyer, 2016). With regard to orthodontic use, although there are proposals in the literature, further studies are needed to assess the impact of skeletal age, bone metabolic response, and the magnitude of the forces applied on the efficacy and safety of the procedure.

In summary, osseodensification represents a promising and versatile clinical tool in contemporary practice, with growing applications in alveolar ridge preservation, guided bone regeneration, and density improvement in unfavorable regions. In periodontal contexts, the technique has proven useful in regenerative surgeries and post-extraction alveoli, contributing to the maintenance of bone volume (Macari et al., 2024; Cisternas et al., 2023). Although bone densification may also improve the stability of orthodontic mini-implants, this application still lacks robust clinical confirmation. Thus, despite the advances observed, it is essential to strengthen the scientific basis through controlled studies with prolonged follow-up. Until this evidence is consolidated, the technique should be applied with caution, integrated into a minimally invasive therapeutic philosophy and guided by biological principles that aim for functional and aesthetic excellence.

5.4. Complex Cases

The application of osseodensification in anatomical regions characterised by thick, dense cortical bone has attracted growing attention in the scientific literature, while simultaneously posing a significant technical challenge. This technique—based on burs designed to compact, rather than remove, bone tissue—seeks to increase peri-implant bone density and enhance primary stability, a decisive factor for successful osseointegration (Bergamo et al., 2022). In type I or II bone, where a compact, hypovascular cortical layer predominates, caution is advised, as the high rigidity and limited blood perfusion may theoretically raise the risk of over-compression and jeopardise cellular viability.

Initially designed to optimize stability in low-density trabecular regions, such as the posterior maxilla (bone type III and IV), osseodensification works by using reverse rotation drills (counterclockwise), which induce controlled plastic deformation of the surrounding bone (Ferreira Amancio & Hipólito da Silva, 2024). This compaction process increases insertion torque and creates a denser osteotomy bed, thus promoting primary stability (Bittar et al., 2024).

To mitigate the previously identified risks, careful adaptation of the osseodensification protocol is recommended, especially in substrates with high cortical density. One possible strategy is to start the osteotomy with conventional rotation (clockwise), using drills that allow for slight removal of mineralized tissue before the actual densification phase (Ferreira Amancio & Hipólito da Silva, 2024). This hybrid approach facilitates initial decompression of the bone bed, reduces intramedullary pressure, and preserves the integrity of Haversian canals, structures essential for perfusion and cell viability (Stacchi et al., 2022). Maintaining reverse rotation during all phases of the procedure, on the other hand, can generate supraphysiological pressures that compromise the bone microenvironment and increase the risk of adverse events (Yu et al., 2022a).

Thermal control is another critical aspect. The friction generated during cortical bone compaction can cause a significant increase in local temperature, increasing the risk of thermal necrosis (Bittar et al., 2024). For this reason, continuous irrigation with saline solution, combined with strict adherence to operating parameters—speeds between 800 and 1,500 rpm, moderate torque, and controlled axial pressure—is essential (Huwais & Meyer, 2016). In certain clinical situations, the prior use of a conventional drill for initial bed enlargement can make subsequent densification safer and more biologically compatible.

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Table 4 - Main clinical applications of osseodensification (OD)

No.	Surgical indication	Associated OD procedure	Documented advantages	Limitations / precautions	Key evidence (year)† / Level*
1	Transcrestal sinus lift in posterior maxilla (residual height ≤ 6 mm)	OD burs drill 1 mm below sinus floor → compaction + biomaterial pumping	• Vertical gain 3–5 mm • Zero perforations • Torque ≥ 45 N·cm → early loading	Thick membrane or large septa may require lateral window; ensure copious irrigation	Elsaid 2022; Gaspar 2024 ; Salgar 2021 / 1B
2	Horizontal ridge expansion (≤ 4 mm)	OD sequence 1–2 diameters below final implant, “spring-back” 1–3 mm	• Final width +2–3 mm without cracks • Simultaneous implant; reduces block grafting	Very thin cortical (< 0.5 mm) at risk of fractures; moderate pressure advised	Koutouzis 2 019; Cisternas 20 23 / 2B
3	Immediate loading in D3–D4 bone	Compaction until torque 55–65 N·cm; ISQ ≥ 70 immediately after insertion	• Immediate prosthetics with low failure rate (≤ 5 %) • Shorter edentulous period	Requires balanced occlusion; bruxist patients need splints	Bergamo 20 22; Ferreira Amancio 20 24 / 2A
4	Atrophic post-extraction socket (type III–IV)	OD concurrent with septum drilling → healing chambers	• Preserves buccal wall • Reduces initial volumetric resorption	Check integrity of thin buccal plate; gradual torque advised	Bleyan 2021 ; Mello-Mach ado 2021 / 2B
5	Minimally invasive lateral sinus lift (height ≤ 3 mm)	OD perforates thin lateral wall + compacts graft into sinus	• Shorter surgical time & oedema compared to conventional window	Long learning curve; limited visibility	Samir 2024 / 3B

Note. This table summarises five key clinical scenarios where osseodensification (OD) is commonly employed: transcrestal sinus lift, horizontal ridge expansion, immediate loading, atrophic post-extraction sockets, and minimally invasive lateral sinus lift. For each, the typical OD protocol, primary benefits (bone gain, torque, complication reduction), practical limitations, and the most cited scientific evidence are presented, along with the level of evidence according to the Oxford scale. OD is supported by controlled trials (levels 1B–2A) for transcrestal sinus lift, ridge expansion and immediate loading. In contrast, newer indications like lateral sinus lifts with OD rely mainly on case series (3B).

Level of evidence – Oxford: 1A = meta-analysis of RCTs; 1B = RCT; 2A = prospective study; 2B = cohort study or multicentre series; 3B = case series.
† Only the most representative study for each application is listed; see Chapter 5 for a full review.

6. CLINICAL IMPACT AND BENEFITS

6.1. Patient Benefits

Osseodensification (OD) has established a minimally invasive surgical paradigm that redefines implant site preparation, yielding tangible clinical benefits for the patient. In contrast to conventional subtractive drilling, OD employs reverse-rotating burs with negative geometry to compact trabecular bone, preserve mineralised volume and reduce intraoperative haemorrhage while attenuating postoperative oedema. These attributes translate into lower self-reported pain, reduced analgesic requirements and an earlier return to routine activities. The clinical data on reductions in operative time and postoperative pain are summarised in figure 9.

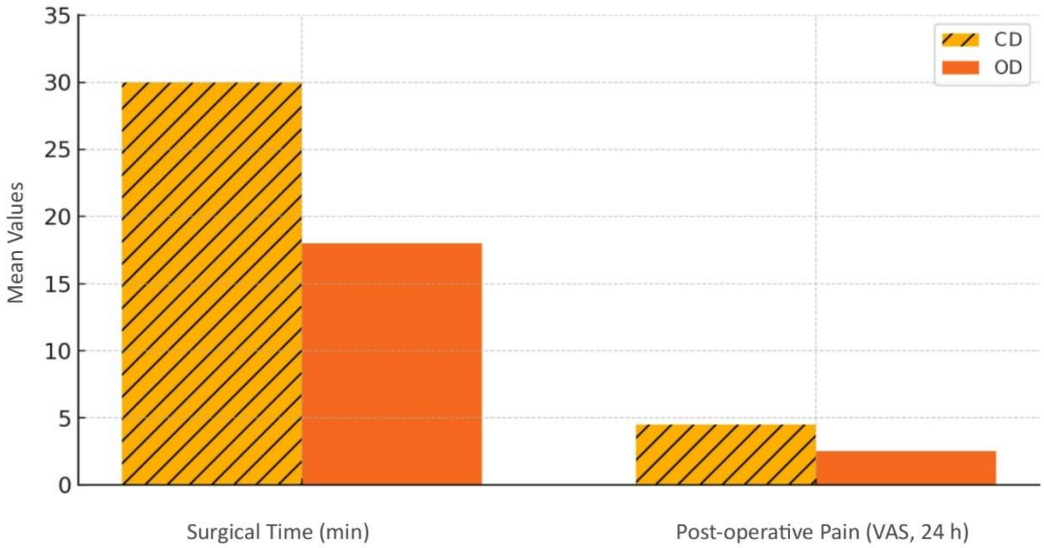

Figure 9. Operative and patient-comfort benefits of osseodensification (OD) versus conventional drilling (CT).
Bar chart depicting mean surgical time (minutes) and postoperative pain (VAS 0–10 scale during the first 24 hours), based on the clinical trials by Elsaid et al. (2022; n = 20) and Gaspar et al. (2024; n = 28). The OD technique is associated with a mean reduction in operative time from 30 to 18 minutes and in self-reported pain from 4.5 to 2.5 points compared with the conventional technique.

In a randomised clinical trial focused on transcrestal sinus elevation, Gaspar et al. (2023) recorded lower pain scores and uneventful healing within the first 72 hours in patients treated with OD. Comparable results were reported by Elsaid et al. (2022) in maxillae with a residual height of 4–6 mm, where a significant reduction in operative time and an absence of sinus-membrane perforation were attributed to the hydrodynamic modulation induced by bone compaction.

Beyond immediate comfort, OD accelerates the reparative timeline by promoting osteogenesis from autogenous grafts compacted against the osteotomy walls. Using high-resolution micro-computed tomography in porcine tibiae, Bittar et al. (2024) observed a 37 % increase in peri-implant trabecular volume and an insertion torque almost three times higher than that achieved with conventional drilling—parameters strongly correlated with primary stability. This volumetric gain is also confirmed in humans: by means of cone-beam computed tomography, Cisternas et al. (2023) reported a mean ridge-width expansion of 2.11 ± 1.66 mm and a vertical gain of up to 2.28 mm three months after OD in posterior maxillae, substantially reducing the need for particulate grafts or autogenous blocks.

Prosthetic longevity is closely linked to peri-implant bone density and the preservation of secondary stability. The meta-analysis by Pai et al. (2018) demonstrated a significant increase in bone-implant contact (BIC) percentage and bone volume fraction (%BV) in sites prepared with OD, translating into lower implant micromobility during the early phases of functional healing. Convergently, Stacchi et al. (2023), in a multicentre randomised trial, reported a survival rate of 96.2 % after one year of functional loading in implants placed with OD, exhibiting stability comparable with that achieved by piezoelectric surgery but with a superior tendency to preserve marginal bone. In an ovine model, Lahens et al. (2016) identified the formation of healing chambers composed of condensed bone particles capable of modulating mechanobiological responses and sustaining bone remodelling without significant resorption.

From a biological perspective, OD triggers mechanotransductive stimuli that activate essential osteogenic pathways. Bone compression induces strains that stimulate integrin-mediated signalling and up-regulate the RUNX2 transcription factor, thereby promoting early mineral deposition. Macari et al. (2024) note that this micromodulation favours the expression of bone-maturation markers, shortening the interval between primary and secondary stability. This element is critical in immediate-loading protocols. In the same vein, Ferreira Amancio and Hipólito da Silva (2024) emphasise that the increased insertion torque and intimate bone-implant contact reduce micromovements to below 50 µm, a threshold considered fundamental for predictable osseointegration.

The biomechanical consistency conferred by OD extends to low-density scenarios. In posterior maxillae with limited residual height, Elsaid et al. (2022) recorded an increase in the Implant Stability Quotient (ISQ) from 61.4 to 80 over six months, concomitant with a 75.9 % rise in bone density measured in Hounsfield units. When combined with the Summers protocol, OD proved to be a less invasive alternative to lateral sinus-lift procedures, achieving insertion torques of 45 N·cm and allowing for functional loading after only four months without any clinical complications (Gaspar et al., 2023).

In addition to the clinical advantages, the benefits of OD extend to the psychosocial domain. The possibility of immediate loading—made feasible by the stability achieved—eliminates prolonged periods of edentulism or dependence on provisional removable prostheses, thereby reducing emotional impact and enhancing the patient's quality of life (Ferreira Amancio & Hipólito da Silva, 2024). In essence, OD offers a comprehensive response to the limitations imposed by low bone density, combining reduced operative morbidity, faster healing and prolonged biomechanical stability of implants.

Nevertheless, it is important to acknowledge the methodological heterogeneity present in existing studies, particularly concerning implant design, drilling protocols and follow-up duration. Stacchi et al. (2023) point out that, although ISQ variations during the first three weeks do not differ significantly between OD and piezosurgery, the absolute values obtained depend heavily on implant surface roughness and macro-design. Accordingly, future randomised clinical trials should seek to standardise operative protocols and include follow-ups exceeding five years in order to consolidate evidence on long-term success rates and the management of late failures.

6.2. Practitioner Benefits

The introduction of osseodensification (OD) has significantly altered clinical practice in implantology, providing greater predictability of outcomes and expanding therapeutic indications. Multicentre controlled trials have demonstrated that OD yields higher insertion-torque values and resonance-frequency stability (ISQ), consistently maintaining scores above the critical threshold of 70 during the first six weeks of healing, irrespective of implant diameter or length (Bergamo et al., 2021). Ex-vivo studies corroborate these findings, reporting a nearly three-fold increase in insertion torque and favourable alterations in peri-implant trabecular microarchitecture, thereby creating a biomechanical environment more conducive to osseointegration (Bittar et al., 2024). In low-density animal models, OD increased bone-implant contact and reduced biomechanical variability compared with conventional drilling, underscoring its reliability in unfavourable substrates (Oliveira et al., 2018).

From a biological standpoint, OD generates particulate autografts that act as nuclei for new bone formation, allowing a seamless transition from primary to secondary stability and avoiding the stability dip commonly observed during the initial remodelling phase (Macari et al., 2024). This effect explains the sustained high ISQ values in the critical stages of healing (Bergamo et al., 2021). In vivo studies also indicate that densifying burs deliver consistent insertion torques, thereby enhancing operative safety (Oliveira et al., 2018).

The clinical versatility of OD is particularly valuable in atrophic ridges, where expansion of up to 3 mm can permit implant placement without the need for additional grafting. In a retrospective multicentre series, Koutouzis et al. (2019) reported a mean torque of 61 N·cm and an ISQ of 77 in ridges only 3 mm thick, achieving a survival rate of 92.8 % and reducing the need for guided regeneration. Comparable results were obtained by Cisternas et al. (2023), who documented significant horizontal and vertical bone gains in the posterior maxilla for both immediate and delayed implants, thereby enhancing surgical flexibility. In resorbed posterior maxillae, Gaspar et al. (2023) achieved torques of 45 N·cm and successful healing when OD was combined with the Summers sinus-lift technique. Other authors, such as Ferreira Amancio and Hipólito da Silva (2024), highlight OD as a highly predictable approach for posterior-maxillary rehabilitation, emphasising cortical-volume preservation and increased bone density. A case series of transcrestal sinus elevation demonstrates that the autogenous compaction produced by OD yields vertical gains sufficient for implants of conventional length, thereby obviating the need for bulky heterologous grafts and shortening operative time (Huwais & Meyer, 2017).

The technique has also proved advantageous in immediate-loading protocols. Ferreira Amancio and Hipólito da Silva (2024) report that the bone compaction achieved with OD increases primary stability in low-density beds, allowing for the early installation of crowns or fixed prostheses, thereby reducing total treatment time and improving patient satisfaction. This potential for immediate loading, without compromising osseointegration, renders OD particularly useful in demanding aesthetic situations where time is critical. These benefits are supported by prospective data showing maintenance of marginal bone stability and no significant complications after five years (Huwais & Meyer, 2017).

Operatively, OD provides robust objective parameters for assessing initial stability, reduces the need for complex grafts and simplifies surgical planning. Controlled densification avoids the over-compression and necrosis often associated with conventional osteotomy under-preparation (Koutouzis et al., 2019). Furthermore, the technique has a relatively short learning curve, employing a standardised sequence of reverse-rotation burs that fosters reproducibility and operator confidence (Bergamo et al., 2021).

Recent biomechanical and clinical data have reinforced the predictability of OD. Bonfante et al. (2019) described reduced shear stress and preservation of trabecular micro-architecture through controlled compaction, promoting an efficient transition between stability phases. Tanello et al. (2019) reported a survival rate exceeding 97% in 254 implants placed with OD in a five-year multicenter study, irrespective of macro-design, further attesting to the method's reliability.

In a double-blind, randomised clinical trial, Mello-Machado et al. (2021) showed that controlled compaction with OD in D3/D4 bone produced a significantly higher mean torque without compromising the six-month success rate. The technique has likewise proved beneficial in minimally invasive sinus elevation: Gaspar et al. (2023) documented effective vertical gains in maxillae with 3–6 mm of residual height, with no sinus-membrane perforations. Comparisons with other atraumatic methods, such as piezosurgery, reveal that OD enables faster recovery of initial stability (Stacchi et al., 2023), a finding corroborated by a meta-analysis that identifies an average 10-point increase in ISQ relative to conventional drilling (Yu et al., 2022b).

In animal models, Gaikwad et al. (2022) demonstrated a significant rise in bone-implant contact and bone-area percentage within the first six weeks after OD, supporting applications such as transcrestal elevation with immediate implant placement, where Elsaid et al. (2022) achieved 100 % survival in 20 implants with 4–6 mm residual height.

In summary, OD delivers predictability that extends beyond initial torque, encompassing the entire healing process, adaptability to different burs and adjunct techniques, and sustainable clinical benefits. For the implantologist, it translates into less-invasive approaches, reduced reliance on substantial grafts and more efficient surgical protocols without compromising biomechanical safety or biological efficacy.

6.3. Reduction of Complications

Osseodensification (OD) was developed as an alternative to subtractive bone-drilling techniques, which frequently result in thermal necrosis, crestal bone loss, and early failure due to inadequate primary stability. Using reverse-geometry burs operated in anti-clockwise rotation, OD radially compacts trabecular bone, promoting the formation of a densified autograft. This process preserves local microvascularisation and immediately increases peri-implant bone density, thereby reducing micro-lesions, inflammation and other predisposing factors for failure (Pai et al., 2018). See Figure 10 for a comparative summary of the incidence of these complications in osseodensification versus conventional drilling. A lower incidence of complications is observed with OD than with CT.

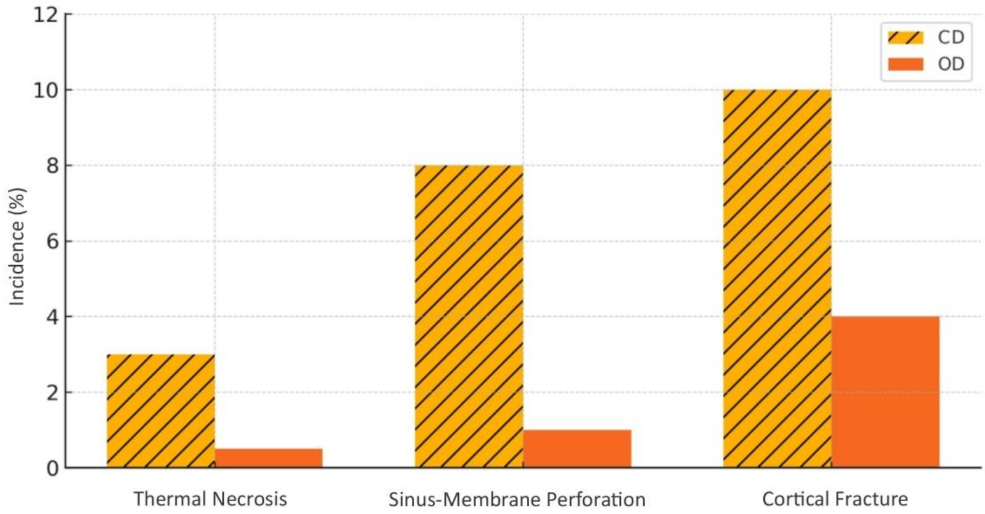

Figure 10. Incidence of surgical complications in osseodensification (OD) versus conventional drilling (CT).
Bar chart illustrating the weighted mean incidence (%) of the three most frequently reported adverse events in the literature: thermal necrosis, sinus membrane perforation (during transcrestal sinus elevation) and cortical fracture/fissure (during ridge expansion). The CT group values derive from conventional subtractive techniques (Summers, 1994; piezosurgery), whereas the OD data correspond to the use of Densah® and Maximus® burs (Huwais, 2016; Witek, 2019; Koutouzis, 2019; Elsaid, 2022; Salgar, 2021). A lower incidence of complications is observed with OD compared with CT.

Ex vivo models have shown that OD provides substantial biomechanical benefits. Bittar et al. (2024) reported that the insertion torque achieved with OD was three times higher than that of conventional drilling (19.78 ± 5.26 N·cm), accompanied by a 38 % increase in peri-implant bone volume and a more densely organised trabecular architecture. These findings are consistent with those of Gaikwad et al. (2022), whose animal meta-analysis revealed significant increases in insertion torque (+2.27 N·cm), bone-to-implant contact (BIC) and bone-area fraction during the early weeks of healing, suggesting earlier and more robust osseointegration.

Clinically, the systematic review by Tretto et al. (2018), analysing twenty-nine comparative studies, indicated that although overall survival rates do not differ between techniques, OD confers measurable biomechanical advantages—including higher insertion torque and ISQ values—particularly in low-density bone. By contrast, osteotome techniques showed a higher risk of micro-fractures and crestal resorption, reinforcing the superiority of OD in controlling the forces applied to mineralised tissue.

High-resolution micro-computed tomography has demonstrated that OD optimises trabecular parameters such as thickness (Tb.Th), number (Tb.N) and separation (Tb.Sp), producing a denser, stronger matrix that is less susceptible to marginal resorption (Bittar et al., 2024). These structural changes are associated with the maintenance of marginal bone level, a lower incidence of peri-implant mucositis and greater feasibility of immediate loading, even in anatomically unfavourable situations. Macari et al. (2024) note that the technique shortens healing time, minimises the need for grafting and increases clinical predictability.

Clinical cases further underline the utility of OD in critical zones. Andrade and Valiense (2023) reported successful rehabilitation of the resorbed posterior maxilla, with high stability and no complications, attributed to the volumetric preservation and reduced bone deformation afforded by OD. In transcrestal sinus lifts, controlled compaction diminished the risk of membrane perforation, permitting single-session placement of short implants and reducing operative morbidity. Ferreira Amancio and Hipólito da Silva (2024) confirm that the increased primary stability makes immediate-loading protocols feasible without a rise in failure rates, even in low-density bone.

Biologically, OD prevents excessive heat generation during drilling, thereby avoiding thermal necrosis and protecting the Haversian canals that are essential for initial angiogenesis. The redistribution of autogenous bone particles along the osteotomy walls creates an osteoconductive matrix that favours osteoblast adhesion and proliferation, accelerating the transition from mechanical to biological stability. Long-term multicenter studies have shown the maintenance of marginal bone levels and low rates of late complications associated with OD (Bergamo et al., 2021).

In addition, trabecular compaction increases peri-implant bone density without inducing significant thermal elevation, maintaining cortical micro-vascularisation and reducing the risks of necrosis and early crestal loss (Pai et al., 2018). The literature establishes a direct relationship between high insertion torque (IT) and ISQ values and a lower probability of early failure, especially in compromised bone substrates (Bonfante et al., 2019).

Multicenter clinical studies have demonstrated consistent increases in IT and ISQ with OD, regardless of the anatomical region. Bergamo et al. (2021) reported ISQ values above 68 throughout the healing period, a level considered safe for preventing micro-movements. In further follow-up, Bergamo et al. (2022) linked the simultaneous improvement in primary and secondary stability to high survival rates and a reduced need for re-intervention. In the controlled study by Ibrahim et al. (2020), OD provided significantly greater stability than conventional drilling, indicating lower susceptibility to biomechanical complications.

In narrow ridges, OD has proved both effective and safe. Koutouzis et al. (2019) recorded a mean expansion of 2.8 mm in ridges 3–4 mm wide, with a survival rate of 92.8 % and no cortical fractures, demonstrating the bone plasticity induced by compaction. The "spring-back" phenomenon described improves stress distribution and reduces the incidence of micro-fissures often associated with conventional osteotomies.

For sinus elevation, Salgar (2021) reported vertical gains of 10.3–13.6 mm with crestal osteotomy, without Schneiderian membrane perforation, positioning the technique as a minimally invasive alternative to the lateral window. In combination with the Summers protocol, Rodrigues et al. (2023) documented immediate implant placement in the posterior maxilla with an insertion torque of 45 N·cm and an uncomplicated postoperative course.

Direct comparisons with other techniques further underscore the performance of OD. In a randomised trial, Stacchi et al. (2023) observed similar stability between OD and piezoelectric surgery (PISP) over 90 days, with only one failure—recorded in the OD group. Samir et al. (2024) found OD to be superior in bone gain, trabecular density, and operative time, with higher patient satisfaction despite a slight PISP advantage in initial stability.

OD has also shown promising results in the concept of a healing chamber. Mello-Machado et al. (2021) demonstrated that broader site preparation followed by controlled compaction preserved primary stability and avoided fibrous encapsulation even in low-density bone. The meta-analysis by Yu et al. (2022) supports these findings, positioning OD as one of the most effective techniques for optimising initial stability.

In summary, osseodensification reduces the complications associated with contemporary implantology through interdependent mechanisms: increased bone density, structural preservation, lower heat generation, controlled compaction and osteogenic stimulation. These benefits translate into lower incidences of early failure, bone resorption and late complications, consolidating OD as a preferential approach in anatomically and biomechanically demanding contexts.

7. LIMITATIONS AND CONTROVERSIES

7.1. Technical Challenges: Execution Complexity and Learning Curve

Osseodensification (OD), as an innovative and non-subtractive technique for preparing the bone bed prior to dental implant placement, represents a paradigm shift from conventional osteotomy methods. Although its benefits are well documented—such as increased primary stability, preservation of the bone matrix, and optimization of osseointegration—its clinical application requires an advanced set of skills, strict control of operative parameters, and a significant learning curve (Macari et al., 2024; Huwais & Meyer, 2016).

One of the first challenges faced by the professional lies in the transition from a philosophy based on bone removal to a concept of compaction. During osseodensification, tissue is not removed during drilling, but rather displaced laterally and densified, which promotes increased peri-implant bone density (Oliveira et al., 2018). This conceptual change requires clinicians to have a thorough understanding of the viscoelastic properties of bone and the biological response to controlled mechanical deformation—fundamental knowledge for preventing cell necrosis and promoting efficient regeneration (Machado et al., 2018).

From an operational point of view, the technique requires alternating between clockwise rotation, used in the initial drilling phase, and counterclockwise rotation, characteristic of the densification phase, with speeds generally ranging from 800 to 1,500 rpm. This transition requires the use of specialized drills, such as Densah® or Maximus®, as well as precise control of axial pressure and the execution of a pumping motion to ensure effective compaction without causing microfractures or thermal damage (Witek et al., 2019; Macari et al., 2024).

The friction generated during osseous densification, particularly under reverse rotation, can raise the temperature of the osteotomy bed. If not adequately managed by copious saline irrigation, such heating poses a significant risk of thermal necrosis and consequent failure of osseointegration (Huwais & Meyer, 2016; Oliveira et al., 2018). Thermal management, therefore, becomes a critical component of the operative protocol.

Moreover, each OD bur manufacturer adopts distinct protocols. Systems such as Versah®, Maximus®, and Neodent® differ in their drill sequences, diameter increments, and recommended rotational speeds for each phase. This heterogeneity obliges practitioners to undergo specific training and to adapt their technique to the requirements of the chosen system (Macari et al., 2024; Bergamo et al., 2022).

Technical complexity increases when OD is applied to different bone types. The literature demonstrates superior performance in low-density trabecular bone (Types III and IV), particularly in the posterior maxilla (Andrade, 2023; Macari et al., 2024). By contrast, application in dense cortical bone (Types I and II), characterised by lower vascularity and greater rigidity, demands heightened caution owing to the increased risk of over-compression and necrosis; careful case selection is therefore essential (Bergamo et al., 2022). The principal adverse events reported and their mitigation strategies are summarised in table 5.

Table 5 - Main complications associated with osseodensification (OD) and mitigation strategies

No.	Potential complication	Typical risk scenario	OD-specific preventive/corrective strategy	Key evidence (year)†	Reported incidence
1	Thermal necrosis	Rotation > 1,500 rpm without continuous irrigation (D1 bone)	• External + internal irrigation ≥ 50 mL/min • Pause every 3 mm of advancement (≈ 2 s)	Huwais 2016; Witek 2019	< 1 %
2	Cortical overcompression / microcrack fracture	Full OD sequence used in thick D1 bone	• Underprepare up to Ø 0.5 mm below implant diameter • Maximum insertion torque 45 N·cm	Bergamo 2022	Isolated cases
3	Sinus membrane perforation	Transcrestal lift in thick septa or thin membrane	• Stop 1 mm short of sinus floor • Gentle pressure, visual control (CBCT)	Elsaid 2022; Gaspar 2024	0–2 %
4	Buccal cortical plate fracture	Ridge expansion ≥ +3 mm in cortical < 0.5 mm	• Stepwise compaction (Ø +1 mm) • Support with particulate biomaterial	Koutouzis 2019	3–5 %

5	Excessive torque → implant rotation	D4 bone with aggressive underpreparation	• Electronic torque wrench; stop at 65 N·cm • Insert at 15 rpm	Ibrahim 20 20	< 1 %
6	Increased postoperative oedema / pain	Continuous axial pressure > 15 N in D3 bone	• "Pumping" technique: 3 s compression / 2 s relief • Preventive NSAID 400 mg	Salgar 202 1	Similar to CT
7	Micromovement during immediate loading	Inaccurate prosthetics / bruxism	• Precise occlusal adjustment + MI splint • Ensure ISQ ≥ 70 before loading	Bergamo 2 022	2–4 % early failures
8	Late peri-implantitis from initial overheating	Inadequate irrigation + rough surface implant	• Keep temperature < 47 °C (probe) • Post-op rinse with 0.12 % CHX	Mello-Mac hado 2021	Not quantified

Note. The table lists the complications most frequently cited in the osseodensification literature, relating each risk scenario to the preventive or corrective strategies specific to OD and, where available, the reported incidence. It should be emphasised that the majority of adverse events are linked to inappropriate operative parameters (excessive rotational speed, insufficient irrigation or uncontrolled axial pressure) and that adherence to the recommended best-practice protocols restricts the occurrence of thermal necrosis, cortical fractures or sinus perforations to levels lower than those observed with conventional drilling. † Key references describing the complication or the mitigation measure: Huwais & Meyer 2016; Witek 2019; Bergamo 2022; Koutouzis 2019; Ibrahim 2020; Elsaid 2022; Gaspar 2024; Salgar 2021; Mello-Machado 2021.

In combined procedures—such as transcrestal maxillary sinus elevation with simultaneous implant placement—OD should be integrated with adjunctive techniques and intraoperative monitoring of primary stability, for example, by means of Osstell devices (Bergamo et al., 2022; Machado et al., 2018). These measures facilitate safer clinical decision-making, particularly in anatomically challenging scenarios.

The acquisition of the technique also presents institutional challenges. Incorporating OD into undergraduate curricula and postgraduate training requires pedagogical revision, access to synthetic training models and, ideally, virtual simulation to mitigate clinical risk. Studies advocate supervised hands-on training with an emphasis on clinical reasoning and manual dexterity, thereby ensuring not only theoretical knowledge but also robust technical competence (Bergamo et al., 2022).

A secondary, yet not negligible, consideration concerns cost. Procuring dedicated burs, motors with precise torque control and reverse rotation, and efficient irrigation systems may constitute a limitation for clinics with restricted resources, hindering dissemination of the technique in less well-equipped settings (Macari et al., 2024).

It should be emphasised that, notwithstanding the advances demonstrated in clinical and laboratory studies, the efficacy of OD is directly contingent upon meticulous adherence to the protocol. Minor deviations—such as excessive force application, irrigation failure or improper bur use—can jeopardise the entire osseointegration process, underscoring the importance of continuing education and continual technical updating (Oliveira et al., 2018; Huwais & Meyer, 2016).

In summary, although osseodensification is emerging as a promising and innovative surgical approach, its clinical implementation is technically demanding, requiring structured training, mastery of operative variables and rigorous execution. The steep learning curve must be acknowledged and addressed through appropriate educational resources to ensure predictability, safety, and efficacy in the therapeutic outcomes of contemporary implantology.

7.2. Conflicting Evidence — A Critical Review of Divergent Findings

Although osseodensification (OD) is widely promoted as an innovative approach in contemporary implant practice, the available body of evidence does not yet permit a definitive consensus to be reached regarding its effects on all the clinical, biomechanical and histological parameters evaluated. A critical appraisal of studies with inconsistent findings is therefore essential, not only to delineate the limitations of the technique but also to highlight the shortage of high-quality randomised clinical trials with large samples and extended follow-up periods.

One of the principal areas of controversy concerns the dissociation observed between the immediate biomechanical benefits afforded by OD and the consistent absence of significant histological gains. The meta-analysis conducted by Gaikwad et al. (2022), based on animal experimental models, confirmed consistent improvements in insertion-torque (IT) values, reinforcing the efficacy of OD in promoting primary stability. However, the data relating to bone-to-implant contact (BIC) and bone area fraction occupied (BAFO) exhibited considerable variability among studies and, in several analyses, the results were not statistically significant. These findings suggest that initial improvements in mechanical performance do not invariably translate into a lasting biological advantage.

The systematic review by Tretto et al. (2018) provides further support for this interpretation. Comparing different methods of implant-site preparation—such as conventional drilling, piezosurgery and OD—the authors observed that, although OD was associated with clear enhancements in insertion torque and removal resistance, no clinically relevant differences were identified in BIC values or marginal bone-loss levels. These data underscore the complexity of osseointegration, indicating that isolated biomechanical indicators are not, in themselves, determinative of long-term clinical success.

In addition, the meta-analysis published by Yu et al. (2022b)—which compared various osteotomy techniques, including OD, osteotomes, piezosurgery, under-drilling and conventional drilling—found, in some of the studies included higher implant-stability quotient (ISQ) values for the OD and under-drilling approaches. Nevertheless, the overall methodological quality of the evidence was rated as ‘moderate’ owing to factors such as heterogeneity in the populations analysed, study design and the absence of clinical trials with prolonged follow-up. This limitation compromises the generalisability of the results to routine clinical practice.

The analysis of in vitro and ex vivo studies reveals further nuances that hinder the direct extrapolation of OD’s benefits to clinical conditions. Cardozo et al. (2022), using polyurethane blocks to simulate Type IV bone, observed that Maximus burs induced greater densification and insertion torque than the Neodent system. However, the absence of biological phenomena such as vascularisation, tissue remodelling and cellular response in these artificial models severely restricts the translation of these findings to real clinical situations.

Similarly, Bittar et al. (2024), in an ex-vivo study involving porcine mandibles, documented significant increases in insertion torque and trabecular density after the application of OD. Nevertheless, no significant differences were detected in ISQ values between the groups examined, suggesting that structural gains do not necessarily translate into immediate improvements in functional stability. This observation underscores the importance of using multiple metrics when evaluating implant performance.

In the clinical sphere, doubts persist regarding the universal applicability of the technique. In a multicenter trial, Bergamo et al. (2022) recorded higher torque and ISQ values throughout the healing phase in implants placed with OD, yet also noted that the beneficial effects were less evident in shorter implants, suggesting that anatomical factors and implant geometry influence outcomes. The authors advocate longitudinal studies to monitor bone changes after functional loading and to validate the efficacy of OD in different clinical scenarios.

Stacchi et al. (2022) compared OD with piezosurgery and concluded that the effectiveness of each approach depends heavily on bone density and the anatomical topography involved. The scarcity of direct comparisons and the variability of the protocols employed hinder the standardisation of clinical indications and weaken the robustness of the conclusions available to date.

Although narrative reviews and case reports frequently ascribe advantages to osseodensification (OD), many of these publications lack stringent methodological control. Macari et al. (2024) acknowledge the technique's potential for enhancing primary stability and shortening the healing period yet emphasise that well-designed comparative clinical trials are still required to prove its superiority in immediate-loading protocols and in situations of marked bone resorption.

In the case study reported by Cisternas et al. (2023), a measurable increase in both the thickness and height of the alveolar ridge was noted following the application of OD in the posterior maxilla. However, the small sample size (n = 9) and the absence of a control group compromise the statistical validity of the findings and preclude generalisation regarding the technique's efficacy in ridge-expansion procedures.

Clinical reports such as those of Andrade and Valiense (2023) support the predictability of OD in posterior maxillary regions presenting bone loss but likewise caution against possible limitations in dense substrates (Types I and II), where excessive compaction may lead to mechanical overload and necrosis, thereby requiring an individually adapted operative protocol.

In summary, osseodensification represents a noteworthy innovation, particularly in contexts involving low-density bone. Nevertheless, methodological diversity, heterogeneous clinical data and the lack of randomised trials with prolonged follow-up currently prevent the technique from being fully consolidated as a reference standard. Its effectiveness should continue to be assessed rigorously, in association with well-defined clinical criteria, robust statistical validation and standardised operative protocols.

7.3 Cost and Accessibility: Economic and Logistical Constraints on Widespread Adoption

Despite widespread recognition of the clinical value of bone densitometry (BD) in the specialized literature, its implementation in everyday clinical practice remains limited by financial, logistical, and operational obstacles. Among the main barriers are the high cost of dedicated equipment, the requirement for specialized technical training, and the still limited scientific consolidation of the technique in long-term clinical studies. These factors raise doubts about its cost-effectiveness, especially in resource-constrained settings (Ferreira Amancio & Hipólito da Silva, 2024; Macari et al., 2024).

Initial investment is among the most frequently cited hurdles. Unlike conventional burs—widely used and inexpensive—OD systems require dedicated kits, such as Densah® burs, which operate in reverse rotation and effect controlled osseous compaction. These kits, often accompanied by surgical motors with specific functionalities (torque control and rotational reversal), impose a considerable financial burden, limiting accessibility for small practices and early-career clinicians (Ferreira Amancio & Hipólito da Silva, 2024).

The adoption of the technique also requires investment in hands-on training. As highlighted by Macari et al. (2024), the learning curve for OD is relatively steep and entails participation in specialised courses, practical sessions with synthetic models and, ideally, supervised clinical mentoring. In addition to the associated costs, this process may temporarily reduce clinical productivity, thereby discouraging uptake among practitioners accustomed to more economical methods with lower operative demands.

Resistance to methodological change is not confined to cost considerations. The conceptual premise of OD—substituting tissue removal with biomechanical condensation—diverges from traditional surgical practice and engenders hesitancy, particularly among clinicians whose experience is rooted in conventional implantology. As Andrade (2023) notes, this technical conservatism, coupled with the need for advanced training and investment in equipment, contributes to the slow and largely limited dissemination of the technique to centres possessing differentiated resources and infrastructure.

Another limiting factor concerns the maturity of the available scientific base. Although encouraging data exist, the clinical evidence lacks methodological standardisation and validation in randomised trials with representative samples. The meta-analysis conducted by Gaikwad et al. (2022), for instance, demonstrated clear biomechanical advantages of OD in animal models, including increases in insertion torque and bone density. However, the authors highlight the absence of controlled human studies that confirm these results across diverse clinical realities. This weakness in the literature restricts the structured inclusion of OD in academic curricula, thereby hindering systematic access for students and practitioners in their initial training.

Tretto et al. (2018) note that, despite the biomechanical benefits associated with osseodensification—namely, the rise in insertion torque and removal resistance—histological and clinical indicators, such as bone-to-implant contact and preservation of the marginal crest, do not show a statistically significant advantage over conventional drilling techniques. This lack of consolidated evidence compromises perceptions of the technique's cost-benefit ratio, leading many clinicians to postpone or avoid investment.

Economically, the ex-vivo data of Bittar et al. (2024) demonstrated that OD promotes substantial increases in trabecular density and insertion torque. Nevertheless, immediate stability values measured by ISQ remained comparable to those achieved with conventional drilling. This dissociation between structural and functional parameters raises doubts about the actual clinical added value of OD in relation to its operational costs.

From an anatomical standpoint, the efficacy of OD continues to show variability according to bone type and implant design. Bergamo et al. (2022) observed positive effects in regions of low-density bone but inconsistent results when the technique was applied to short implants, indicating that morphological limitations and prosthetic design may constrain OD performance.

Accordingly, the generalisation of OD as a first-line solution is restricted by a set of practical obstacles, namely high equipment costs, the requirement for advanced technical training, anatomical variability and the scarcity of long-term clinical trials that unequivocally support its superiority. Overcoming these barriers will necessarily involve developing more affordable instruments, incorporating OD into academic training programmes and conducting randomised multicentre studies to consolidate its scientific evidence.

Until such advances are achieved, OD should be regarded as an approach with significant clinical potential whose application must be carefully considered on a case-by-case basis, taking into account available resources, the patient’s anatomical profile and the therapeutic objectives of each rehabilitation.

8. FUTURE PERSPECTIVES

8.1 Promising Research Areas: Integration with Biomaterials, Cell Therapy and Longitudinal Studies

Osseodensification (OD), acknowledged as a non-subtractive technique for bone preparation in implantology, has been highlighted not only for enhancing primary stability and optimising osseointegration but also for its potential application in more complex regenerative scenarios. Emerging research lines are exploring its combination with advanced biomaterials, cellular therapies and biofunctional solutions, positioning OD as a promising tool for the rehabilitation of extensive defects or for patients with systemic limitations. Alongside these advances, the need for longitudinal clinical studies assessing the durability of implants placed by this means is emphasised to consolidate the technique within contemporary implant practice.

According to Macari et al. (2024), the use of OD in conjunction with osteoconductive and osteoinductive biomaterials offers a new perspective for guided bone regeneration. The compaction of trabecular bone, together with the retention of autogenous particles, creates a dense, biologically active bed that facilitates the integration of grafts or bioactive materials. This environment favours not only mechanical stability but also the incorporation of regenerative materials, with evident benefits for the expansion of atrophic ridges and the reconstruction of more demanding bone defects (Macari et al., 2024; Bonfante et al., 2019).

Complementarily, Mello-Machado et al. (2021) suggest that the technique induces the formation of peri-implant spaces capable of functioning as microenvironments conducive to the retention of blood clots, platelet aggregates, or even mesenchymal stem cells. This characteristic paves the way for the use of OD as a support for cellular therapies, stimulating targeted neo-osteogenesis. The association with implants bearing bioactive surfaces—such as those coated with nano-hydroxyapatite—may further intensify this process, promoting early cellular adhesion and more efficient mineralisation.

The integration of OD with cutting-edge regenerative strategies, including grafts enriched with growth factors (e.g. platelet-rich fibrin or BMP-2) and customised three-dimensional scaffolds, represents a promising clinical research avenue. The possibility of shortening healing times and adopting minimally invasive approaches, even in cases of osseous or systemic compromise, broadens the therapeutic indications of OD and reinforces its relevance within regenerative medicine applied to implantology.

Despite the advances achieved, scientific evidence regarding osseodensification continues to show significant gaps in terms of its long-term effectiveness. Although studies such as that by Tanello et al. (2018), which followed patients for up to 65 months, show promising results in terms of initial stability and success rate, the absence of a control group and the retrospective design of the study limit the generalizability of these findings. It is therefore essential to conduct randomized clinical trials with statistically robust samples and prolonged follow-up.

This need is corroborated by Ferreira Amancio and Hipólito da Silva (2024), who advocate the implementation of sequential evaluation protocols based on clinical and high-resolution imaging examinations. The priority is to verify whether the initial increases in bone density and insertion torque are maintained over the years and whether these results effectively translate into benefits for the functional stability of the implant and the preservation of the peri-implant bone architecture.

In an animal model, Alifarag et al. (2018) demonstrated that OD favours early bone-to-implant contact and the maintenance of prolonged biomechanical stability. Nevertheless, the authors themselves caution against extrapolating these data directly to clinical practice, underscoring the need for human investigations with comparable clinical parameters.

The systematic review by Yu et al. (2022b) reinforces these conclusions by showing that OD performs better in terms of primary stability, particularly in low-density bone substrates. However, the transition between initial (primary) stability and that acquired through biological regeneration (secondary stability) remains poorly understood, constituting a critical point for assessing implant longevity.

Authors such as Bergamo et al. (2022) and Andrade & Valiense (2023) note that, although the initial results of OD are favourable, its long-term clinical validity requires objective validation. The use of cone-beam computed tomography (CBCT), for example, may permit detailed follow-up of bone remodelling, preservation of the marginal crest and maintenance of peri-implant bone volume—determinant variables for confirming the technique's efficacy over time.

In summary, recent advances in osseodensification point to two priority research pathways: on the one hand, deepening its integration with bioactive biomaterials, cellular therapies and emerging regenerative technologies; on the other, conducting multicentric clinical studies with longitudinal monitoring capable of providing high-level evidence to underpin its definitive incorporation into modern implant-surgical protocols. The convergence of these strands could elevate OD to a reference clinical solution capable of meeting the mechanical, aesthetic and biological demands of contemporary oral rehabilitation.

8.2 Expected Technological Advances: Improvements in Burs and Devices, and Integration with CAD/CAM Technology

The continuous evolution of technology applied to implantology has yielded significant gains in surgical accuracy, therapeutic predictability and intra-operative control. Within this context, osseodensification (OD) has become established as a particularly advantageous technique for preparing osteotomy sites in regions of low bone density. For its adoption to become broader and more systematic, it is essential to foster innovations in both instrument design and their compatibility with advanced digital platforms, such as CAD/CAM systems.

A principal focus of development concerns the geometry of the burs employed in the procedure. Densah® burs, devised by Salah Huwais, operate in reverse rotation and compact trabecular bone rather than removing it, thereby delivering controlled densification and greater primary stability (Kanathila & Pangi, 2018). Recent literature indicates, however, that further adjustments to parameters such as cutting angle, fluting configuration and surface coating could reduce operative friction, minimise heat generation and thus diminish the risk of thermal necrosis (Macari et al., 2024).

A study conducted by Bittar et al. (2024) using micro-computed tomography showed that OD performed with Versah® burs produced a significant increase in the volume of bone adjacent to the implant and higher insertion-torque values than those recorded with conventional drilling. Nevertheless, no statistically significant differences were observed in ISQ stability indices, suggesting that although the structural gain is evident, the translation into lasting functional stability remains dependent on other biomechanical and biological factors.

The influence of instrument design on the clinical efficacy of OD is likewise emphasised by Tretto et al. (2018), who demonstrated significant variations in the bone-implant interface according to the type of bur used. These differences directly affect critical parameters such a trabecular contact and resistance to implant micromovement. In response to this challenge, biomedical engineering has been exploring innovative solutions, including burs with optimised ergonomics, integrated sensors and assisted tactile feedback. Alifarag et al. (2018) even highlight the potential of so-called ‘smart burs’, which could automatically adjust drilling depth and torque in line with tissue resistance, thereby providing greater safety in zones of heightened anatomical risk.

In parallel, the integration of these tools with CAD/CAM technologies represents an additional opportunity to increase the predictability and individualisation of procedures. The use of three-dimensional digital planning, personalised surgical guides and real-time bone simulation can enhance the performance of densifying burs, enabling more precise execution and reducing dependence on the operator’s tactile sensitivity.

Digital advances in implantology have profoundly transformed surgical planning and execution methods, providing greater predictability and safety, especially in cases with anatomical challenges. In this context, the integration of osseodensification (OD) with digital workflows, such as CAD/CAM systems, represents a strategic advance. These platforms allow the fusion of images obtained by cone beam computed tomography (CBCT) with intraoral digital impressions, enabling virtual three-dimensional planning of the procedure and the production of customized surgical guides that accurately guide the trajectory of the drills during osteotomy (Yu et al., 2022b).

The compatibility between OD instruments and digital surgical guides is an important step toward standardizing the technique. According to Macari et al. (2024), this integration is particularly advantageous in immediate rehabilitation scenarios in patients with reduced bone volume, as it allows reliable prediction of insertion torque, expected tissue response, and the ideal choice of implant type. This preoperative individualization has the potential to reduce the risk of failure and optimize biomechanical performance from the moment of placement.

The clinical case reported by Rodrigues et al. (2023) clearly illustrates this synergy between bone densification and digital planning. In this study, OD was associated with the Summers technique for transcrestal sinus elevation, with immediate implant placement in the posterior region of the maxilla. The use of dedicated drills in conjunction with a digital surgical guide enabled high insertion torque and immediate clinical stability, reinforcing the potential of the technique in minimally invasive procedures.

Bonfante et al. (2017) and Lahens et al. (2018) underline that the efficacy of OD depends on a precise interplay between implant type, recipient-bone properties and bur configuration. Digitising these parameters and integrating them into three-dimensional planning algorithms could pave the way for intelligent software capable of recommending drilling protocols tailored to each patient's anatomical and biomechanical characteristics.

In the current landscape, we anticipate the development of artificial intelligence-based systems capable of analyzing, in real time, the individual bone density of the patient and automatically suggesting the most appropriate type of drill, as well as the ideal drilling speed and torque. This personalized automation could elevate surgical practice to a new level of precision and safety.

In summary, the expected advances in the field of bone densification focus on two complementary areas: on the one hand, the improvement of drill design, with a focus on ergonomics, functionality, and the minimization of thermal and mechanical risks; on the other hand, the full integration of these instruments with CAD/CAM digital platforms, aiming at a more personalized, predictable, and efficient clinical practice. This convergence between mechanical technology and computational intelligence positions osseodensification as a central technique in the precision implantology of the future.

8.3 Impact on Professional Training: The Need for Specialised Education

Osseodensification (OD) has introduced a new biomechanical approach to preparing implant osteotomies, breaking with the traditional paradigm of subtractive techniques. By employing reverse-rotating burs to compact trabecular bone, OD obliges the clinician not only to adopt new instruments but also to acquire specific technical and scientific competencies—chiefly the control of compressive force, operative speed and the adaptation of torque to the bone type. The growing consolidation of the technique in clinical practice reinforces the need to update training models and to incorporate targeted content into higher-education programmes.

Since its formulation by Huwais and Meyer, OD has proven particularly useful in challenging clinical scenarios, such as maxillary resorptions and immediate loading contexts (Lahens et al., 2016; Pai et al., 2018). The technique's effectiveness, however, depends on an in-depth understanding of bone-tissue response to mechanical compaction, demanding a broader educational approach than that provided by conventional implant courses.

Kanathila and Pangi (2018) emphasise that the success of OD hinges on judicious decisions regarding the burs employed, the correct adjustment of operative parameters and mastery of the patient's osseous architecture. These factors make guided hands-on training, grounded in up-to-date scientific evidence, indispensable.

According to Macari et al. (2024), OD should not be regarded merely as an instrumental evolution but as a methodological reconfiguration requiring the revision of conventional curricula. Beyond manual dexterity, practitioners must develop clinical reasoning adapted to the new biomechanical demands of bone compaction. Simply transposing classical drilling protocols does not secure the technique's benefits; it is essential to embed teaching models that integrate theory, supervised practice and three-dimensional simulation.

The learning curve associated with OD can be steep, particularly when it is applied to more complex procedures, such as transcrestal sinus elevation or the immediate placement of implants in freshly extracted sockets. As Ferreira Amancio and Hipólito da Silva (2024) emphasise, the safe execution of these approaches requires systematic training in a controlled environment, combining theoretical knowledge with supervised practice. The specialised literature further warns that errors in bur handling, rotational direction or axial-force application can compromise clinical outcomes, reinforcing the importance of structured technical education.

Academic institutions and training centres have been incorporating OD into postgraduate and continuing education programs through methodologies that blend biomechanical and biological fundamentals with practice on synthetic models or animal tissues (Rodrigues et al., 2023). This format enables practitioners not only to grasp the principles of the technique but also to develop the operative skills required for its application in challenging clinical contexts.

The variability among different drilling systems, as demonstrated by Tretto et al. (2018), demands that clinicians understand the specific properties of each bur set, from their potential for bone expansion to their impact on primary stability and stress distribution. In the same vein, Bergamo et al. (2022) note that technical failures during drilling are often linked to a lack of knowledge of the torque and speed protocols recommended by each manufacturer.

In procedures involving anatomically complex areas, such as the posterior maxilla, the training requirement is even more pronounced. Andrade and Valiense (2023) stress that reduced bone density, proximity to the maxillary sinuses and anatomical variability necessitate absolute precision in execution, making the application of OD inadvisable without prior appropriate training and consolidated practical experience.

In addition to practical training, access to specialized literature and protocols supported by scientific evidence is essential for the development of clinical competence. Research such as that by Bonfante et al. (2017) and Alifarag et al. (2018) should be included in the reading plan for professionals in training, encouraging not only technical repetition but also critical thinking regarding the indication of bone densification based on bone conditions and specific therapeutic objectives.

In summary, the safe and effective application of bone densification depends heavily on the technical qualifications of professionals. The specificity of the instruments, the unconventional biomechanical logic, and the need to adapt to different anatomical situations make it imperative to include the technique in formal academic curricula and continuing education programs. This educational investment is essential to ensure the responsible adoption of bone densification and maximize the clinical benefits that the technique offers in contemporary oral rehabilitation.

9. CONCLUSION

Osseodensification has established itself as an innovative surgical approach in contemporary implant dentistry, demonstrating particular effectiveness in anatomically unfavourable regions, such as areas of low bone density. By replacing the traditional subtractive logic with a controlled bone compaction mechanism, this technique has enabled significant advances in the volumetric preservation of the recipient bed and in the primary stability of implants.

Experimental models have demonstrated that the use of specific drills for bone densification favours the microstructural reorganisation of bone tissue, with relevant clinical effects, namely increased insertion torque and peri-implant trabecular thickness. These structural changes result in greater predictability for immediate rehabilitation, even in compromised substrates.

In addition, the benefits extend to the healing phase, promoting faster healing thanks to the preservation of bone vascularisation and the generation of autogenous grafts in situ during osteotomy. This feature is particularly advantageous in contexts where aesthetic and functional rehabilitation time must be reduced.

The integration of this technique with procedures such as transcrestal maxillary sinus elevation has provided considerable vertical gains, allowing the simultaneous placement of implants with safety and predictability, even in cases of severe bone resorption. Its applicability to different clinical situations, combined with a learning curve compatible with daily practice, reinforces its value as a versatile tool.

From a functional and aesthetic point of view, bone densification favours the use of short or small-diameter implants in locations previously considered unfeasible, minimising morbidity and increasing postoperative comfort. In this sense, the objectives outlined in this review – to identify the advances and clinical benefits of the technique, as well as to explore its limitations – were fully achieved.

Despite the progress achieved, the available evidence still calls for caution. The absence of longitudinally robust studies currently prevents definitive validation of its long-term benefits. The current literature is largely based on preclinical studies, case reports, and trials with short follow-up periods, limiting the extrapolation of results.

It is therefore essential to prioritise randomised, multicentre clinical investigations with representative samples and follow-up periods of more than five years. The analysis of the bone-implant interface from biomechanical and histomorphometric perspectives, as well as the comparative evaluation of the different drill geometries available, are promising areas of study.

In addition, there remains a gap in knowledge about the performance of the technique in high-risk populations, such as osteoporotic patients, chronic smokers, or those with metabolic comorbidities. Systematic evaluation of these subgroups will allow for a more accurate understanding of the therapeutic scope of bone densification.

Finally, convergence with digital technologies, such as CAD/CAM systems and artificial intelligence, could usher in a new era of personalised planning and greater surgical precision, contributing to the individualisation of treatments and the mitigation of surgical errors.

In summary, osseodensification presents itself as a promising strategy for redefining bone preparation protocols in implant dentistry. Its growing scientific validation and observed clinical versatility justify its progressive adoption, provided it is accompanied by adequate technical training and continuous professional updating.

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