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OSSEODENSIFICATION

A Novel Implantologic System VS Traditional Implantologic System

João Paulo Alves Fontes Pereira

Tese conducente ao **Grau de Doutor** em **Ciências Biomédicas**

—

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Trabalho realizado sob a Orientação de

Professor Doutor Marco Infante da Câmara

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Abbreviations

BAFO – Bone Area Fraction Occupancy

BIC – Bone Implant Contact

BL – Bucco-Lingual

BLT – Bone Level Tapered

BV—Bone volume;

CCW—Counterclockwise;

CI- Confidence Interval

CW—Clockwise;

ED—Extraction drilling;

F—female

HU – Hounsfield Units

IDR—Immediate dentoalveolar restauration

ISQ - Implant Stability Quotient

IT – Insertion Torque

JBI- Joanna Briggs Institute

LCL—Lower Control Limit

M—male

MD – Mesio-Distal

N—no

n—number of subjects and percentages

NA-Not Applicable

NC- Narrow Connection

Ncm – Newton/cm

NR—Non-referred

OD – Osseodensification

RC- Regular Connection

RFA – Resonance Frequency Analysis

RTV—Removal torque value

SD- Subtractive Conventional Drilling

SLA- Sand blast large grit acid-etched

SO—Summers' osteotome

T1 – ISQ First Measurement (surgical time)

T2 – ISQ Second Measurement (6 months)

T3 – ISQ Third Measurement (1 year)

TET—Threaded expander surgical technique

TM implants—Trabecular metal implants

TSV implants—Twisted screw-vent implants

UCL—Upper Control Limit

UN- Uncertain

VAM- Value of the actual micromotion.

Y—yes

Resumo

A osseodensificação é um método inovador para realização do leito implantar com recurso a brocas que promovem a auto-compactação óssea. O principal objetivo desta técnica é promover a densificação óssea peri-implantar e a compactação do osso autólogo e aumentar a estabilidade primária do implante devido às características viscoelásticas do osso alveolar, utilizando brocas Densah® no sentido anti-horário a uma velocidade de 800 a 1500 rpm. Foi realizada uma pesquisa utilizando a estratégia que incluiu bases de dados eletrónicas de 2016 a 2023 por dois revisores independentes. As bases de dados utilizadas foram: MEDLINE via PubMed, Cochrane Library, Scopus, and Web of Science (de 2013 a 2023) dos últimos 10 anos. Estudos realizados em humanos e animais foram considerados. Foi utilizada a seguinte estratégia de pesquisa: (implante dentário [MeSH Terms]) AND (osteotomia [MeSH Terms]); ((osteotomia) OR (osseodensificação)) AND (dental implants). Os resultados demonstram a vantagem da técnica de osseodensificação em relação à perfuração convencional, permitindo um aumento da densidade óssea e da estabilidade primária do implante, da densidade óssea e do contacto osso-implante. A técnica de osseodensificação pode ser aplicada em diferentes situações clínicas: enxertos ósseos sub-antrais, cristas ósseas alveolares estreitas, áreas de baixa densidade óssea e colocação imediata de implantes em alvéolos pós-extração. Foi elaborado um projeto de investigação de acordo com as normas legais e aprovado pela Comissão de Ética do Instituto Universitário de Ciências da Saúde - CESPU. Após concordância em participar no estudo e assinatura do consentimento informado, foram colocados 278 implantes em 90 pacientes do Programa de Pós-Graduação em Implantologia Oral da Clínica Universitária da CESPU. O quociente de estabilidade (ISQ) dos implantes foi medido pelo investigador principal e pelo seu supervisor em três momentos diferentes (T1, T2 e T3). O principal objetivo deste estudo foi avaliar a eficácia do protocolo de perfuração de osseodensificação versus a técnica cirúrgica convencional na estabilidade dos implantes. De acordo com a ANOVA multifatorial, houve diferenças estatisticamente significativas nos valores médios de IT em função apenas da arcada (F (1,270) = 4,702, p-valor = 0,031 < 0,05). Em relação ao comprimento do implante, houve diferenças estatisticamente significativas na média do IT no grupo OD (p = 0,041), com valores médios de IT significativamente menores para os implantes Regulares em relação aos Longos. Relativamente à arcada, as análises dos valores globais do ISQ mostraram uma tendência ascendente em ambos os grupos na maxila e na mandíbula. Os níveis elevados de IT também mostraram valores elevados de ISQ, que representam bons indicadores de estabilidade primária. A OD não tem uma influência negativa na osteointegração em comparação com a osteotomia subtrativa convencional.

Palavras-chave: osseodensificação; baixa densidade óssea; estabilidade do implante; osseointegração; análise de frequência de ressonância; torque de inserção.

Abstract

Osseodensification is an innovative method of preparing the implant osteotomy using drills that promote bone self-compaction. The main objective of this technique is to promote peri-implant bone densification and compaction of autologous bone and to increase the primary stability of the implant due to the viscoelastic characteristics of the alveolar bone using Densah® burs in a counterclockwise direction at a speed of 800 to 1500 rpm. A search was carried out using the search strategy included electronic databases from 2016 to 2023 and was performed by two independent reviewers. The electronic databases used were MEDLINE database via PubMed, Cochrane Library, Scopus, and Web of Science (from 2013 to 2023) referring to the last 10 years. Studies carried out with humans and animals were included. The following search strategy used was: (dental implant [MeSH Terms]) AND (osteotomy [MeSH Terms]); ((osteotomy) OR (osseodensification)) AND (dental implants). The results demonstrate the advantage of the osseodensification technique in relation to conventional drilling, allowing an increase in the bone density and primary stability of the implant, bone density, and bone–implant contact. The osseodensification technique can be applied in different clinical situations: sub-antral bone grafts, narrow alveolar bone crests, low-density bone areas, and immediate implant placement in post-extraction sockets. A research project was designed in accordance with legal regulations and approved by the Ethics Committee of the University Institute of Health Sciences - CESPU. After agreeing to take part in the study and signing an informed consent form, 278 implants were placed in 90 patients at the Oral Implantology Postgraduate Programme at the CESPU University Clinic. The stability quotient (ISQ) of the implants was measured by the principal investigator and his supervisor in three different times (T1, T2 and T3). The main objective of this study was to assess the effectiveness of the osseodensification drilling protocol versus the conventional surgical technique on implant stability. According to the multifactorial ANOVA, there were statistically significant differences in the mean IT values due to the arch only (F (1.270) =

4.702, p-value = 0.031 < 0.05). Regarding the length of the implant, there were statistically significant differences in the mean IT in the OD group (p = 0.041), with significantly lower mean IT values for the Regular implants compared to the Long. With respect to the arch, the analyses of the overall ISQ values showed an upward trend in both groups in the maxilla and mandible. High levels of IT also showed high ISQ values, which represent good indicators of primary stability. OD does not have a negative influence on osseointegration compared to conventional subtractive osteotomy.

Keywords: osseodensification; low bone density; implant stability; osseointegration; resonance frequency analysis; insertion torque.

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CHAPTER I – Introduction

1. Background and objectives

A dental implant, also known as an endosseous implant, is a surgical device that establishes a connection between the bone of the maxilla or mandible and a dental prosthetic component. There are multiple factors to consider before selecting the type of oral rehabilitation to perform, in order to achieve the much desired 90 per cent success rate (1).

Factors such as bone mineral density, anatomical variations, trauma, natural bone resorption, racial considerations, surgical techniques affect implant stability and play a major role in the rehabilitation longevity (2-4). Implant stability can be defined as the mechanical retention between the implant and the bone and the biological relationship that is achieved by osseointegration (1).

Brånemark PI defined osseointegration as the direct connection between living bone and a load-bearing endosseous implant at the light microscopic level (5). Osseointegration may not be achieved when there is a lack of negative responses in the peri-implant tissue, generated, for example, by surgical trauma, infection, or insufficient primary stability (1).

Several innovations have been made over the years regarding implant design to improve primary stability and osseointegration. Recently, the concept of osseodensification was introduced by Huwais S. The author described a new concept of drilling with non-cutting specially designed drills to increase bone density and bone expansion (6).

The theory behind this technique is based on the projection of the drill, which allows the creation of an environment that increases initial primary stability through non-subtractive drilling. The justification for using this process is that the densification of the bone in contact with the dental implant, will result in greater primary stability due to wider contact areas, but also in faster bone remodelling due to the nucleation of osteoblasts in the instrumented bone, which is in close proximity to the implant (6). In contrast to the traditional drilling process, which uses a positive angle of inclination to extract a small thickness of bone with the passage of each drill creating an osteotomy with no bone residue remaining in the drill hole (7).

The drilling process using osseodensification begins with the creation of an osteotomy using a conical, multi-laminated drill with a negative angle of inclination to create a compact layer of dense bone that surrounds the osteotomy wall (7).

The densifying drill has a cutting chisel and conical shape that allows it to progressively increase the diameter as it is moved deeper into the implant bed, which controls the expansion process that takes place at high speed. It can operate both counter-clockwise and clockwise, where the former exerts the densification process more efficiently than the latter and is therefore indicated for low and high density bone respectively (7).

These concepts will make it possible to differentiate osseodensification from the traditional method, and to conclude whether there is a better treatment option that drastically disrupt traditional drilling procedures in implant dentistry.

In order to assess and compare the stability of the implants according to the different techniques, the Osstell® resonance frequency measuring device was used to measure implant stability, a crucial factor in osseointegration, which consequently affects the longevity of oral rehabilitation.

The main objective of this project was to assess the advantages/disadvantages of this new implantological system, which diverges from traditional concepts of oral implantology. This study could make an important contribution to daily clinical practice, providing access to a set of tools that could eventually ensure greater success in oral rehabilitation with dental implants, as well as guaranteeing their longevity.

1.1 Anatomical and pathophysiological considerations of bone

In implant placement surgery, it is important to consider the different types of bone in the jaws, as well as to understand the biological response of the tissues both in post-exodontia bone resorption and in subsequent implantation. Considering the variability of bone between different individuals and in the same individual, it is essential to understand the different types of bone and their classifications in order to increase the predictability of osseointegration and, consequently, guarantee the success of rehabilitation with dental implants.

1.2 Tissue response to implantation

A series of cellular and extracellular biological processes occur at the bone-implant interface during the process of bone healing surrounding implants, culminating in the appearance of freshly created bone covering the implant surface (2). These biological events include the initial host response-like activation of osteogenetic mechanisms that are similar to the bone healing process (3-5). At the bone-implant interface, stimulated blood cells release growth and differentiation molecules that control this series of biological events (6).

A growing body of research has examined the mechanical and histological aspects of the skeleton's response to trauma, with a particular focus on the molecular biology of this phenomena. The existence of following implantation alters the host's reaction. The features of the implant, the stability of the fixation, and the intraoperative heating damage, which include the death of osteoblasts extending 100–500 Åm into the host bone (2-5).

Following the insertion and mechanical fixation of cementless implants, major stages of the skeletal reaction to implantation-associated damage and important histology events connected to the host response include hematoma development and mesenchymal tissue growth, the creation of woven bone via the intramembranous route, and the development of lamellar bone above woven bone spicules. Blood is the first biological material that comes into touch with an endosseous implant. After leaving post-capillary venues, blood cells, including red blood cells, platelets, and inflammatory cells like polymorphonuclear granulocytes and monocytes, go into the tissue surrounding the implant. Activated blood cells trapped at the implant interface emit soluble growth and differentiation agents, including cytokines (6).

Clot development is influenced by the blood cells' initial interactions with the implant. In reaction to the foreign surface, platelets experience morphological and metabolic changes such as adhesion, spreading, aggregation, and intracellular biochemical alterations include phospholipid hydrolysis, intracellular calcium rise, and phosphotyrosine induction. In the healing compartment, the fibrin matrix that has created serves as a scaffold (osteoconduction) for the migration of osteogenic cells and their eventual differentiation (osteoinduction). Osteogenic cells directly contact the majority of the implant surface to generate osteoid tissue and new trabecular bone, which eventually remodels into lamellar bone (osseointegration) (6-8).

From the first day following implantation, osteoblasts and mesenchymal cells appear to migrate and adhere to the implant surface, depositing proteins associated to bone formation and forming a noncollagenous matrix layer that controls mineral binding and cell adhesion. On the implant surface, this matrix is an early-formed calcified afibrillar layer including laminae limitans, a continuous layer that is 0.5 mm thick and rich in calcium, phosphate, osteopontin, and bone sialoprotein, as well as weakly mineralized osteoid that resembles the bone cement lines (9).

1.2.1 Peri-implant osteogenesis

Both in proximity to and in touch with the host bone can occur during peri-implant osteogenesis. The term "distance osteogenesis" describes the newly developed peri-implant bone trabeculae that from the surface of the implant to the host bone cavity. On the other hand, the term "contact osteogenesis" describes the growth of peri-implant bone that extends from the implant to the healing bone. The recently developed network of bone trabeculae encircles the bone gaps, which are home to numerous mesenchymal cells and extensive blood arteries, and assures the biological fixation of the implant. Osteoblasts develop a thin layer of calcified and osteoid tissue immediately onto the implant surface. Where there is no calcified tissue, the voids are filled with mesenchymal cells and blood vessels (6, 10, 11).

The thin layer of calcified collagen fibrils, flat osteoblast-like cells, and a slightly mineralized area at the interface between a titanium implant and bone was initially reported by Murai *et al.* (9). Following osteoclastic activity, the newly produced bone was deposited on the old bone's surface that had been reabsorbed. This implied that the implant surface is favorably identifiable to the osteogenic cells as a biomimetic scaffold that could support osteogenesis in the early stages of the peri-implant phase. Poorly mineralized osteoid cement lines indicated the point at which bone production began and bone resorption was finished. Even osteoblasts in close proximity to the implant surface started to deposit collagen matrix immediately a few days after implantation the layer on the implant surface known as the lamina limitans or early developed cement line. Because osteoblasts can't always travel quickly enough to avoid being totally encased in the calcifying matrix's mineralizing front, these osteoblasts congregated as osteocytes in bone lacunae (9).

The organization of the woven bone and bone trabeculae comes after the early deposition of fresh calcified matrix on the implant surface. This exhibits a very active large surface area that is contiguous with marrow regions rich in vascular and mesenchymal cells, which is ideal for the periimplant bone healing process. Rich vascular marrow tissue promotes mononuclear precursors of osteoclasts, allowing bone trabeculae to rebuild more quickly than cortical bone (11).

The production of woven bone happens quickly on implants at first in order to maintain continuity, despite the fact that the random orientation of its collagen fibers means that it has less mechanical strength than lamellar bone. Initial gaps at the implant-bone interface are filled by woven and trabecular bone. It has a strong resistance to early implant loading and is arranged in a regular network in three dimensions. The biological scaffold for cell attachment and bone deposition that is biological fixation is provided by its physical architecture, which includes arches and bridges (11, 12). It is ensured that tissue anchoring matches to the implant's biological fixing via early peri-implant trabecular bone formation 10 to 14 days following surgery is when this starts.

Biological fixation differs from primary (mechanical) stability that is easily obtained during the implant insertion. Biological fixation of the implant involves biophysical conditions such as primary stability that is implant mechanical fixation, biomimetic implant surface and right distance between the implant and the host bone. It is prevalently observed in rough implant surfaces (11). Next, woven bone is progressively remodeled and substituted by lamellar bone that may reach a high degree of mineralization. At three months post-implantation, a mixed bone texture of woven and lamellar matrix can be found around different types of titanium implants (3, 13).

Regular osteons and host bone chips encased in mature bone can be found in peri-implant bone. Flattened cellsak covers the implant surface. The inter-trabecular marrow gaps at the bone-implant interface are bounded on one side by the titanium surface and on the other by newly created bone that is rich in blood vessels and cells (11). Between the implant and the host bone cavity, host bone chips most likely result during surgical bur preparation or implant placement. Encased in a recently generated peri-implant trabecular bone, these appear to play a role in trabecular bone formation in the initial weeks of implant healing, meaning that they aid in the biological fixation of the implant by promoting and directing peri-implant osteogenesis as a biological material that is both osteoconductive and osteoinductive. Thus, in clinical practice, it might be advantageous to aspirate the bone cavity prior to or during implant insertion rather than cleaning with a saline solution (14).

On the implant side, there have been reports of both in vitro and in vivo metallic implant oxidation (3). A joint replacement implant's cementless fixation takes place within the framework of the surgical trauma sustained during installation. Cementless fixation connects the implant at its surface through freshly generated bone tissue, as opposed to cemented fixation, which uses the interdigitation of cement and the surrounding trabecular bone to offer a degree of fixation. The creation and maintenance of a strong bond between the implant and host skeleton are essential for the success of cementless fixation (15, 16).

The decrease in osteogenic cell number and/or activity, the increase in osteoclastic activity, the imbalance between anabolic and catabolic local factors acting on bone formation and remodeling, the abnormal bone cell proliferation rate and response to mechanical stress and systemic and local stimuli, and the impaired vascularization of the peri-implant tissue are major factors contributing to the failure of peri-implant osteogenesis (17). The process of osseointegration depends critically on vascularization. Osteogenic cell differentiation is exclusively dependent on tissue vascularity. The process of ossification and the revascularization of the developing tissue are closely associated. Age also reduces biomaterial osseointegration because it hinders angiogenesis. Implant failure risk in the elderly is increased by the correlation between osteoporosis and poor angiogenesis (17).

1.2.2 Peri-implant bone remodeling

In order to respond to stress and mechanical loading, bone that comes into touch with the implant surface goes through morphological remodeling. The presence of medullary or marrow gaps containing osteoclasts, osteoblasts, mesenchymal cells, and lymphatic/blood arteries adjacent to the implant surface confirms the turnover of peri-implant mature bone in osseointegrated implants. New osteons form circles around implants during peri-implant bone remodeling, with their long axes aligned perpendicular to the implants' long axis and parallel to the implant surface. Osteoblasts create osteoid tissue, indicating that osteogenesis is in progress up to 1 mm of the remodeled bone may protrude from the implant surface (11, 13).

1.2.3 Bone classification

Tooth loss is often followed by a complex biophysical process known as residual ridge resorption. This process reaches its highest point in the first year after tooth loss and then resorption continues at a slower but steady pace in the following years (18, 19). All edentulous patients suffer from bone resorption, which is a chronic, gradual, and irreversible process (20). The availability of cortical and trabecular bone at the implant interface may affect the biomechanical stability of the implant and the bone healing response (21, 22). For this reason, it is important to understand the particularities, characteristics, and differences and anatomy of the maxilla and mandible.

1.2.3.1 Lekholm and Zarb (1985)

According to the Lekholm and Zarb (1985) classification (the most popular classification of bone quality), bone types are classified based on the amount of cortical versus trabecular bone from I to IV (23-25). The biomechanical properties of osteoporotic bone are similar to those of type IV bone, and do not provide appropriate stability for implants.

1.2.3.2 Cawood and Howell (1988)

In 1988, to simplify the description of the residual ridge and thus aid communication between clinicians, Cawood *et al.* (26) developed a classification of edentulous jaws based on a randomized cross-sectional study. According to this classification, the residual ridge is classified into six classes (Class I to Class VI) according to the type of bone loss in height and width (26). In the posterior maxillary region, bone loss is both vertical and horizontal (from the buccal aspect).

1.2.3.3 Carl E. Misch (1996)

Carl E. Misch suggested a straightforward technique for evaluating bone types in for dental implant sites that has proven to be quite effective. Bone categories are categorized as follows: type I bone (D1) is found in dense cortical bone. Type II bone (D2) presents less dense cortical bone. Type III bone (D3) consists of a porous crestal layer of cortical bone and fine trabecular bone underneath. Type IV bone (D4), is composed of primarily fine trabecular bone and often the absence of cortical bone. The primary distinctions between these bone types are made on the basis of density and quality of osteocytes. The main types of bone are cortical bone and cancellous osseous tissue. In some cases, it is also satisfactory to utilize an intermediate bone type that is an association of other types of bone (27). Type 1 is found in the anterior mandible, Hounsfield unit (HU) reading of 1250 and above. Type 2 is commonly found in the anterior and posterior mandible, HU reading between 850 and 1250 units. Type 3 is found in anterior and posterior maxilla and sometimes in the posterior mandible, HU reading between 350 and 850 units. Type 4, mostly be found in the posterior maxilla and poses the greatest challenge in implant placement. A Hounsfield reading between 150 and 350 units is indicative of D4 bone (27).

1.2.3.4. Norton and Gamble

Bone density is another important aspect according to anatomical location which is characterized by the Norton and Gamble classification. Norton and Gamble described different bone density range according to their typical anatomical locations in the maxilla and mandible. All of the subjectively rated areas in each of the four qualities were subsequently grouped together so that a range of Hounsfield (HU) values could be assigned to each specific quality (28) . Low-density bone (type III and type IV), commonly seen in the posterior mandible, especially in elderly patients, represents a high percentage of those seeking implant treatment. On the other hand, high-density bone (type I and II), is commonly seen in the anterior mandible (28).

1.3 Osseointegration

Osseointegration is a fundamental concept in oral implantology, describing the process by which the dental implant bonds with the adjacent bone, forming a stable and functional connection. This direct integration between implant and bone is essential for the long-term success of implant treatments, providing stability and support for dental prostheses.

1.3.1 Concept

The term osseointegration was introduced by the Swedish orthopaedic surgeon Per-Ingvar Brånemark, who observed the ability of titanium implants to integrate into bone during an experimental study in 1950. Brånemark PI was initially investigating blood circulation in living bones when he realised that titanium implants could not be removed from the bone of rabbits without causing significant damage to the surrounding tissue. This phenomenon was the initial milestone in understanding osseointegration and its application in dentistry. *Brånemark PI* defined osseointegration as "A direct connection between living bone and a load-carrying endosseous implant at the light microscopic level (29).

Osseointegration is a complex biological process that involves several stages, from implant insertion to healing and maturation of the bone tissue around the implant. The main mechanisms of osseointegration include cell adhesion and migration, extracellular matrix formation, bone mineralisation and bone remodelling (30).

After the implant is inserted into the bone, bone cells, such as osteoblasts, adhere to the surface of the implant. These cells are responsible for producing bone matrix and forming a solid interface between the implant and the bone. Osteoblasts deposit an extracellular matrix composed mainly of collagen, which serves as a substrate for bone mineralisation. During the healing phase, calcium and phosphate ions are deposited in the newly formed bone matrix, promoting mineralisation and strengthening of the bone around the implant. After initial healing, the bone undergoes a continuous process of remodelling, in which it is formed and resorbed in response to biomechanical needs (30).

1.3.2 Primary and secondary stability

Achieving good primary stability at the end of surgery (which can be defined as biomechanical bone-implant engagement with micromovements of less than 150 μm) has been considered essential for successful osseointegration and for predicting loading time (1). Clinically, the degree of primary implant stability can be estimated objectively by insertion torque (IT) values using surgical handpieces or through the implant stability quotient (ISQ) by analysing resonance frequency. IT values above 35 Ncm or ISQ values above 68 were considered reasonable values for more predictable osseointegration, early loading or immediate loading, suggesting that such values should not only be achieved after implant placement, but ideally these values should be maintained during the initial course of osseointegration (31-33).

1.3.3 Implant Stability Quotient (ISQ)

ISQ data is essential to monitor implant stability at different stages of the healing process and over time after prosthetic loading. The ability to objectively record and monitor implant stability is key to evaluate the effectiveness of surgical and therapeutic procedures and to identify any early problems that may arise during the healing process. In addition, ISQ results can be compared with established reference values to help interpret the results. Scientific literature and clinical data accumulated over time provide average ISQ values for different types of implants, bone tissues and surgical techniques. These range values guide professionals to assess whether the patient's ISQ results are within ranges considered normal for their specific situation.

Accurate interpretation of ISQ results is essential to ensure the long-term success of dental implant treatments. Consistently low ISQ values over time can indicate lack of osseointegration. On the other hand, consistently high ISQ values over time are generally indicative of robust and stable osseointegration, suggesting a good prognosis for the implant in the long term. However, it is important to interpret ISQ results within the patient's overall clinical context, taking into account factors such as systemic health, oral hygiene habits and possible complications that could influence implant stability (31, 34).

In addition to monitoring implant stability, ISQ data can also be useful for guiding prosthetic loading. Determining the ideal time for prosthetic loading can be based on implant stability, as assessed by the ISQ, along with additional clinical considerations, such as the quality of the surrounding bone and the patient's general health.

1.3.4 Osstell®

Osstell® equipment was introduced to the market as a tool for measurement implant stability quotient (ISQ) in 1996, revolutionising the way professionals assess implant integration into adjacent bone. Since then, the equipment has undergone several interactions and updates to improve its accuracy, usefulness and reliability.

Osstell® uses the resonance frequency analysis (RFA) technique to calculate the ISQ based on the principle that the natural vibration frequency of an implant is related to its structural stability. During the measurement procedure, a vibration transducer is placed on the implant head and a specific frequency is applied. Osstell® records the implant's resonance response and calculates the ISQ based on this data. The ISQ measurement protocol is a standardised procedure designed to guarantee accurate and consistent results (31, 32, 34).

The ISQ measurement protocol, directly influences the accuracy and reliability of the results obtained. It is crucial to remove any soft tissue that could interfere with the placement of the vibration transducer. This includes inflamed gingiva, excess scar tissue or any other structure that could jeopardise direct contact between the transducer and the implant surface. The presence of soft tissue can cause artefacts in the results, compromising the accuracy of the ISQ measurement. Therefore, careful removal of these structures is essential to ensure reliable results. Any residue of blood, saliva or other body fluids can interfere with the ISQ measurement, resulting in inaccurate readings. It is therefore recommended to thoroughly clean the area using antiseptic solutions and dry it carefully with a sterile cotton pad or air (31, 34).

When positioning the vibration transducer in the Smartpeg®, it is essential to ensure firm and stable contact between the Smartpeg® and the implant surface. This is essential to enable the efficient transmission of vibrations and the accurate capture of the implant's resonance response. Inadequate contact can result in inaccurate ISQ readings, jeopardising the assessment of implant stability. In addition, it is important that the transducer is correctly aligned with the implant's axis. Any misalignment can distort the ISQ reading, leading to inconsistent and unreliable results. Therefore, professionals should take the time to position the transducer accurately, ensuring that it is properly aligned with the implant's longitudinal axis. It is therefore essential to carry out a careful inspection of the engagement of the Smartpeg® in the implant connection to ensure it is secure and stable before ISQ reading (31, 33, 34).

With the transducer properly positioned, the stage of applying the specific resonance frequency to the implant using Osstell® begins. This moment is crucial in the ISQ measurement protocol, as it is during this phase that the implant's resonance response is analysed, providing vital information on its structural stability and osseointegration. During the process, the transducer emits a controlled vibration at the implant connection, which propagates through the surrounding bone. This vibration induced by the transducer generates a resonance response in the implant and adjacent bone tissue. The ISQ measurement process usually takes just a few seconds, during which time the equipment records and analyses the implant's resonance response (31, 33, 34).

After capturing the implant's resonance response, the ISQ is calculated. This numerical score ranges from 1 to 100 and is essential for assessing implant stability and bone integration. Higher values indicate greater implant stability, while lower values may suggest less ideal bone integration or stability problems that require clinical intervention. Accurate calculation of the ISQ is fundamental to providing implantology professionals with reliable information on the state of the implant and guiding subsequent clinical decisions.

Recording and interpreting ISQ results plays a key role in the management of patients undergoing dental implant treatment. This evidence-based approach provides objective, quantitative information on implant stability and osseointegration, enabling accurate assessment of treatment progress and informed clinical decision-making to ensure successful long-term results. By providing a quantitative measure of implant stability, ISQ helps professionals determine the appropriate time to load the implant with a dental prosthesis. Implants with lower ISQ may indicate incomplete bone integration, suggesting the need for more healing time before functional loading (31, 33, 34).

1.4 Osseodensification

Osseodensification has proven to be effective in areas of compromised bone, enabling oral rehabilitation with implants even in regions where more complex techniques, such as bone grafts, would traditionally be required. For professionals in the field of oral implantology, osseodensification represents a significant evolution in clinical practice, offering greater predictability in results, less morbidity for patients and a greater ability to face anatomical challenges more safely. A thorough understanding of this technique and its skilful incorporation into clinical practice are essential for providing patients with advanced, efficient rehabilitation centered on quality results.

1.4.1 Concept and technique

Osseodensification is a new biomechanical method of bone preparation for the placement of dental implants. The procedure is characterised by the plastic deformation of the bone that is created by rotating and oscillating contact using a densifying drill manufactured in such a way that it densifies the bone through minimal temperature rise. Osseodensification is a non-subtractive technique developed by Huwais S that uses specially designed drills (Densah®) to densify the bone while preparing an osteotomy (35). These drills are advantageous over traditional drills and osteotomes. Traditional drills extract bone during the osteotomy and osteotomes tend to induce fractures in the bone trabeculae, which will cause a longer bone remodeling time and, consequently, delay the secondary stability of the implant. Osseodensification drills allow bone preservation and condensation through autograft by compacting the bone during osteotomy, thus increasing peri-implant bone density and improving the mechanical stability of the implant (35-39).

Bone remodeling requires 12 weeks to repair the area damaged by traditional drills that extract a substantial amount of bone, while osseodensification preserves bone tissue and increases its density, thus shortening the healing period (35, 39).

Unlike traditional osteotomy, osseodensification does not extract bone, but simultaneously compacts and autografts particulate bone in the external direction to create the implant bed, thus preserving vital bone tissue. This is achieved using specialised densifying drills. When these drills are used at high speed in a counter-clockwise direction with constant external irrigation, densification mode, compact bone tissue is created along the walls of the osteotomy (40). The pumping movement (in and out movement) creates a tension that allows the saline solution to gently press on the bone walls. This combination facilitates an increase in bone plasticity and bone expansion. Huwais S showed that osseodensification helped to expand the crest while maintaining the integrity of the alveolar crest, thus allowing implants to be placed in autogenous bone, achieving adequate primary stability (36, 38, 41). Thus, it can be seen that osseodensification allowed bone preservation.

1.5 Literature review

The development of the concept of osseointegration by Branemark PI *et al.* (29) revolutionised the rehabilitation of total and partial edentulous individuals, providing stability and long-term, high success rates in dental implants (1, 29, 42-45). Osseointegration corresponds to the stable and functional union between the bone and the implant surface, which is crucial for its stability and success (21, 46).

Primary stability is considered one of the most important factors for implant success, which is related to the bone density, surgical protocol, type, and geometry of the implant (21, 46). There are methods such as Resonance Frequency Analysis (RFA) or Periotest® and insertion torque that can determine implant stability and osseointegration (35, 47).

In the atrophic posterior maxilla, there is often insufficient residual alveolar bone, which is why it is necessary to increase the base of the maxillary sinus to obtain an adequate volume for the insertion of dental implants. Maxillary sinus elevation was first described by Boyne PV in 1980 (44).

In 1994, Summers R described a technique using a crestal approach using progressive diameter osteotomes that increased the density of the maxillary bone by compaction, allowing the insertion of implants with a high primary stability and the atraumatic elevation of the sinus membrane (45).

Preparation of the implant site can be carried out using the conventional technique of cylindrical or conical drills capable of cutting and extracting bone tissue for the subsequent placement of the implant (48). However, in 2013, Huwais S introduced an atraumatic osteotomy preparation procedure known as osseodensification (OD) (49). OD promotes an increase in peri-implant bone density, compaction of autologous bone, plastic deformation of the bone, and increased primary stability of the implant due to the viscoelastic characteristics of the alveolar bone using Densah® drills (2000 Spring Arbor Rd Suite D, Jackson, MI 49203, United States) in a counterclockwise direction at a speed of 800 to 1500 rpm (21). This technique is indicated in the posterior maxilla in cases of low bone density type IV, sub-antral bone grafts, and in the expansion of narrow bone crests and post-extraction implants (50, 51).

The main objective of this systematic review is the analysis of the osseodensification technique as used in sub-antral bone grafts, low-density bone areas, narrow bone crests, and immediate implant placement in post-extraction sockets. According to several studies, the OD technique has advantages over the SD and osteotome techniques in terms of primary implant stability, bone density, BIC, and clinical success of the implants (21, 36, 38, 39, 50, 52). The OD technique achieved a greater bone density around implants, greater bone–implant contact, and a higher implant success rate after healing when compared to conventional techniques (21, 35-37, 39, 43, 53, 54). These results can be explained by the fact that the OD technique preserves and increases the bone matrix during the implant site preparation, which ultimately favours the osseointegration of the implants, as well as allowing additional procedures such as the elevation of the maxillary sinus, the expansion of narrow alveolar ridges, and the prevention of cortical collapse (39, 43, 49, 51, 53, 55). These results are in line with the existing literature, which suggests that the OD technique can be a very viable and minimally invasive option for optimising the implant site preparation (54, 56, 57).

The results obtained in the studies analysed using the technique suggest a better prognosis for dental implants placed in different clinical situations: low-density bone (type IV), narrow alveolar ridges, maxillary sinus grafts, and post-extraction implants (21, 35, 52).

1.5.1 Insertion Torque and Primary Stability

Several studies have investigated and compared the OD technique and the SD techniques in the context of the primary stability of dental implants. According to Lahens *et al.* (39), Trisi *et al.* (36), Huwais and Meyer (35), Alifarag *et al.* (37), Oliveira *et al.* (21), Torroni *et al.* (54), and Mello-Machado *et al.* (50), OD promotes significantly greater primary stability when compared to SD techniques.

Specifically, when analysing the results related to insertion torque, which is a measure of primary stability, the studies reported that OD had higher insertion torque values compared to SD osteotomy. According to Lahens *et al.* (39), they observed an average increase of 30% in insertion torque with OD compared to the SD technique, with an average insertion torque value for the SD technique of approximately 10 Ncm and for the OD techniques (CW and CCW) it was significantly higher, with values of over 50 Ncm for CW and around 80 Ncm for CCW. Similarly, Huwais and Meyer (35) reported an average 25% increase in insertion torque with OD.

Alifarag *et al.* (37) carried out a comparative study and observed an average insertion torque of 45 Ncm with the OD, while the SD technique showed an average insertion torque of only 30 Ncm. In a study by Oliveira *et al.* (21), similar results were found, with an average insertion torque of 40 Ncm using OD osteotomy and 25 Ncm using the SD technique.

In a study carried out by Trisi *et al.* (36), statistically significant values of approximately 30% to 40% higher ($p < 0.05$) were observed in relation to primary stability when comparing the OD technique with the SD technique. Mello-Machado *et al.* (52) obtained an insertion torque of 45 Ncm and an ISQ > 70 when placing the implant using the OD technique, while Mele et al. (55) obtained an ISQ of 74 using the technique in felines.

Oliveira *et al.* (21), Trisi *et al.* (36), and Alifarag *et al.* (37) consistently report that osseodensification is a promising surgical technique that improves the primary stability of dental implants. The osseodensification technique has shown favourable results, measured by insertion torque, indicating greater implant strength and stability in bone tissue compared to conventional osteotomy techniques. These findings highlight the importance and clinical potential of osseodensification in optimising osseointegration (21, 36, 37).

1.5.2 Bone-to-Implant Contact (BIC) and Bone Area Fraction Occupancy (BAFO)

The osteogenic parameters along the surface of the implants were evaluated by measuring the BIC and the bone growth in the space between the implant spirals as a percentage called BAFO. Animal and human studies have also confirmed that these values tend to increase when using the OD technique.

Tian *et al.* (57), Trisi *et al.* (36), Huwais and Meyer (35), Lopez *et al.* (58), Slete *et al.* (43), Oliveira *et al.* (21), Lahens *et al.* (53), Torroni *et al.* (54), and Mello-Machado *et al.* (50) compared the BIC and BAFO values between the OD technique and other SD techniques. The results showed that OD has higher BIC and BAFO values compared to SD osteotomy, although there are variations in the values obtained depending on the implant surface, healing time, and study methodology.

According to Tian *et al.* (57), OD showed an average BIC value of 80% and BAFO of 70.5%, while with SD osteotomy, the average values were 60% for BIC and 47.5% for BAFO ($p = 0.018$ and $p = 0.198$, respectively). However, according to Torroni *et al.* (54), there was no significant difference in BIC or BAFO when comparing the different techniques.

Another factor that can influence BIC and BAFO is the type and surface treatment of the implant, as can be seen in the studies carried out by Lahens *et al.* (39), Alifarag *et al.* (37), and Oliveira *et al.* (21). There are different types of implant designs (parallel, conical), which can be manufactured using different materials (titanium, zirconia, or titanium-zirconia). In addition, there are different implant surface treatments, such as alumina, magnesium oxide, or anodising. According to Oliveira *et al.* (21), surface treatment with magnesium oxide showed significantly higher BIC and BAFO values than implants with alumina surface treatment in all the osteotomy techniques analysed ($p < 0.05$ BIC and BAFO). The same was found in the study by Lahens *et al.* (39).

Considering the above, the OD technique improves BIC and BAFO compared to the SD osteotomy techniques.

1.5.3 Immediate Loading

Immediate loading is defined as the stabilization of a prosthesis within a week after the surgical insertion of the fixture (1). The implant immediate loading concept, initially introduced in the 1970s, gained popularity in 1990 (43). Since a few couple of decades ago, growth in the application of immediate loading protocol in both the maxilla and mandible has been observed across several clinical situations, such as edentulous patients, partial edentulous patients, and single-tooth areas (44). Moreover, implant immediate loading also extends possibilities of single stage (one-phase) or double stage (two-phase) protocol owing to the faster integration of the implant, a single surgery is required for the implant and the prosthesis with a single stage protocol.

Submerged technique implants require a few months for osseointegration, which is not absolutely necessary with immediate loaded implants (1). Osseointegration assures the healing of implants with the bone and provides a solid foundation for the prosthetic restoration. The prerequisite for immediate loading is a minimum primary stability of 32 Ncm according to the clinical studies. Although compressive loading protocols are effective, but the tensile forces should be unavoidable with especially a screw-retained design that can't avoid the formation of screw loosening over time. In order to prevent the screw loosening, settings, thread lock or splinting can be utilized. Increased implant surface area by using a rough surface, apical or progressive threads, wide implant and short implants will increase the implant stability.

Immediate loading defined as the placement of a prosthetic restoration on the newly placed implant, within 24–48 h of implant surgery, has become a popular technique in implant restorations with very predictable outcomes (49). Immediate loading of dental implants has many advantages including patient satisfaction, patient motivation, and decreases the second surgical procedures (43, 44). But it is contraindicated in many clinical situations like in cases of bone grafting, where the stability of the implants will be minimal. The protocol includes careful patient selection, correct implant placement with proper torque to achieve primary stability, and consolidated crowns to distribute the functional forces across a large surface area.

1.5.4 Osseointegration

Placing implants in the posterior region of the maxilla is a challenge when faced with bone resorption and pneumatisation of the maxillary sinus. To overcome this problem, there are various bone grafting techniques that aim to increase the height and width of the alveolar ridge and prevent the collapse of the buccal cortex. OD is a predictable and advantageous alternative for maxillary sinus elevation and alveolar ridge expansion, improving bone density, primary stability, and osseointegration of dental implants (37, 49, 53).

The results obtained in the studies suggest that dental implants placed using the OD technique in areas of low bone density or with bone defects have a better prognosis and may reduce the time needed for the implant to achieve osseointegration (21, 37, 39, 51).

OD has emerged as a promising technique in various procedures, especially in clinical situations involving low-density bone. Lahens *et al.* (39) demonstrated that OD acts as a compacted autotransplant, improving the primary stability of the implant and bone–implant contact. However, further research is needed to better understand the osseointegration process using this technique. Similarly, Lahens *et al.* (53) highlighted the benefits of OD, indicating that this technique directly influences insertion torque values and improves the stability and osseointegration of endosseous implants in low-density bone, as observed in studies carried out on sheep.

Jarikian *et al.* (49) emphasised the importance of bone expansion in patients with narrow alveolar ridges, using the OD technique as an effective and less invasive option for increasing the width of the alveolar ridge. Compared to the bone expansion technique with SO, both methods appear to be effective. However, the OD technique was considered more predictable and less invasive. This discussion highlights the importance of proper treatment planning and careful patient assessment to ensure predictable results and minimise complications.

OD has also proved to be a promising technique for maxillary sinus elevation, as described by Salgar *et al.* (56), whose application of the technique in three patients with difficult clinical situations demonstrated an average increase in bone height of 10.3 mm. OD was able to overcome the limitations of traditional crestal approaches in terms of residual bone height and the limit of vertical height increase, proving to be a minimally invasive option with satisfactory results.

All the results obtained should be analysed and observed with caution since the studies have several limitations and risks of bias, such as the sample size and the short follow-up period. Therefore, more studies with greater methodological rigour and longer follow-up periods are needed to confirm the benefits of the OD technique in oral implantology. In future clinical human trials, it would be worthwhile to perform digitally guided OD in order to evaluate if it improves the promising results of the technique even further (59).

Chapter II – Material and Methods

2.1 Informed consent and ethical and legal aspects

This study was carried out in accordance with legal regulations and was submitted to and approved by the Ethics Committee of the University Institute of Health Sciences - CESPU.

Each patient was explained the purpose of the study, namely the objectives, procedures, risks, expected results, participation and/or spontaneous withdrawal, data confidentiality, insurance, contacts and informed consent.

Each patient who agreed to take part in the study read and signed the informed consent form. Annexes 1 and 2 contain both the Letter of Approval from the Ethics Committee and the Informed Consent form given to each patient.

2.2 Bibliographical Research

For the literature review and theoretical contextualisation of this dissertation, a systematic review of the literature was carried out. This systematic review was carried out between November 2022 and April 2023 in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines, using the MEDLINE database via PubMed, Cochrane Library, Scopus and Web of Science (from 2013 to 2023) for the last 10 years. The systematic review was published in J Clin Med. 2023 Nov 11;12(60):7046. doi: 10.3390/jcm12227046 and is available in appendix 4 of this dissertation. Books with relevance to the area were also selected.

Throughout the research, articles were included due to the relevance of the topic and its topicality.

2.3 Study Design

This study was designed as a clinical trial study according to the CONSORT guidelines [14]. The interventions were approved by the Ethical Committee of the University Institute of Health Sciences (reference: 02/CE-IUCS/2019) and conducted in compliance with the provisions of the Declaration of Helsinki. This study was registered in the ISRCTN registry (registration number ISRCTN15797074). This work was carried out as part of the PhD programme in Biomedical Sciences at the University Institute of Health Sciences - CESPU, from 2018 to 2024.

2.4 Patient Selection

All patients underwent a preliminary assessment that included a careful analysis of their medical and dental histories and a detailed clinical examination. The patients were thoroughly informed, by means of oral and written explanations, about the purpose and procedures of the study, and informed consent was obtained from all participants.

For inclusion, participants had to be at least eighteen years old, had to have healed edentulous sites on the posterior maxillae region with at least a 3-month post-extraction period; had to need to receive at least two dental implants; and had to have sufficient residual bone volume for implant placement without the need for bone augmentation, i.e., minimum ridge height and width of ≥8 and ≥6 mm, respectively. The exclusion criteria were alcoholism, drug abuse, diabetes, heart disease, bleeding disorders, weakened immune systems, radiation exposure, past or ongoing use of steroids or bisphosphonates, and previous bone regenerative or augmentation procedures.

From February 6th to March 10th 2019, 120 patients from CESPU's Famalicão clinical unit were screened from this patient pool, 90 patients of whom met the study's inclusion criteria and were selected to participate.

In order to perform a comparison between osseodensification (OD) and subtractive conventional drilling (SD), implants were placed side by side or contralateral with both techniques to establish a comparison in the RFA and torque values. In some patients two implants were placed, but in other patients they had between three and four implants.

Two independent examiners (J.F.P. and M.I.C.) performed the comparisons to demonstrate intra- and inter-examiner reliability, and measurements of the clinical parameters for implant primary stability were repeated in 50% of the sample.

2.5 Medical Records

In order to carry out this study, a clinical form was filled out for each patient, one part with information for the patient and the other with clinical information, to be filled out by the researcher. This clinical form was drawn up taking into account the relevance of the data for the study, and can be found in appendix 3 of this dissertation.

2.5.1 Pre-operative radiographic planning

The pre-operative radiographic examination was performed as follows: A panoramic X-ray and cone beam computed tomography (CBCT, New Tom® Go 3D, CEFLA S.C., Imola (BO) Italy) were used for the initial participant screening. CBCT was crucial in order to provide a guide for assessing the condition of the Schneiderian membrane; the ostium patency; the presence of antral septa; and other pathologies that may influence the alveolar bone, the degree of sinus pneumatization, and the thickness of the Schneiderian membrane.

2.5.2 Pre-surgical phase

All patients underwent scaling 8 days prior to implant surgery. During this phase, preoperative instructions were given:

-To eat a light diet, avoiding fatty, fried, laxative and fermentable foods (milk, cheese, bananas) on the day of surgery.

-Not to wear jewelry or make-up, in the case of women.

-Avoid smoking in the 72 h before and 30 days after surgery, to avoid anesthetic and surgical complications, as well as contributing to better tissue healing.

-Not to take medication based on acetylsalicylic acid (aspirin) in the 4 days before surgery.

-Start antibiotic therapy 48 h before surgery (875 mg of amoxicillin and 125 mg of clavulanic acid) twice daily for 8 days.

2.5.3 Surgical Phase

2.5.3.1 Implant design and surface characteristics

Bone Level Tapered (BLT) Straumann® implants (Basel, Switzerland) with a CrossFit® connection (Basel, Switzerland) 3.3.mm diameter (Narrow connection — NC) or 4.1/4.8 mm diameter (Regular connection — RC) were used. These implants feature a tapered, self-cutting design with a 0.8 mm thread pitch, and are designed for excellent primary stability. BLT implants are available in lengths of short (8 mm), Regular (10 mm, 12 mm, 14 mm) and Long (16 mm, 18 mm). The implant surface SLA® (Basel, Switzerland), Sandblasted, large grit, acid-etched is a type of surface treatment that creates surface roughness with the goal of enhancing osseointegration through greater bone-to-implant contact (BIC).

The BLT implant is characterised by its optimised macroscopic structure, surface treated with SLA® technology and comprehensive surgical protocol. These combined elements contribute to predictable results, reliable osseointegration and a positive patient experience throughout dental implant treatment.

The Straumann BLT implant is accompanied by a comprehensive surgical protocol developed by the brand, available in Appendix 6 of this dissertation. This protocol provides detailed guidelines for each stage of the surgical procedure, from the initial assessment of the patient to the placement and stabilisation of the implant in the bone bed. Before surgery, it is crucial to carry out a full assessment of the patient, including radiographic examinations and an evaluation of the local bone anatomy. Based on this information, the professional can select the most suitable size and type of implant for the patient's specific needs.

During surgery, Straumann's protocol includes precise techniques for preparing the bone bed and inserting the implant. This may include the use of surgical guides to ensure precise implant placement and minimise tissue trauma. After implant placement, specific guidelines are followed for proper stabilisation and fixation of the prosthetic component.

In addition, Straumann's surgical protocol emphasises the importance of communication and collaboration between the implantologist and the dental technician. This ensures effective coordination between the surgical and prosthetic phases of treatment, resulting in harmonious integration of the implant into the overall treatment plan.

The characterisation of the dental implant is a crucial aspect in the planning and execution of implant surgery procedures. The BLT implant is widely recognised for its clinically proven quality and performance.

The conical shape of the implant has a gradual transition from the diameter of the platform to the apex, allowing for efficient load distribution and anatomical adaptation to the bone bed. This feature is especially important in situations where bone density is variable or when there is a need to preserve the alveolar bone.

In addition, the BLT implant design includes a straight neck and a tapered tip, providing initial stability during insertion and minimising tissue trauma. The presence of a double thread in the coronal portion of the implant contributes to solid primary fixation and resistance to torque during the implant installation procedure.

Straumann® Roxolid® BLT implants are made of a metal alloy composed of 15 % zirconia and 85 % titanium. The combination of these two metals creates a material with greater resistance to fracture and fatigue than conventional titanium implants. The surface of the implant plays a key role in osseointegration and the long-term success of implant treatment. The Straumann® BLT implant features a surface treated with SLA® technology, developed to promote a favourable biological response and accelerate the healing process.

SLA® technology involves modifying the surface of the implant through a chemical activation process, which results in a highly hydrophilic surface structure. This allows for greater absorption of proteins and biologically active molecules present in the oral environment, promoting cell adhesion and differentiation, as well as the formation of bone matrix around the implant. The SLA® surface also exhibits antibacterial properties, reducing the risk of bacterial colonisation and peri-implant infection. This characteristic is particularly advantageous in clinical environments where oral hygiene can be challenging, providing greater predictability and security in implant treatment results.

2.5.3.2 Conventional Protocol

The patients were prepared by administering long-acting local anesthesia (4% articaine with 1:100.000 adrenaline).

A mid-crestal incision was made, and a full thickness mucoperiosteal flap was raised. The anterior region of the edentulous area was prepared using subtractive conventional drilling according to the Straumann® guidelines for RPM values. Independent of the implant diameter selected for the site (∅ 3.3mm, 4.1mm, or 4.8mm), a narrow drill (pilot drill ∅ 2.2mm, 800 rpm) was used until the desired depth was reached under abundant saline irrigation. The drilling sequence is shown in Tables 1, 2, and 3. After using the drill sequence, the BLT implant was delivered in the implant bed.

Table 1. Conventional drilling sequence for Ø 3.3 mm BLT implant.

Straumann® BLT			Drilling Sequence				
Geometry	Implant Diameter	Type of Bone	Needle Drill Ø 1.6 mm (800 rpm)	Pilot Drill Ø 2.2 mm (800 rpm)	BLT Drill Ø 2.8 mm (600 rpm)	Profile Drill Ø 3.3 mm (300 rpm)	BLT Tap Ø 3.3 mm (15 rpm)
Tapered	Ø 3.3 mm	Type I	•	•	•	•	•*
		Type II	•	•	•	•*	
		Type III	•	•	•*		
		Type IV	•	•*			

• Performing the osteotomy; •* Osteotomy and implant placement.

Table 2. Conventional drilling sequence for Ø4.1 mm BLT implant.

Straumann® BLT			Drilling Sequence					
Geometry	Implant Diameter	Type of Bone	Needle Drill Ø 1.6 mm (800 rpm)	Pilot Drill Ø 2.2 mm (800 rpm)	BLT Drill Ø 2.8 mm (600 rpm)	BLT Drill Ø 3.5 mm (500 rpm)	Profile Drill Ø 4.1 mm (300 rpm)	BLT Tap Ø 4.1 mm (15 rpm)
Tapered	Ø 4.1 mm	Type I	•	•	•	•	•	•*
		Type II	•	•	•	•	•*	
		Type III	•	•	•	•*		
		Type IV	•	•	•	•*		

• Performing the osteotomy; •* Osteotomy and implant placement.

Table 3. Conventional drilling sequence for Ø 4.8 mm BLT implant.

Straumann® BLT			Drilling Sequence						
Geometry	Implant Diameter	Type of Bone	Needle Drill Ø 1.6 mm (800 rpm)	Pilot Drill Ø 2.2 mm (800 rpm)	BLT Drill Ø 2.8 mm (600 rpm)	BLT Drill Ø 3.5 mm (500 rpm)	BLT Drill Ø 4.2 mm (400 rpm)	Profile Drill Ø 4.8 mm (300 rpm)	BLT Tap Ø 4.8 mm (15 rpm)
Tapered	Ø 4.8 mm	Type I	•	•	•	•	•	•	•*
		Type II	•	•	•	•	•	•*	
		Type III	•	•	•	•	•*		
		Type IV	•	•	•	•*			

• Performing the osteotomy; •* Osteotomy and implant placement.

2.5.3.3 Osseodensification Protocol

The posterior region of the edentulous area was prepared using the osseodensification procedure to test what has already been described in the literature, which is that this technique is especially used in situations of low-density bone (type III/IV) (which is typically found in the posterior region of the maxilla/mandible) in order to increase bone volume, percentage of bone to implant contact and, subsequentially, the primary stability of the implant.

Drilling was carried out to the desired depth using the pilot drill (clockwise drilling speed from 800 to 1500 rpm) with abundant saline irrigation. Depending on the implant diameter selected (Ø 3.3,4.1 or 4.8 mm), the narrower Densah® Bur (Bur 1 for each implant diameter- Table 4) was used in a counterclockwise direction (800 to 1500 rpm) with a pumping motion until reaching the desired depth under abundant irrigation. All drills were used in counterclockwise rotation. The drilling sequence is shown in Table 4.

After using the drill sequence, the osteotomy received a threaded Sandblast large grit acid-etched (SLA®) implant. In some cases, we finished placing the implant with a ratchet wrench, when the drill motor that drives the implant into place has reached the maximum placement torque.

Table 4. Drilling sequence of Densah® Burs.

Straumann®		Soft Bone (Type III and IV)			
Geometry	Implant Diameter	Pilot	Bur 1	Bur 2	Bur 3
Tapered	Ø 3.3 mm	Pilot drill	VT1828 * (2.3)	—	—
	Ø 4.1 mm	Pilot drill	VT1525 (2.0)	VT2535 * (3.0)	—
	Ø 4.8 mm	Pilot drill	VT1525 (2.0)	VT2535 (3.0)	VT3545 * (4.0)

* Implant placement.

Figure 1 shows the final drill used for each group (SD and OD) and implant diameters (∅ 3.3mm, ∅ 4.1mm, ∅ 4.8mm).

Figure 1. The configuration of the final drill used for each group (SD and OD). **(a)** VT1828; **(b)** ∅ 2.8 BLT Drill; **(c)** VT2535; **(d)** ∅ 3.5 BLT Drill; **(e)** VT3545; **(f)** ∅ 4.2 BLT Drill.

Before using the osseodensification technique, it is essential to understand the characterisation of the Versah® System, especially in relation to the osseodensification process, as well as the drilling protocol for the implants used, Straumann® BLT. Osseodensification is an innovative technique in oral implantology that aims to increase bone density and improve the stability of dental implants. The Versah® System plays a crucial role in this process, providing instruments specifically designed to carry out osseodensification effectively and safely.

The Versah® System features specially designed drills with unique geometry and specific cutting properties to facilitate osseodensification. These drills are characterised by their ability to compact the surrounding trabecular bone during the surgical procedure, resulting in greater bone density around the implant. This compaction of the trabecular bone is fundamental to promoting the primary stability of the implant and facilitating osseointegration. The Versah® System offers a variety of drills with different diameters and lengths to meet the specific needs of each clinical case. This allows for a personalised approach for each patient, ensuring optimal results in terms of implant stability and bone quality. The ability to choose from a variety of drills also allows for precise adaptation to the surrounding bone, taking into account its density and anatomy.

2.5.3.4 Evaluation of Implant Stability Parameters

Immediately after implant placement, the IT was measured (T1) using a manual torque wrench (Straumann®, Basel, Switzerland), and the Implant stability quotient (ISQ) value was registered as the average of the buccal, lingual, mesial and distal readings using the Osstell® IDX (Osstell, W&H, Gothenburg, Sweden). IT and ISQ values were measured in all implants placed with the SD and OD technique. A cover screw was placed in all implants.

Afterwards, the surgical site was closed with several interrupted sutures using a monofilament suture (Nylon, Resorba® 4.0, Nuremberg, Germany).

The ISQ is a measure of the stability of an implant, represented on a scale of 1 to 100. The ISQ scale has a non-linear correlation with micro mobility. It has been described that high stability means an ISQ value >70, between 60-69 is considered medium stability and <60 is considered low stability.

During this study, measurements were taken of the stability of each implant placed at 3 different points in time: the first measurement was taken on the day the implant was placed in the bone (T1); the second measurement was taken after 6 months (T2) and the third measurement after 1 year (T3).

Figure 2 illustrates the OD osteotomies

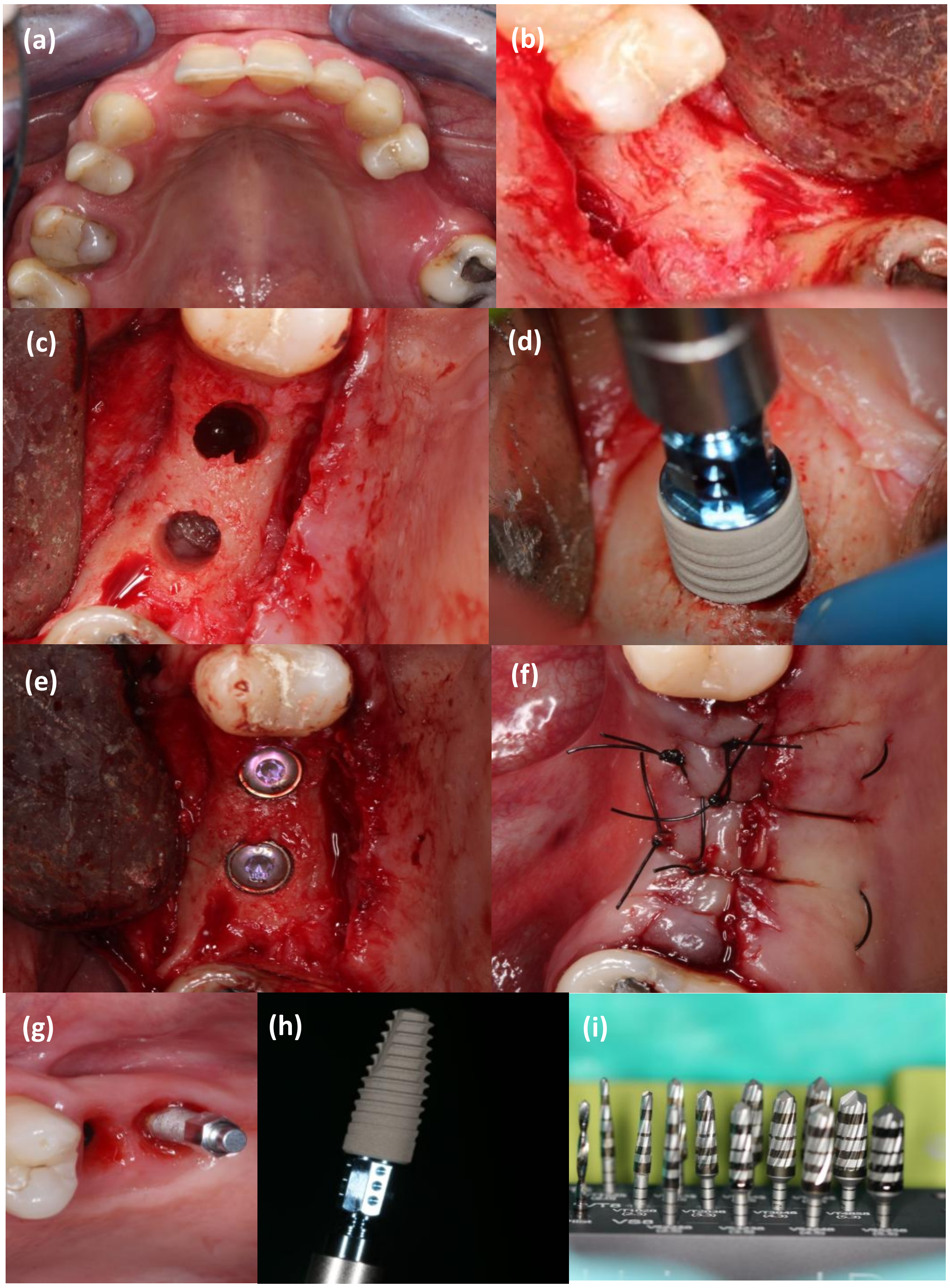

Figure 2. A visual representation of the surgery. **(a)** The initial case. **(b)** A full thickness mucoperiosteal flap. **(c)** The osteotomies. **(d)** The implant placement (∅ 4.1mm BLT). **(e)** A view of the cover screws. **(f)** The interrupted sutures using a monofilament suture (Nylon, Resorba®4.0). **(g)** The SmartPeg placement for ISQ reading. **(h)** The tapered implant design. **(i)** The Densah Bur kit.

2.5.3.5 Post-operative instructions

Postoperative instructions were given of some important actions to avoid increased edema (swelling), pain, bleeding and infections:

- To lie down for the first three days after surgery to stabilize the blood clot, as this is a critical period for a good post-operative result without complications.
- To continue the antibiotic therapy and to take Naproxen (500 mg) twice daily for a 3 day period.
- Paracetamol 1 g 3 times a day for pain control management.
- To use 0.12% chlorhexidine gluconate mouthwash (Bexident® Post Isdin, Barcelona, Spain,) thrice daily for two weeks to reduce plaque formation.
- To apply ice to their faces in the first 6 to 8 h after surgery in order to significantly reduce facial edema, while also improving pain control and reducing local vascularization, thus preventing bleeding.
- To prepare a liquid/pasty and cold diet for 8 days.
- To bite on a piece of sterile gauze for 30 min to promote hemostasis.
- Not to spit, which could cause negative pressure in the mouth and dislodge the clot. Drinking liquids through straws is also contraindicated.
- Avoid vigorous mouthwashes.
- Not to smoke during the entire osseointegration process (especially during the first two weeks). Nicotine destroys vitamin C, which is essential for tissue regeneration, delaying the repair of the surgical wound.
- To refrain from physical activity or heavy lifting for three days after surgery.

After the post-operative indications were made, the patients were scheduled to have the sutures removed ten days after surgery.

2.5.3.6 Healing abutment- 6 Months

After six months of healing, the survival of the implants was verified, the secondary stability was measured though ISQ values (T2), and an appropriate healing abutment was inserted considering the emergence profile and gingival height. Subsequently, the patients were scheduled for digital implant impressions with a 3Shape® scanner (Copenhagen, Denmark), and final ceramic crowns were manufactured.

2.5.3.7 One-Year Follow-up

Removal of the screw-retained zirconia crowns and ISQ values were recorded (T3) using Osstell® IDX.

2.6 Statistical analysis

Descriptive statistics were calculated for each variable, including mean values and the corresponding 95% confidence interval (CI). The quantitative variables were assessed for normality using the Kolmogorov–Smirnov test and Normal probability graphical methods (QQ-plot), and the fit to the normal distribution was verified. The homogeneity of variances was assessed using Levene's test.

The factorial ANOVA model test and multiple comparison tests were carried out to compare torque/torque values. Repeated measures analysis of variance and the respective Tukey tests for multiple comparisons were used to analyze the ISQ data. Pearson's correlation test was applied to investigate the relationship between IT and immediate ISQ values for all the variables studied.

All analyses were carried out using IBM® Statistical Program for Social Sciences (SPSS®) Statistics software, version 29.0 for Windows, with a significance level of 5%.

2.7 Objectives

2.7.1 Primary Objective

To assess the effectiveness of the osseodensification drilling protocol versus conventional surgical techniques on implant stability.

2.7.2 Secondary Objective

To analyse the scientific literature regarding the applicability of the osseodensification technique in oral implantology.

Chapter III - RESULTS AND DISCUSSION

Of the 120 patients screened at the CESPU - Famalicão clinical unit, only 90 met the study's inclusion criteria and were selected to participate.

Figure 3 illustrates the design of the study in the form of a CONSORT diagram.

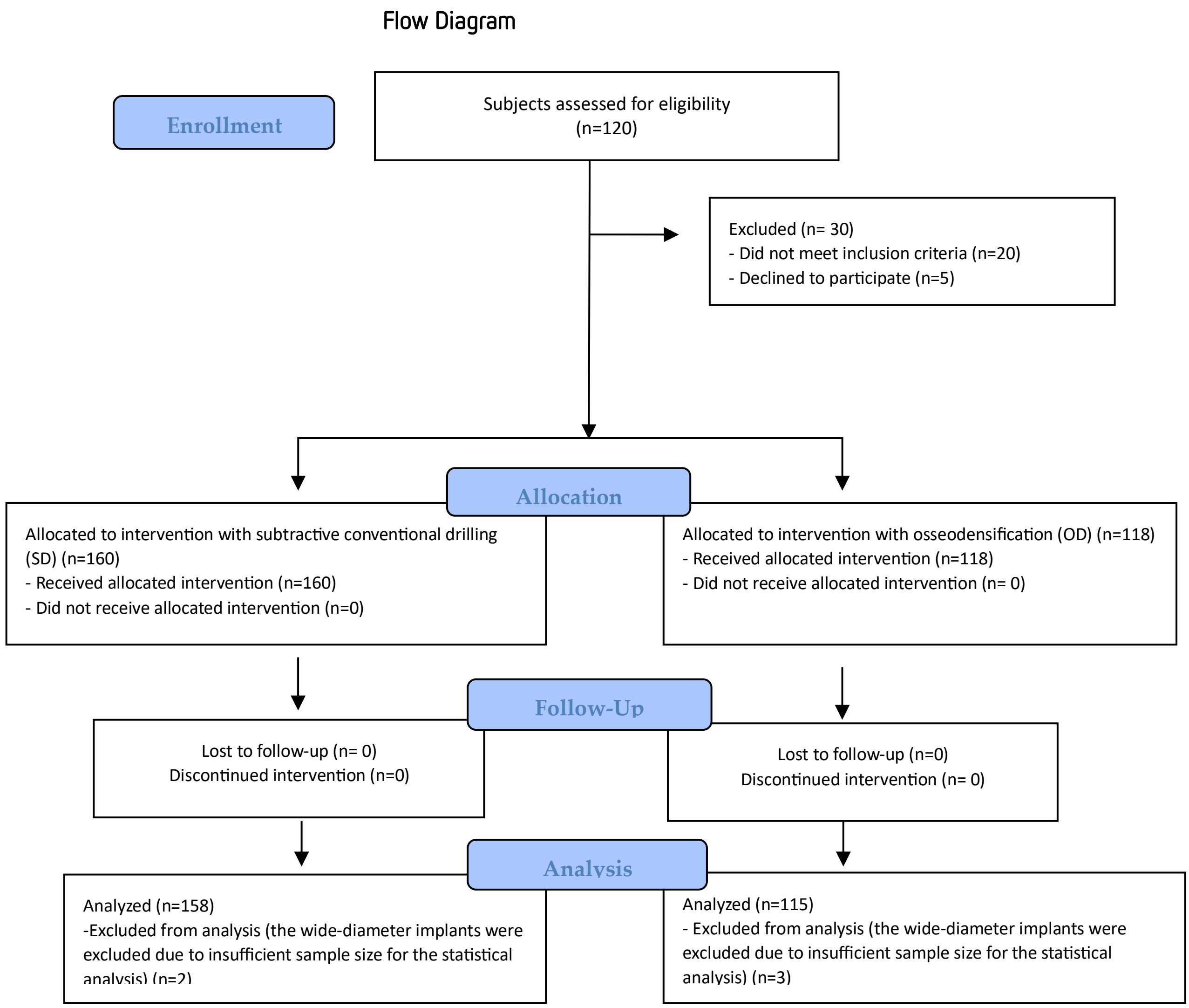

Figure 3. CONSORT flow chart.

As shown in Table 5, the total sample consisted of 90 individuals, 55 of whom were female (61.1%) and the remaining 35 male (38.9%). The limits of the 95% confidence intervals are also shown.

Table 5. Distribution of members by gender.

Gender	n	%	CI 95.0%	
			LCL	UCL
F	55	61.1%	50.8%	70.7%
M	35	38.9%	29.3%	49.2%
Total	90	100.0%		

Note: F—female; M—male; n—number of subjects and percentages; LCL—Lower Control Limit; UCL—Upper Control Limit.

Table 6 shows the data characterizing the sample in terms of age by gender and overall.

Table 6. Summary statistics for age by gender.

		Gender		Total
		F	M	
Age	Mean	47.7	50.3	48.7
	Median	49.0	48.0	48.5
	Standard deviation	12.7	11.2	12.1
	Minimum	19.0	20.0	19.0
	Maximum	72.0	69.0	72.0
	Percentile 25	37.0	44.0	42.0
	Percentile 75	56.0	59.0	57.0

Note: F—female; M—male.

Table 7 shows the results of the characterization of the sample in terms of the characteristics of the individuals assessed, as well as the respective limits (Lower Control Limit (LCL) and Upper Control Limit (UCL)) of the 95% confidence intervals (CI).

Table 7. Summary statistics for the individual's characteristics.

		n	%	CI 95.0%	
				LCL	UCL
Smoker	N	74	82.2%	73.4%	89.0%
	Y	16	17.8%	11.0%	26.6%
	Total	90	100.0%		
Systemic Disease	N	71	78.9%	69.6%	86.3%
	Y	19	21.1%	13.7%	30.4%
	Total	90	100.0%		
Number of cigarettes/day	4	1	6.3%	0.7%	25.7%
	5	1	6.3%	0.7%	25.7%
	6	1	6.3%	0.7%	25.7%
	10	5	31.3%	13.1%	55.6%
	15	2	12.5%	2.7%	34.4%
	20	6	37.5%	17.4%	61.7%
	Total	16	100.0%		

Note: N—no; n—number of subjects and percentages; LCL—Lower Control Limit; UCL—Upper Control Limit; Y—yes.

Table 8 shows the sample characterization data regarding the implant for each surgical technique and as a whole.

Table 8. Implant-related characterization.

		Surgical Techniques											
		SD				OD				Total			
				CI 95.0%				CI 95.0%				CI 95.0%	
		n	%	LCL for %	UCL for %	n	%	LCL for %	UCL for %	n	%	LCL for %	UCL for %
Implant diameter (mm)	Narrow	26	16.3%	11.2%	22.5%	25	21.2%	14.6%	29.2%	51	18.3%	14.1%	23.2%
	Regular	132	82.4%	76.1%	87.8%	90	76.3%	68.0%	83.2%	222	79.9%	74.8%	84.2%
	Wide	2	1.3%	0.3%	3.9%	3	2.5%	0.7%	6.6%	5	1.8%	0.7%	3.9%
	Total	160	100%	.	.	118	100.0%	.	.	278	100.0%	.	.
Implant length (mm)	8	33	20.6%	14.9%	27.4%	30	25.4%	18.2%	33.8%	63	22.7%	18.0%	27.8%
	10	65	40.6%	33.2%	48.3%	51	43.2%	34.5%	52.2%	116	41.7%	36.0%	47.6%
	12	37	23.1%	17.1%	30.1%	25	21.2%	14.6%	29.2%	62	22.3%	17.7%	27.5%
	14	9	5.6%	2.8%	10.0%	7	5.9%	2.7%	11.3%	16	5.8%	3.5%	9.0%
	16	7	4.4%	2.0%	8.4%	3	2.5%	0.7%	6.6%	10	3.6%	1.9%	6.3%
	18	9	5.6%	2.8%	10.0%	2	1.7%	0.4%	5.3%	11	4.0%	2.1%	6.7%
	Total	160	100.0%	.	.	118	100.0%	.	.	278	100.0%	.	.
Arch	Maxilla	78	48.8%	41.1%	56.5%	86	72.9%	64.4%	80.3%	164	59.0%	53.1%	64.7%
	Mandible	82	51.3%	43.5%	58.9%	32	27.1%	19.7%	35.6%	114	41.0%	35.3%	46.9%
	Total	160	100.0%	.	.	118	100.0%	.	.	278	100.0%	.	.
Position	11	1	0.6%	0.1%	2.9%	0	0.0%	.	.	1	0.4%	0.0%	1.7%
	12	3	1.9%	0.5%	4.9%	2	1.7%	0.4%	5.3%	5	1.8%	0.7%	3.9%
	13	4	2.5%	0.8%	5.8%	2	1.7%	0.4%	5.3%	6	2.2%	0.9%	4.4%
	14	15	9.4%	5.6%	14.6%	6	5.1%	2.1%	10.2%	21	7.6%	4.9%	11.1%
	15	15	9.4%	5.6%	14.6%	13	11.0%	6.3%	17.6%	28	10.1%	6.9%	14.0%
	16	9	5.6%	2.8%	10.0%	14	11.9%	7.0%	18.6%	23	8.3%	5.5%	11.9%
	17	3	1.9%	0.5%	4.9%	3	2.5%	0.7%	6.6%	6	2.2%	0.9%	4.4%
	21	0	0.0%	.	.	1	0.8%	0.1%	3.9%	1	0.4%	0.0%	1.7%
	22	5	3.1%	1.2%	6.7%	2	1.7%	0.4%	5.3%	7	2.5%	1.1%	4.9%
	23	2	1.3%	0.3%	3.9%	2	1.7%	0.4%	5.3%	4	1.4%	0.5%	3.4%
	24	5	3.1%	1.2%	6.7%	12	10.2%	5.7%	16.6%	17	6.1%	3.7%	9.4%
	25	11	6.9%	3.7%	11.6%	11	9.3%	5.1%	15.6%	22	7.9%	5.2%	11.5%

		Surgical Techniques											
		SD				OD				Total			
		n	%	CI 95.0%		n	%	CI 95.0%		n	%	CI 95.0%	
				LCL for %	UCL for %			LCL for %	UCL for %			LCL for %	UCL for %
	26	5	3.1%	1.2%	6.7%	13	11.0%	6.3%	17.6%	18	6.5%	4.0%	9.8%
	27	0	0.0%	.	.	5	4.2%	1.6%	9.0%	5	1.8%	0.7%	3.9%
	32	1	0.6%	0.1%	2.9%	2	1.7%	0.4%	5.3%	3	1.1%	0.3%	2.9%
	34	6	3.8%	1.6%	7.6%	1	0.8%	0.1%	3.9%	7	2.5%	1.1%	4.9%
	35	3	1.9%	0.5%	4.9%	2	1.7%	0.4%	5.3%	5	1.8%	0.7%	3.9%
	36	22	13.8%	9.1%	19.7%	4	3.4%	1.2%	7.9%	26	9.4%	6.3%	13.2%
	37	8	5.0%	2.4%	9.2%	3	2.5%	0.7%	6.6%	11	4.0%	2.1%	6.7%
	42	3	1.9%	0.5%	4.9%	0	0.0%	.	.	3	1.1%	0.3%	2.9%
	44	5	3.1%	1.2%	6.7%	2	1.7%	0.4%	5.3%	7	2.5%	1.1%	4.9%
	45	7	4.4%	2.0%	8.4%	7	5.9%	2.7%	11.3%	14	5.0%	2.9%	8.1%
	46	17	10.6%	6.6%	16.1%	9	7.6%	3.8%	13.5%	26	9.4%	6.3%	13.2%
	47	10	6.3%	3.3%	10.8%	2	1.7%	0.4%	5.3%	12	4.3%	2.4%	7.2%
	Total	160	100.0%	.	.	118	100.0%	.	.	278	100.0%	.	.
Operated Area	Anterior	19	11.9%	7.6%	17.6%	11	9.3%	5.1%	15.6%	30	10.8%	7.6%	14.8%
	Posterior	141	88.1%	82.4%	92.4%	107	90.7%	84.4%	94.9%	248	89.2%	85.2%	92.4%
	Total	160	100.0%	.	.	118	100.0%	.	.	278	100.0%	.	.

Note: n—number of implants and percentages; LCL—Lower Control Limit; OD—osseodensification; SD—subtractive conventional drilling; UCL—Upper Control Limit.

Table 9 shows the 95% CI insertion torque in relation to surgical technique as a function of arch and area operated.

			Surgical Techniques														
			SD					OD					Total				
			Valid N	Mean	Standard Deviation	95,0% Lower CL for Mean	95,0% Upper CL for Mean	Valid N	Mean	Standard Deviation	95,0% Lower CL for Mean	95,0% Upper CL for Mean	Valid N	Mean	Standard Deviation	95,0% Lower CL for Mean	95,0% Upper CL for Mean
Insertion Torque (IT)	Maxilla	Anterior	15	42	18	32	52	9	50	17	37	63	24	45	18	38	52
		Posterior	63	42	15	38	45	77	42	14	39	45	140	42	15	39	44
		Total	78	42	15	38	45	86	43	15	40	46	164	42	15	40	45
	Mandible	Anterior	4	60	12	42	78	2	50	0	50	50	6	57	10	46	68
		Posterior	78	50	16	46	53	30	49	15	43	55	108	50	16	47	52
		Total	82	50	16	47	54	32	49	15	44	54	114	50	15	47	53
	Total	Anterior	19	46	18	37	55	11	50	15	40	60	30	47	17	41	54
		Posterior	141	46	16	43	49	107	44	15	41	47	248	45	15	43	47
		Total	160	46	16	44	49	118	45	15	42	47	278	45	16	44	47

Table 9. 95% CI insertion torque in relation to surgical technique as a function of arch and area operated.

To assess whether there are differences in IT, a multifactorial ANOVA was carried out, and it was found that there are statistically significant differences in the mean IT values due to the arch only (F (1.270) = 4.702, p-value = 0.031 < 0.05).

Table 10 shows the IT tests between-subjects and effects (arch and position).

Table 10. The IT tests between-subjects and effects (arch and position).

IT tests Between-Subjects and Effects

Dependent Variable: Insertion Torque (IT)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Technique	5,009	1	5,009	,022	,883
Arch	1092,025	1	1092,025	4,702	,031
Area	393,569	1	393,569	1,695	,194

IT tests Between-Subjects and Effects

Dependent Variable: Insertion Torque (IT)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Technique * Arch	359,409	1	359,409	1,548	,215
Technique * Area	4,091	1	4,091	,018	,895
Arch * Area	6,958	1	6,958	,030	,863
Technique * Arch * Area	279,741	1	279,741	1,205	,273
Error	62705,320	270	232,242		
Corrected Total	67620,263	277			

The results can be seen in the graphs in Figure 4.

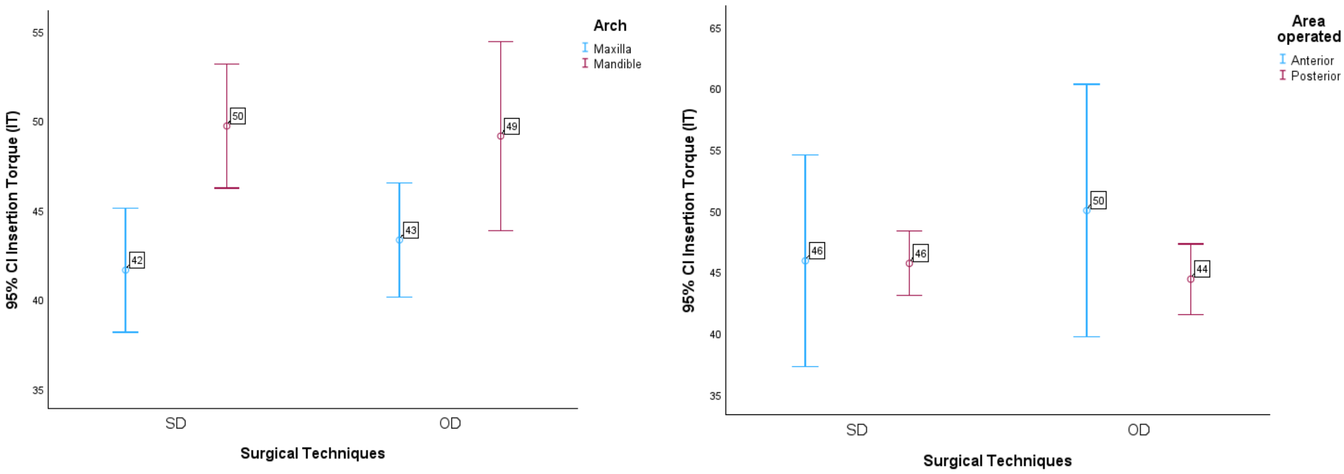

Figure 4. 95% CI insertion torque in relation to surgical technique as a function of arch (maxilla and mandible) and area operated (anterior and posterior).

Table 11 shows the 95% CI insertion torque in relation to surgical technique as a function of implant diameter and length.

Table 11. The IT tests between-subjects and effects (diameter and length).

			Surgical Techniques														
			SD					OD					Total				
			Valid N	Mean	Standard Deviation	95,0% Lower CL for Mean	95,0% Upper CL for Mean	Valid N	Mean	Standard Deviation	95,0% Lower CL for Mean	95,0% Upper CL for Mean	Valid N	Mean	Standard Deviation	95,0% Lower CL for Mean	95,0% Upper CL for Mean
Insertion Torque (IT)	Narrow	Short	1	30	.	.	.	4	48	10	32	63	5	44	11	30	58
		Regular	18	36	17	27	44	18	41	13	35	48	36	38	15	33	44
		Long	7	40	9	32	48	3	62	14	26	98	10	47	14	36	57
		Total	26	37	15	31	43	25	45	14	39	50	51	41	15	36	45
	Regular	Short	31	46	15	41	52	25	48	16	41	55	56	47	16	43	51
		Regular	83	47	15	44	51	56	43	15	39	47	139	46	15	43	48
		Long	18	50	19	40	59	9	50	13	40	60	27	50	17	43	57
		Total	132	47	16	45	50	90	45	15	42	48	222	46	15	44	49
	Wide[1]	Short	1	70	.	.	.	1	20	.	.	.	2	45	35	-273	363
		Regular	1	70	.	.	.	2	35	21	-156	226	3	47	25	-16	109
		Long	0	.	.	.	.	0	.	.	.	.	0	.	.	.	.
		Total	2	70	0	70	70	3	30	17	-13	73	5	46	25	15	77
	Total	Short	33	47	16	41	52	30	47	16	41	53	63	47	16	43	51
		Regular	102	46	16	42	49	76	42	14	39	46	178	44	15	42	46
		Long	25	47	17	40	54	12	53	14	44	62	37	49	16	44	54
		Total	160	46	16	44	49	118	45	15	42	47	278	45	16	44	47

[1] Will not be considered due to lack of observations.

Another multifactorial ANOVA procedure was carried out, and statistically significant differences were found in mean IT values due to the effects of implant length (F(2.261) = 3.243, *p*-value = 0.041 < 0.05), and due to the effects of the interaction between technique used and implant diameter (F(1.261) = 4.538, *p*-value = 0.034 < 0.05), in the sense that the mean IT value with the SD technique for the Narrow implant is significantly lower when compared to the Regular.

The multiple comparison tests showed that the differences in the mean IT values with length are significantly lower for the Regular implants when compared to the Long implants ($p = 0.011 < 0.05$).

Table 12 shows the IT tests between-subjects and effects (diameter and length).

Table 12. The IT tests between-subjects and effects (diameter and length).

IT tests Between-Subjects and Effects

Dependent Variable: Insertion Torque (IT)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Technique	831,515	1	831,515	3,592	,059
Diameter	381,862	1	381,862	1,650	,200
length	1501,469	2	750,735	3,243	,041
Technique * Diameter	1050,655	1	1050,655	4,538	,034
Technique * length	720,052	2	360,026	1,555	,213
Diameter * length	320,404	2	160,202	,692	,501
Technique * Diameter * length	183,671	2	91,835	,397	,673
Error	60421,601	261	231,500		
Corrected Total	65098,381	272			

These results are illustrated in the graphs in Figure 5.

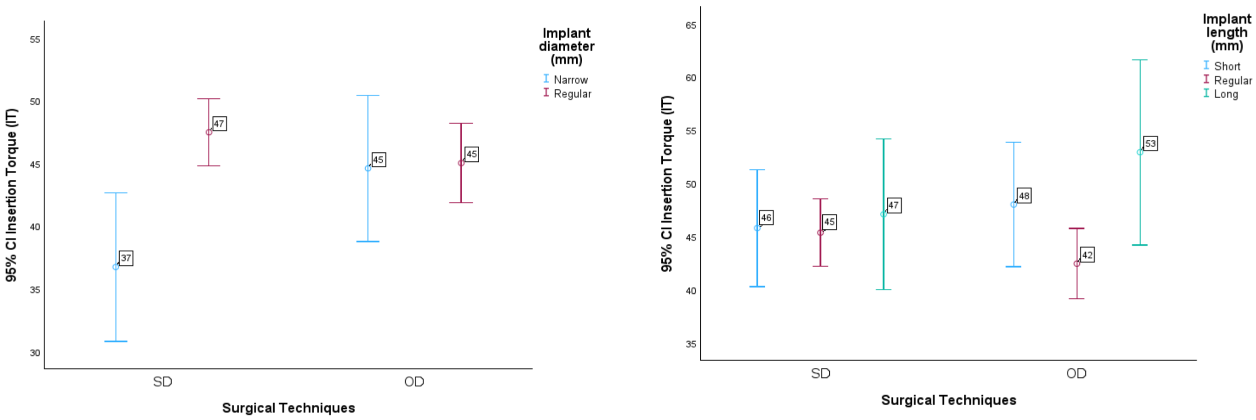

Figure 5. 95% CI insertion torque in relation to surgical technique as a function of implant diameter (Narrow and Regular) and implant length (Short, Regular, Long).

To evaluate the effect of the different factors (surgical technique, arch and area operated) in relation to ISQ over time, a repeated measures ANOVA (three times) was performed.

These results are illustrated in the graphs in Figures 6 and 7.

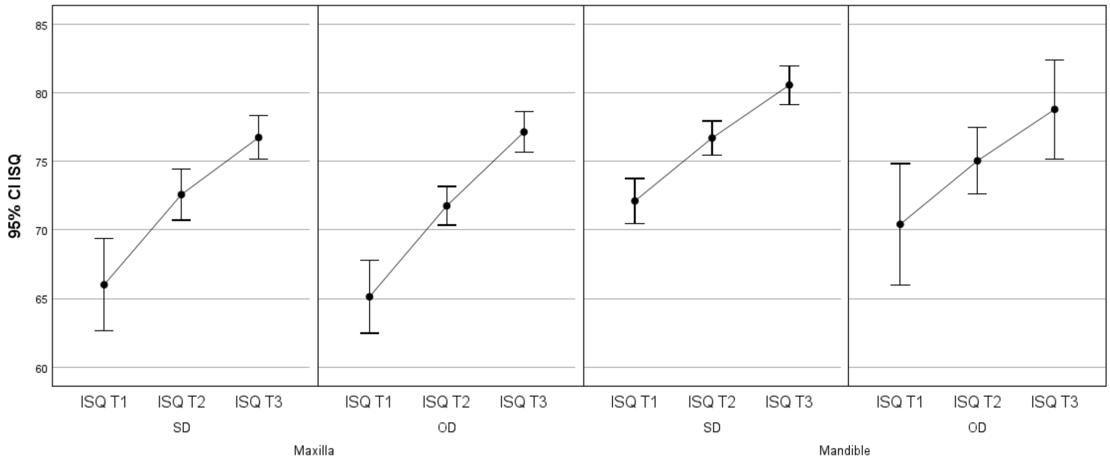

Figure 6. 95% CI implant stability quotient in relation to surgical technique (SD and OD) at three different times (T1, T2 AND T3) in relation to arch (maxilla and mandible).

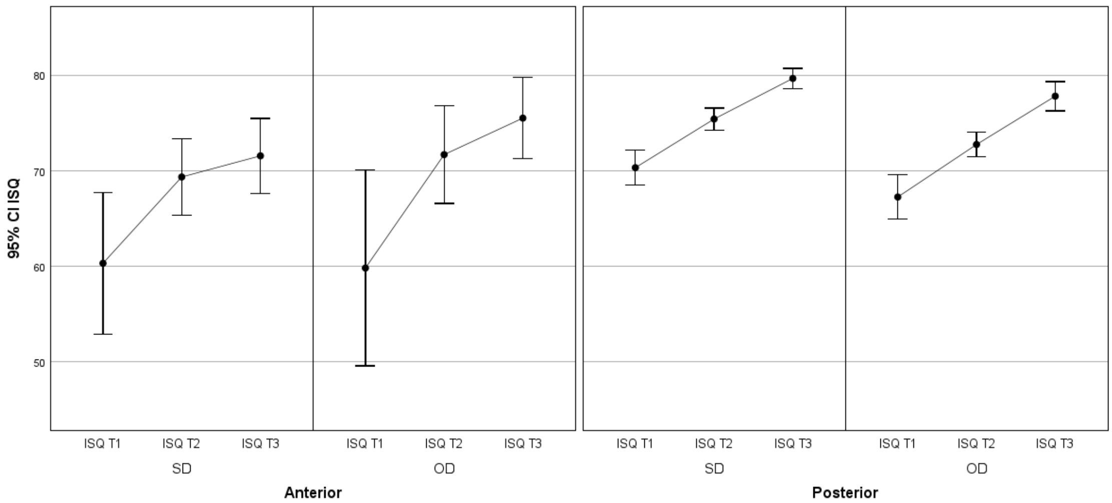

Figure 7. 95% CI implant stability quotient in relation to surgical technique (SD and OD) at three different times (T1, T2 AND T3) in relation to area operated (anterior and posterior).

Table 13 shows the ISQ summary statistics for the different times, broken down according to the factors considered.

Table 13. Descriptive statistics of the ISQ measure according to Procedure, arch and area of operation.

	Surgical Techniques	Arch	Area operated	Mean	Std. Deviation	N
ISQ T1	SD	Maxilla	Anterior	56,4333	14,97840	15
			Posterior	68,2778	14,06975	63
			Total	66,0000	14,90838	78
		Mandible	Anterior	74,8750	3,42479	4
			Posterior	71,9615	7,58577	78
			Total	72,1037	7,45221	82
		Total	Anterior	60,3158	15,36610	19
			Posterior	70,3156	11,07675	141
			Total	69,1281	12,05376	160
	OD	Maxilla	Anterior	58,3333	16,62265	9
			Posterior	65,9156	11,65412	77
			Total	65,1221	12,36502	86
		Mandible	Anterior	66,5000	,70711	2
			Posterior	70,6667	12,66092	30
			Total	70,4063	12,28915	32
		Total	Anterior	59,8182	15,23199	11
			Posterior	67,2477	12,07609	107
			Total	66,5551	12,51628	118
	Total	Maxilla	Anterior	57,1458	15,28247	24
			Posterior	66,9786	12,80426	140
			Total	65,5396	13,59842	164
		Mandible	Anterior	72,0833	5,08347	6
			Posterior	71,6019	9,23012	108
			Total	71,6272	9,04581	114
		Total	Anterior	60,1333	15,05389	30
			Posterior	68,9919	11,59505	248
			Total	68,0360	12,29601	278
ISQ T2	SD	Maxilla	Anterior	68,1333	9,04841	15
			Posterior	73,6270	7,74595	63
			Total	72,5705	8,24295	78
		Mandible	Anterior	73,8750	1,60078	4
			Posterior	76,8397	5,79604	78
			Total	76,6951	5,69587	82
		Total	Anterior	69,3421	8,36004	19
			Posterior	75,4043	6,90055	141
			Total	74,6844	7,32868	160
	OD	Maxilla	Anterior	71,8889	8,07302	9
			Posterior	71,7338	6,43775	77
			Total	71,7500	6,57211	86
		Mandible	Anterior	70,7500	7,42462	2
			Posterior	75,3167	6,72935	30
			Total	75,0313	6,73812	32
		Total	Anterior	71,6818	7,60682	11
			Posterior	72,7383	6,68720	107
			Total	72,6398	6,74945	118
	Total	Maxilla	Anterior	69,5417	8,71520	24
			Posterior	72,5857	7,09340	140
			Total	72,1402	7,40203	164
		Mandible	Anterior	72,8333	3,89444	6
			Posterior	76,4167	6,07604	108
			Total	76,2281	6,02287	114
		Total	Anterior	70,2000	8,04042	30

			Posterior	74,2540	6,92323	248
			Total	73,8165	7,14816	278
ISQ T3	SD	Maxilla	Anterior	71,0667	7,52583	15
			Posterior	78,0794	6,27669	63
			Total	76,7308	7,05392	78
		Mandible	Anterior	73,3750	11,19058	4
			Posterior	80,9231	5,99409	78
			Total	80,5549	6,43966	82
		Total	Anterior	71,5526	8,11531	19
			Posterior	79,6525	6,26269	141
			Total	78,6906	6,99278	160
	OD	Maxilla	Anterior	77,1667	5,49432	9
			Posterior	77,1299	7,02411	77
			Total	77,1337	6,85240	86
		Mandible	Anterior	68,0000	4,24264	2
			Posterior	79,5000	9,93687	30
			Total	78,7813	10,04742	32
		Total	Anterior	75,5000	6,30079	11
			Posterior	77,7944	7,97075	107
			Total	77,5805	7,83592	118
	Total	Maxilla	Anterior	73,3542	7,35361	24
			Posterior	77,5571	6,69131	140
			Total	76,9421	6,93051	164
		Mandible	Anterior	71,5833	9,29740	6
			Posterior	80,5278	7,28198	108
			Total	80,0570	7,61977	114
		Total	Anterior	73,0000	7,63612	30
			Posterior	78,8508	7,09550	248
			Total	78,2194	7,36922	278

Once the assumption of sphericity was tested using the Mauchly test (p-value < 0.05), the sphericity of the data was rejected. As the value of the epsilon estimate is less than 0.75, the Greenhouse-Geisser correction will be used to interpret the results for intra-subject effects (Table 14).

Table 14. Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
ISQ	Sphericity Assumed	2718,176	2	1359,088	26,085	<.001
	Greenhouse-Geisser	2718,176	1,438	1890,708	26,085	<.001
	Huynh-Feldt	2718,176	1,481	1835,708	26,085	<.001

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
	Lower-bound	2718,176	1,000	2718,176	26,085	<.001
ISQ * Technique	Sphericity Assumed	42,299	2	21,149	,406	,667
	Greenhouse-Geisser	42,299	1,438	29,422	,406	,599
	Huynh-Feldt	42,299	1,481	28,566	,406	,605
	Lower-bound	42,299	1,000	42,299	,406	,525
ISQ * Arch	Sphericity Assumed	689,800	2	344,900	6,620	,001
	Greenhouse-Geisser	689,800	1,438	479,811	6,620	,004
	Huynh-Feldt	689,800	1,481	465,853	6,620	,004
	Lower-bound	689,800	1,000	689,800	6,620	,011
ISQ * Area operated	Sphericity Assumed	87,284	2	43,642	,838	,433
	Greenhouse-Geisser	87,284	1,438	60,713	,838	,400
	Huynh-Feldt	87,284	1,481	58,947	,838	,403
	Lower-bound	87,284	1,000	87,284	,838	,361
ISQ * Technique * Arch	Sphericity Assumed	14,746	2	7,373	,142	,868
	Greenhouse-Geisser	14,746	1,438	10,257	,142	,797
	Huynh-Feldt	14,746	1,481	9,959	,142	,804
	Lower-bound	14,746	1,000	14,746	,142	,707
ISQ * Technique* Area Operated	Sphericity Assumed	27,596	2	13,798	,265	,767
	Greenhouse-Geisser	27,596	1,438	19,195	,265	,693
	Huynh-Feldt	27,596	1,481	18,637	,265	,699
	Lower-bound	27,596	1,000	27,596	,265	,607
ISQ * Arch * Area Operated	Sphericity Assumed	474,406	2	237,203	4,553	,011
	Greenhouse-Geisser	474,406	1,438	329,987	4,553	,021
	Huynh-Feldt	474,406	1,481	320,388	4,553	,020
	Lower-bound	474,406	1,000	474,406	4,553	,034

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
ISQ * Technique* Arch * Area Operated	Sphericity Assumed	10,280	2	5,140	,099	,906
	Greenhouse-Geisser	10,280	1,438	7,150	,099	,841
	Huynh-Feldt	10,280	1,481	6,942	,099	,848
	Lower-bound	10,280	1,000	10,280	,099	,754
Error(ISQ)	Sphericity Assumed	28135,682	540	52,103		
	Greenhouse-Geisser	28135,682	388,165	72,484		
	Huynh-Feldt	28135,682	399,795	70,375		
	Lower-bound	28135,682	270,000	104,206		

Once the assumption of sphericity was tested using the Mauchly test (*p*-value < 0.05), the sphericity of the data was rejected. As the value of the epsilon estimate was less than 0.75, the Greenhouse−Geisser correction was used to interpret the results for intra-subject effects. In this way, it was found that there are statistically significant differences in the average ISQ values in the different periods considered, i.e., there is significant variation in the average ISQ value over time, in the sense that it increases significantly over time (Figure 8). Statistically significant differences by multiple comparison tests ($p < 0.05$) were detected between all pairs (T1−T2, T1−T3 and T2−T3).

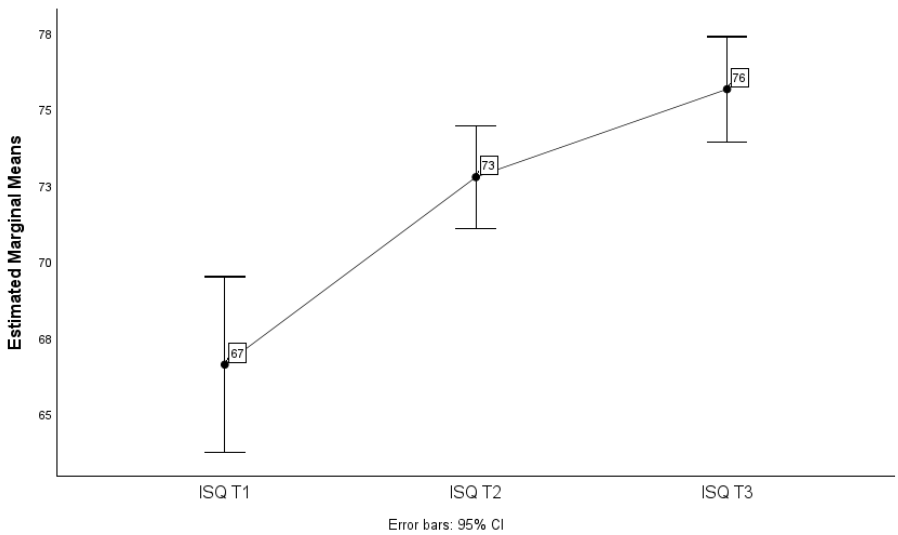

Figure 8. Distribution of mean ISQ values over time and respective 95% confidence intervals.

There were significant differences in the mean ISQ values due to the interaction of time and arch (F(1.438; 388.165) = 6.620, p-value < 0.05), which means that the means of the groups (maxilla and mandible) vary differently over the three times considered (T1,T2 and T3), i.e., the mean ISQ over time is not the same for the arches considered. This is reflected in the non-parallel lines in the graph in Figure 9.

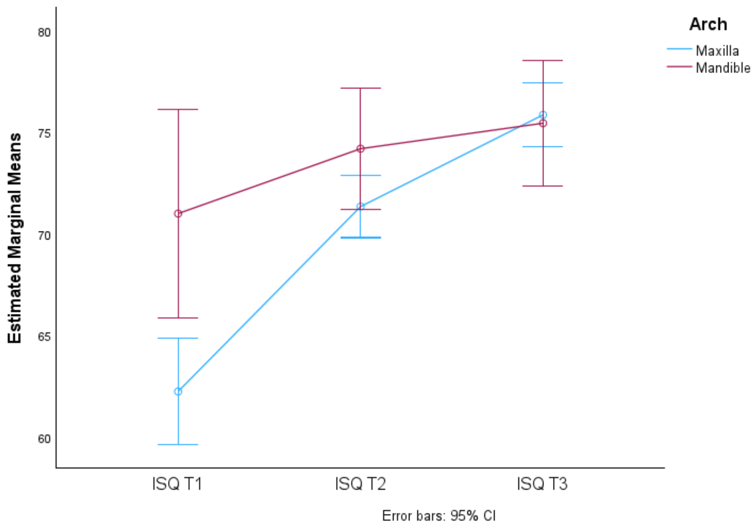

Figure 9. Distribution of mean ISQ values over time according to arch and respective 95% confidence intervals.

There were significant differences in the average ISQ values due to the interaction of time, arch and area (F(1.438; 388.165) = 4.553, p-value < 0.05), which means that the averages of the groups (maxilla and mandible) vary differently depending on the area of operation (posterior or anterior) in the three times considered, i.e., the average ISQ over time is not the same for the arch and area of operation considered. This is illustrated by the different behavior of the graphs in Figure 10.

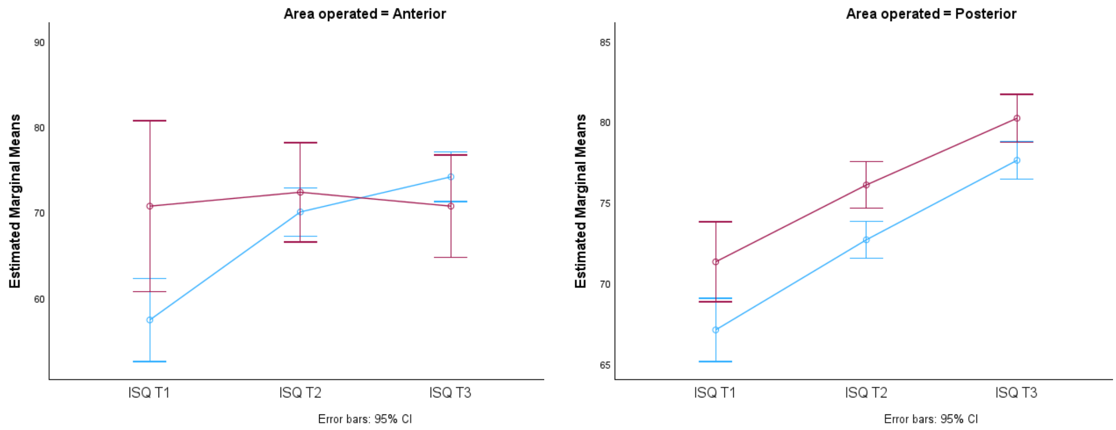

Figure 10. Distribution of mean ISQ values over time according to arch and area with respective 95% confidence intervals.

Thus, as in the previous situation, to assess the effect of the different factors (Surgical Technique, Diameter and Length) on the ISQ over time, an ANOVA with repeated measures (3 times) was carried out.

Table 15 shows the ISQ summary statistics for the different times, broken down according to the factors considered.

Table 15. Descriptive statistics of the ISQ measure according to Procedure, Diameter and Length

	Surgical Techniques	Implant diameter (mm)	Implant length (mm)	Mean	Std. Deviation	N
ISQ T1	SD	Narrow	Short	68,5000	.	1
			Regular	66,1944	8,01311	18
			Long	64,5000	10,58694	7
			Total	65,8269	8,45215	26
		Regular	Short	67,3065	9,64596	31
			Regular	71,9096	11,89465	83
			Long	63,2778	17,28245	18
			Total	69,6515	12,59937	132
		Total	Short	67,3438	9,49145	32
			Regular	70,8911	11,47881	101
			Long	63,6200	15,48876	25
			Total	69,0222	12,07703	158
	OD	Narrow	Short	65,7500	5,23609	4
			Regular	65,3056	9,16377	18
			Long	68,8333	2,25462	3
			Total	65,8000	8,04156	25
		Regular	Short	69,4200	14,45876	25
			Regular	68,0357	11,24797	56
			Long	57,0000	15,71027	9
			Total	67,3167	13,00291	90

	Surgical Techniques	Implant diameter (mm)	Implant length (mm)	Mean	Std. Deviation	N
		Total	Short	68,9138	13,55680	29
			Regular	67,3716	10,78274	74
			Long	59,9583	14,45912	12
			Total	66,9870	12,08331	115
	Total	Narrow	Short	66,3000	4,69840	5
			Regular	65,7500	8,49580	36
			Long	65,8000	8,95731	10
			Total	65,8137	8,17066	51
		Regular	Short	68,2500	11,96244	56
			Regular	70,3489	11,75284	139
			Long	61,1852	16,74305	27
			Total	68,7050	12,78696	222
		Total	Short	68,0902	11,52986	61
			Regular	69,4029	11,29359	175
			Long	62,4324	15,06106	37
			Total	68,1648	12,09940	273
ISQ T2	SD	Narrow	Short	75,0000	.	1
			Regular	70,6667	6,29893	18
			Long	70,6429	5,35968	7
			Total	70,8269	5,88208	26
		Regular	Short	77,7419	4,49235	31
			Regular	75,5663	7,24601	83
			Long	69,9444	9,25121	18
			Total	75,3106	7,34783	132
		Total	Short	77,6562	4,44580	32
			Regular	74,6931	7,30410	101
			Long	70,1400	8,24055	25
			Total	74,5728	7,30344	158
	OD	Narrow	Short	70,6250	5,49811	4
			Regular	69,4167	6,05672	18
			Long	72,1667	2,02073	3
			Total	69,9400	5,56836	25
		Regular	Short	76,3200	5,21792	25
			Regular	73,0446	7,14351	56
			Long	68,9444	6,80737	9
			Total	73,5444	6,89229	90
		Total	Short	75,5345	5,52903	29
			Regular	72,1622	7,03178	74
			Long	69,7500	6,04716	12
			Total	72,7609	6,77079	115
	Total	Narrow	Short	71,5000	5,14782	5
			Regular	70,0417	6,12300	36
			Long	71,1000	4,53872	10
			Total	70,3922	5,69062	51
		Regular	Short	77,1071	4,83709	56
			Regular	74,5504	7,28541	139
			Long	69,6111	8,39337	27
			Total	74,5946	7,20342	222
		Total	Short	76,6475	5,06157	61
			Regular	73,6229	7,27857	175
			Long	70,0135	7,51525	37
			Total	73,8095	7,12780	273
ISQ T3	SD	Narrow	Short	81,0000	.	1

Surgical Techniques	Implant diameter (mm)	Implant length (mm)	Mean	Std. Deviation	N
		Regular	73,2222	8,11539	18
		Long	73,6429	3,02372	7
		Total	73,6346	7,01934	26
	Regular	Short	79,3065	7,35944	31
		Regular	80,3976	5,80357	83
		Long	76,0556	7,45948	18
		Total	79,5492	6,54633	132
	Total	Short	79,3594	7,24595	32
		Regular	79,1188	6,81401	101
		Long	75,3800	6,55153	25
		Total	78,5759	6,96012	158
OD	Narrow	Short	77,7500	4,29146	4
		Regular	73,4722	8,31100	18
		Long	77,6667	1,75594	3
		Total	74,6600	7,43404	25
	Regular	Short	81,7400	5,04794	25
		Regular	77,6518	8,32789	56
		Long	74,3333	9,08983	9
		Total	78,4556	7,89383	90
	Total	Short	81,1897	5,07693	29
		Regular	76,6351	8,46156	74
		Long	75,1667	7,93248	12
		Total	77,6304	7,92179	115
Total	Narrow	Short	78,4000	3,99061	5
		Regular	73,3472	8,09658	36
		Long	74,8500	3,24936	10
		Total	74,1373	7,17153	51
	Regular	Short	80,3929	6,49245	56
		Regular	79,2914	7,03431	139
		Long	75,4815	7,90506	27
		Total	79,1059	7,12645	222
	Total	Short	80,2295	6,32493	61
		Regular	78,0686	7,63129	175
		Long	75,3108	6,91752	37
		Total	78,1777	7,38120	273

Once the assumption of sphericity was tested using the Mauchly test (p-value < 0.05), the sphericity of the data was rejected. As the value of the epsilon estimate is less than

0.75, the Greenhouse-Geisser correction will be used to interpret the results for intra-subject effects (Table 16).

Table 16. Tests of Within-Subjects Effects.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
ISQ	Sphericity Assumed	4050,126	2	2025,063	38,835	<.001
	Greenhouse-Geisser	4050,126	1,438	2816,367	38,835	<.001
	Huynh-Feldt	4050,126	1,505	2691,446	38,835	<.001
	Lower-bound	4050,126	1,000	4050,126	38,835	<.001
ISQ * Technique	Sphericity Assumed	17,021	2	8,511	,163	,849
	Greenhouse-Geisser	17,021	1,438	11,836	,163	,776
	Huynh-Feldt	17,021	1,505	11,311	,163	,787
	Lower-bound	17,021	1,000	17,021	,163	,687
ISQ * Diameter	Sphericity Assumed	71,444	2	35,722	,685	,505
	Greenhouse-Geisser	71,444	1,438	49,681	,685	,459
	Huynh-Feldt	71,444	1,505	47,477	,685	,465
	Lower-bound	71,444	1,000	71,444	,685	,409
ISQ * Length	Sphericity Assumed	211,512	4	52,878	1,014	,400
	Greenhouse-Geisser	211,512	2,876	73,540	1,014	,384
	Huynh-Feldt	211,512	3,010	70,278	1,014	,387
	Lower-bound	211,512	2,000	105,756	1,014	,364
ISQ * Technique ISQ * Diameter	Sphericity Assumed	15,726	2	7,863	,151	,860
	Greenhouse-Geisser	15,726	1,438	10,936	,151	,788
	Huynh-Feldt	15,726	1,505	10,451	,151	,799
	Lower-bound	15,726	1,000	15,726	,151	,698
ISQ * Technique *length	Sphericity Assumed	17,097	4	4,274	,082	,988

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
	Greenhouse-Geisser	17,097	2,876	5,944	,082	,966
	Huynh-Feldt	17,097	3,010	5,681	,082	,970
	Lower-bound	17,097	2,000	8,549	,082	,921
ISQ * Diameter * length	Sphericity Assumed	99,240	4	24,810	,476	,754
	Greenhouse-Geisser	99,240	2,876	34,505	,476	,691
	Huynh-Feldt	99,240	3,010	32,974	,476	,700
	Lower-bound	99,240	2,000	49,620	,476	,622
ISQ * Technique* Diameter * length	Sphericity Assumed	38,790	4	9,697	,186	,946
	Greenhouse-Geisser	38,790	2,876	13,487	,186	,899
	Huynh-Feldt	38,790	3,010	12,889	,186	,906
	Lower-bound	38,790	2,000	19,395	,186	,830
Error(ISQ)	Sphericity Assumed	27219,757	522	52,145		
	Greenhouse-Geisser	27219,757	375,336	72,521		
	Huynh-Feldt	27219,757	392,756	69,304		
	Lower-bound	27219,757	261,000	104,290		

As in the previous situation, to evaluate the effect of the different factors (surgical technique, diameter, and length) in relation to the ISQ over time, an ANOVA with repeated measures (three times) was carried out.

Once the assumption of sphericity was tested using the Mauchly test (p-value < 0.05), the sphericity of the data was rejected. As the value of the epsilon estimate is less than 0.75, the Greenhouse–Geisser correction will be used to interpret the results for intra-subject effects.

As with the previous results, there were statistically significant differences in the mean ISQ values in the different periods considered; statistically significant differences by multiple comparison tests ($p < 0.05$) were detected between all pairs (T1-T2, T1-T3 and T2-T3).

There were no significant differences in the average ISQ values due to the interaction of time and technique used (F(1.438; 375.336) = 0.163, *p*-value > 0.05), meaning that the ISQ averages over time in the groups (SD and OD) did not vary. This is reflected in the almost overlapping lines in the graph in Figure 11.

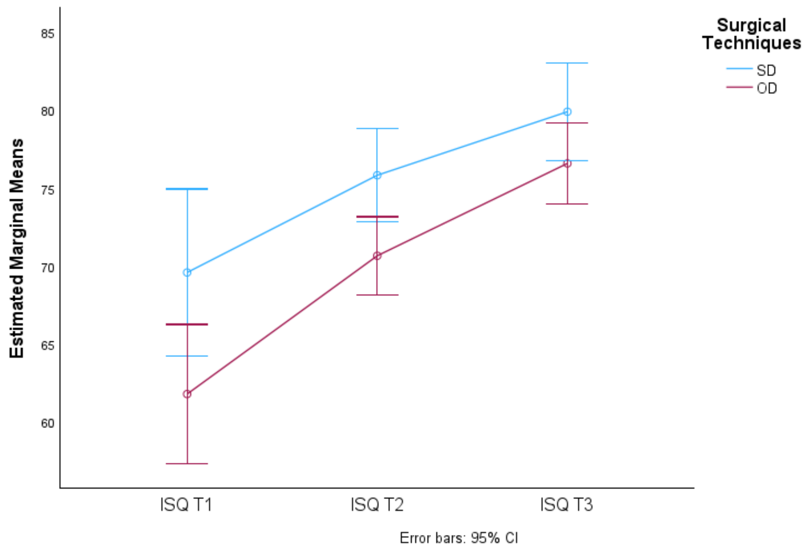

Figure 11. Distribution of mean ISQ values over time according to surgical procedure and respective 95% confidence intervals.

No significant differences were found in the average ISQ values due to the interaction of time and technique used (F (1.438; 375.336) = 0.685, *p*-value > 0.05), meaning that the ISQ averages over time in the diameters considered (Narrow and Regular) do not vary. This is reflected in the almost overlapping lines in the graph in Figure 12.

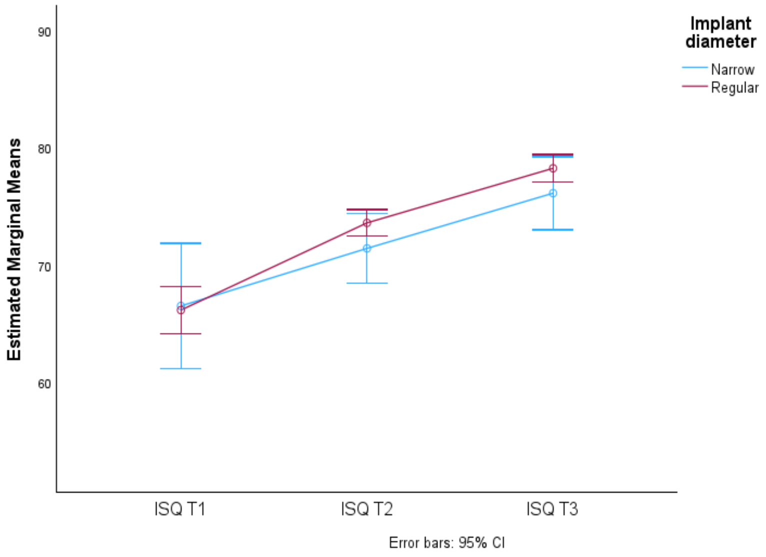

Figure 12. Distribution of mean ISQ values over time according to implant diameter and respective 95% confidence intervals.

There were no significant differences in the average ISQ values due to the interaction of time and technique used (F(2.876; 375.336) =1.014, *p*-value > 0.05), meaning that the ISQ averages over time in the lengths considered (Short, Regular, and Long) do not vary. This is reflected in the lines and confidence limits, which are practically superimposed on the graph in Figures 13 and 14.

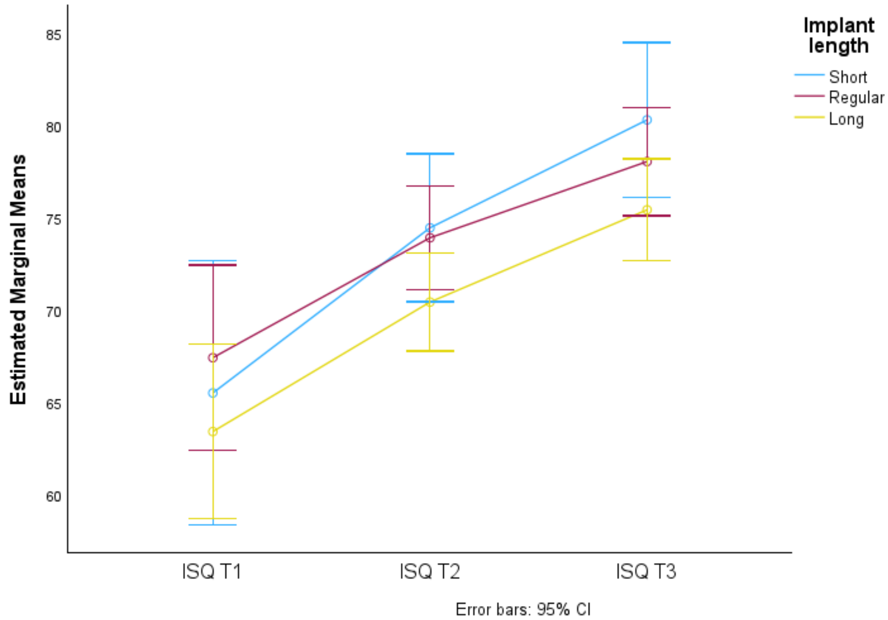

Figure 13. Distribution of mean ISQ values over time according to implant length and respective 95% confidence intervals.

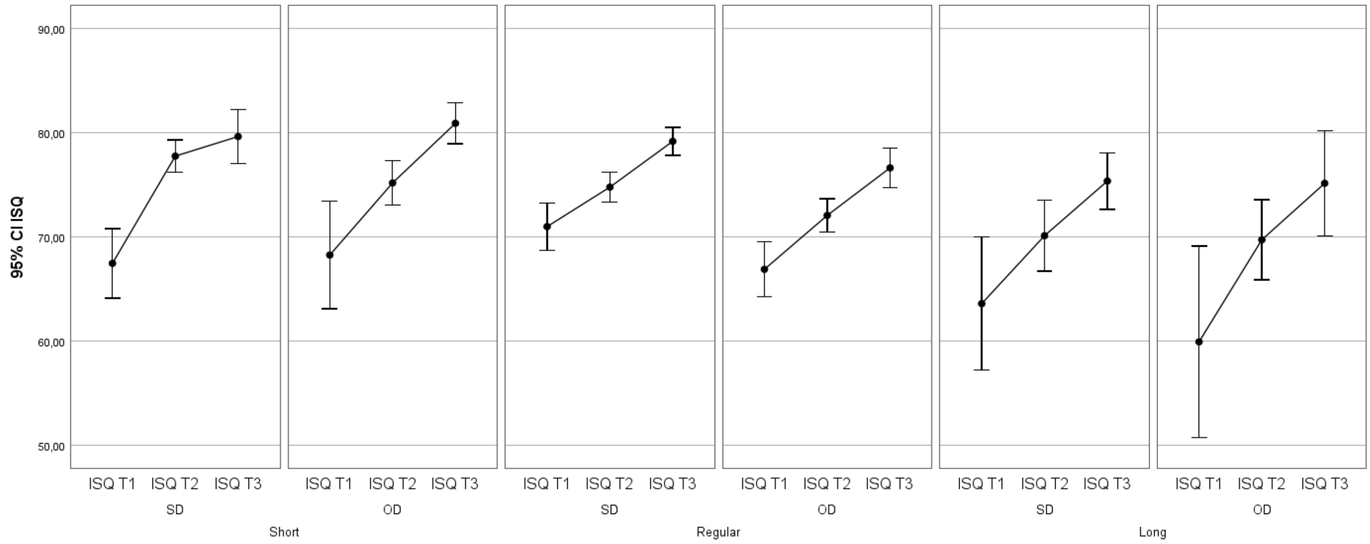

Figure 14. 95% CI Implant stability quotient in relation to surgical technique (SD and OD) at three different times (T1, T2 and T3) in relation to implant length (Short, Regular, and Long).

Table 17 shows the correlation between the IT and ISQ T1 values and the variables under study.

Table 17. Pearson correlation between the IT and ISQ T1 values and the variables under study.

	Maxilla ISQ T1	Mandible ISQ T1	Anterior ISQ T1	Posterior ISQ T1	Narrow ISQ T1	Regular ISQ T1	Wide ISQ T1	Short ISQ T1	Regular ISQ T1	Long ISQ T1	SD ISQ T1	OD ISQ T1	Total ISQ
Maxilla IT	r = 0.192 * $p = 0.014$												
Mandible IT		r = 0.315 * $p < 0.001$											
Anterior IT			r = −0.003 $p = 0.988$										
Posterior IT				r = 0.326 * $p < 0.001$									
Narrow IT					r = 0.195 $p = 0.171$								
Regular IT						r = 0.242 * $p < 0.001$							
Wide IT							r = 0.903 * $p = 0.036$						
Short IT								r = 0.413 * $p < 0.001$					
Regular IT									r = 0.310 * $p < 0.001$				
Long IT										r = 0.058 $p = 0.734$			
SD IT											r = 0.290 * $p < 0.001$		
OD IT												r = 0.221 * $p = 0.016$	
Total IT													r = 0.263 * $p < 0.001$

Note: ISQ T1—implant stability quotient in the surgical phase of implant placement; IT—insertion torque; OD—osseodensification; p = level of significance; SD—subtractive conventional drilling. * significant for the 5% decision rule used.

Osseointegration and primary implant stability are objectives of critical importance because their impediments often lead to implant failure (37). Implant primary stability is a crucial component of osseointegration and is correlated with bone density, surgical drilling technique, implant surface texture, and geometry (21, 31, 32). Besides primary stability, it is important for the implant to obtain secondary stability, which is achieved after bone production and maturation on the implant body (31). For this reason, the application of tests to assess the primary and secondary stability of an implant has become extremely important in implant dentistry. These tests include determining the insertion torque (IT) and performing a resonance frequency analysis (RFA) (32).

Previous studies focused on the analysis of OD effects on implant placement, while the present study evaluated the OD drilling effects on healing at three different stages—T1, T2, and T3—with different diameters and lengths placed in anterior and posterior regions of the maxilla and mandible. To assess the implant stability, insertion torque measurements and a resonance frequency analysis were carried out.

The IT, initially developed by Johansson and Strid, is a measure of the frictional resistance obtained at the time of implant placement (32, 61) and was applied with a torque wrench. The maximum value of the insertion torque was recorded in Newton centimeters (Ncm) (31, 61).

In 1996, Meredith *et al.* (34) developed a noninvasive clinical method to measure implant stability, RFA, by using an Osstell® device that can be used multiple times both intra-operatively and during follow-up (34). The resonance frequencies vary according to the different levels of implant stability, which is presented through an implant stability quotient (ISQ). To measure the ISQ value, the inserted implant is attached to a transducer (SmartPeg). The Osstell® device is positioned 1 mm from the transducer, and four SmartPeg points are measured (mesial, distal, buccal, and lingual/palatal points). The ISQ value ranges from 1 to 100. A value of ISQ<60 represents low stability, ≥60 ISQ≤69 represents medium stability, and ISQ≥70 represents high stability (31, 61). According to our results, there was a progressive increase in IT and ISQ over time, regardless of the technique used, SD or OD. These two independent variables indicate two different characteristics of primary stability; however, they "move" together (62, 63). These results are in line with the findings of our study, in which, overall, the higher the IT, the higher the ISQ. Another study conducted by Vale de Souza *et al.* (31) showed that there is a positive correlation between IT and initial ISQ (correlation: 0.457; $p = 0.022$), so that the greater the IT, the greater the initial ISQ (and vice versa). Therefore, increased IT and ISQ values are positive primary stability indicators, which can be critical for immediate loading and subsequently improving osseointegration.

According to previous studies, the use of the OD drilling technique increases bone mineral density due to the compaction-autografting and the elastic spring-back effect, which promotes increased bone-to-implant contact using the SD technique (39, 60). On the other hand, the conventional drilling technique limits the initial bone–implant interaction due to the excavation of nucleated bone remnants, the amount of which can vary due to factors such as drilling speed, time, and the use of irrigation in the osteotomy (37). Buchter *et al.* (64) argues that the osteotome technique hinders the bone remodeling unit, causing ultrastructural microdamage, which can significantly reduce biomechanical stability shortly after implant placement (65). Several studies showed that the osteotomized group exhibited microfractures, which was evident histologically, and the measured removal torque values were significantly lower for the same group compared with the non-condensed group. Thus, traumatic damage to the bone has been concluded to delay the achievement of secondary stability and to extend the osseointegration period for bone tissue microdamage repair, which stimulates the activation of osteoclasts (66).

The results of our study showed no statistical differences between the OD and SD groups in which the overall IT and ISQ values support the null hypothesis that the drilling technique may not influence clinical parameters of implant primary stability up to 6 months after implant placement. Although most of the studies carried out support the opposite hypothesis, it is important to consider that most of them were carried out on animals. For this reason, more human studies are needed in order to make the comparison of results as reliable as possible.

With respect to the arch, the analyses of the overall ISQ values showed an upward trend in both groups in the maxilla and mandible. According to the evidence, higher ISQ values are expected in the mandible compared with the maxilla, which is in line with our results. However, no statistical differences were found among the OD and SD groups, specially between T1 and T2. This can be explained by the increased bone-to-implant contact that occurs during the osseointegration (37).

Despite the obtained results, in general, we can state that although IT and ISQ are two independent variables, high levels of IT also showed high ISQ values, which represents good indicators of primary stability.

In accordance with the literature, the primary stability of the implant can be significantly influenced by the macrogeometry of the implant. Some studies showed that hybrid (apical conical and crestal cylindrical) and conical designs provided the greatest primary stability (22, 67). The growing popularity of tapered implants can be attributed to their simplicity of use in clinical settings, their shorter drilling sequences, the possibility of shorter healing times, and less trauma during the osteotomy. The lateral compressive forces on the cortical bone may be a significant reason for their increased primary stability (68, 69). Studies conducted on animals suggested that a larger diameter is positively correlated with greater primary stability (70, 71). Thus, a larger implant diameter improves load distribution by increasing primary stability and functional surface area. Nonetheless, a large number of studies has demonstrated that, in lower-quality bone, implants with smaller diameters can still establish adequate primary stability (71). Our findings are in accordance with this theory in which statistically significant differences were seen between the mean IT value and the SD technique in relation to regular implants, which showed significantly higher values when compared with narrow implants ($p=0.034$). The average ISQ values did not vary but always increased over time regardless of the technique used; this could be explained by the percentage of new bone formation over time.

An increase in IT and RFA (ISQ) values was also favorably correlated with implant length. It is well known that the use of a long, tilted implant is a method of improving the IT before immediate load rehabilitation (22). In fact, it is directly correlated with the overall surface area in contact with the bone (22, 68). The results of the present study showed statistically significant differences in the mean IT values for length of the implant in the OD group ($p=0.041$) with significantly lower mean IT values for the regular implants compared with the long ones. Regarding the ISQ, no differences were found in relation to the length of the implants considered, regardless of the technique used.

Some studies indicate that the availability of cortical and trabecular bone at the implant interface may affect the biomechanical stability of the implant and the bone healing response (21, 22). For this reason, understanding the particularities, characteristics, differences, and anatomy of the maxilla and mandible is important. According to the Lekholm and Zarb (1985) classification (the most popular classification of bone quality), bone types are classified based on the amount of cortical versus trabecular bone from I to IV (24, 25). The biomechanical properties of osteoporotic bone are similar to those of type IV bone and do not provide appropriate stability for implants. Another important aspect is bone density according to anatomical location, which is characterized by the Norton & Gamble classification. Norton and Gamble (2001) described different bone density ranges according to their typical anatomical locations in the maxilla and mandible. All of the subjectively rated areas in each of the four qualities were subsequently grouped together so that a range of Houndsfield (HU) values could be assigned to each specific quality (28). Patients with low-density bone (types III and IV), commonly seen in the posterior mandible, especially in elderly patients, represent a high percentage of those seeking implant treatments.

The results of the present study showed statistical differences in the arch and the type of osteotomy with respect to IT. IT and ISQ were higher in the mandible than in the maxilla for both the SD and OD techniques. These results are in line with the study by Turkyilmaz *et al.* (72), in which a strong relationship was found between bone density and ISQ values.

With regard to area, in general, the anterior region showed higher IT values compared with the posterior area for both techniques. These results can be explained by the bone density in the anterior region compared with the posterior region of the arch. However, in terms of technique, the anterior region of the OD group showed higher IT values compared with the SD technique. These results are in compliance with the study by Bergamo *et al.* (73), where 150 implants in the anterior region showed increased IT in the OD group compared with the SD group.

Although not the aim of the present study, in clinical practice, achieving high levels of biomechanical stability has become more necessary to support the current tendency toward early loading protocols. In a study by Trisi *et al.* (74), immediate loading could be performed when the IT value was at least 45Ncm and ISQ was at least 68. Thus, according to the results, rehabilitation with immediate loading was a possible option for implants with an ISQ >68, which can be especially useful for the posterior maxillary region, which has low-density bone that makes immediate loading protocols difficult.

A larger sample of wide implants would be necessary in order to understand whether there was a change in primary stability parameters between Osseodensification and subtractive conventional drilling. Furthermore, more human studies are needed, especially on low-density bone (type III and IV), so that the results can be compared as reliably as possible. Most studies on this technique have been carried out on animals and not humans, which makes it difficult to compare the results.

CHAPTER IV – CONCLUSIONS

The results strongly indicate that OD does not have a negative influence on osseointegration compared to conventional subtractive osteotomy. Furthermore, the tapered implant design may compensate for the low stability expected in soft bone, and dense bone may compensate for short implant length if required by the anatomical bone conditions.

Osseodensification appears to be a viable method for increasing bone quantity and quality, but the literature's results are inconclusive and should be read thoughtfully.

The studies analysed showed that the OD technique has advantages when used in low-density bone (type IV) by increasing primary stability, bone–implant contact, and clinical success.

In addition, the OD technique can allow for additional procedures such as maxillary sinus elevation, narrow alveolar ridge expansion, and post-extraction implants.

However, these results should be interpreted with caution, as the studies had some limitations and biases. Therefore, more studies with greater methodological rigour and external validity are needed to confirm the benefits of the OD technique in oral implantology.

CHAPTER V – FUTURE PROSPECTS

As future perspectives i intend to carry out five diferent studies related to the Versah System:

1- A Clinical trial to evaluate the performance of Versah drill in maxillary sinus augmentation.

2- Transcrestal Sinus Floor Elevation using Versah system vs lateral window.

3- Application of osseodensification technique in alveolar ridge expansion.

4- The effect of osseodensification in mandibular Split Crest procedure.

5- A Radiographic Study using CBCT in osseodensification technique

CHAPTER VI – BIBLIOGRAPHY

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Annex 1. Approval by the Ethics Committee

CESPU
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CARTA RESPOSTA

Título do projeto: Osseodensification – A Novel Implantologic System vs Traditional

Investigador responsável: João Paulo Alves Fontes Pereira

Orientador: Prof. Doutor Marco Infante da Câmara

Nº Registo: 02/CE-IUCS/2019

Parecer:

Exmo(a). Senhor(a),

Em resposta ao pedido efetuado por V. Exa. a esta Comissão de Ética, para emissão de parecer sobre o projeto de investigação supra identificado, somos a informar que, e de acordo com o regulamento, o mesmo recebeu parecer favorável por parte desta Comissão.

Gandra, 5 de fevereiro [illegible]9

Prof. Doutor Jorge Brandão Pe[illegible]
Presidente da Comissão de Ética

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Annex 2. Informed consent

Declaração de Consentimento Informado da tese de doutoramento "OSSEODENSIFICAÇÃO - Novo Sistema Implantológico Vs Sistema Tradicional na Implantologia Oral".

Eu, ____ aceito de minha livre vontade, participar neste estudo intitulado "OSSEODENSIFICAÇÃO - Novo Sistema Implantológico Vs Sistema Tradicional na Implantologia Oral" realizado pelo Médico Dentista João Fontes Pereira sob a orientação do Professor Marco Infante da Câmara.

Compreendi a explicação que me foi fornecida acerca do estudo em que estou a participar, tendo-me sido dada a oportunidade de fazer as perguntas que julguei necessárias e pertinentes.

Tomei também conhecimento que, de acordo com as recomendações da declaração de Helsínquia, a informação ou explicação que me foi prestada versou os objectivos, os métodos, os benefícios previstos e o possível eventual desconforto de um dos testes que será efectuado.

Por isso, consinto a participação no estudo, colaborando em todas as suas etapas, permitindo que todas as informações recolhidas sejam utilizadas em futuros estudos, podendo desistir de participar a qualquer momento, sem que daí resulte qualquer prejuízo para o meu tratamento.

Toda a informação obtida nesta investigação será estritamente confidencial e a identidade do paciente não será revelada em qualquer relatório ou publicação ou a qualquer pessoa não relacionada com esta investigação sem autorização prévia por escrito do participante.

Assinaturas,

Participante: ____

Investigador:____

João Paulo Alves Fontes Pereira

Famalicão, ____, de _____________ de ____

Agradecido pela sua colaboração.

Annex 3. Medical records

Ficha de Recolha de Dados

Tese de Doutoramento "OSSEODENSIFICAÇÃO - Novo Sistema Implantológico Vs Sistema Tradicional na Implantologia Oral"

Investigador João Paulo Alves fontes Pereira

Paciente ____ **Contacto** ________________

Sexo masculino ☐ feminino ☐

Idade ____

Fumador não ☐ sim ☐ nº de cigarros/dia ______

Patologias conhecidas ____

Região reabilitada maxila ☐ mandibula ☐ **Altura da gengiva/crista** __________mm

Área regenerada não ☐ sim ☐ com que material?______________________

Tipo de implante ______________________ **Binário** ______N.cm

Tipo de broca tradicional ☐ osseodensificação ☐ **Carga em T1** sim ☐ não ☐

Medição ISQ Osstell **T1** MD____VL____ **T2** MD____VL____ **T3** MD____VL____

Região reabilitada maxila ☐ mandibula ☐ **Altura da gengiva/crista** __________mm

Área regenerada não ☐ sim ☐ com que material?______________________

Tipo de implante ______________________ **Binário** ______N.cm

Tipo de broca tradicional ☐ osseodensificação ☐ **Carga em T1** sim ☐ não ☐

Medição ISQ Osstell **T1** MD____VL____ **T2** MD____VL____ **T3** MD____VL____

Região reabilitada maxila ☐ mandibula ☐ **Altura da gengiva/crista** __________mm

Área regenerada não ☐ sim ☐ com que material?______________________

Tipo de implante ______________________ **Binário** ______N.cm

Tipo de broca tradicional ☐ osseodensificação ☐ **Carga em T1** sim ☐ não ☐

Medição ISQ Osstell **T1** MD____VL____ **T2** MD____VL____ **T3** MD____VL____

Notas:

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Annex 4. Conference Paper - Oral Pathology and Rehabilitation Research Unit (UNIPRO)

Osseodensification Crestal Sinus Floor Elevation: a Case Report

I.Fraile [1,*], JF. Pereira [2,3], J. Faria [3,4], R. Costa [2], M. Relvas [2,4], M. Vasques [2] and M. Infante da Câmara [2,3]

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Introduction

Osseodensification is a surgical technique based on two essential assumptions: the biological characteristics of the bone and the use of specific drills (Densah), designed to prepare the surgical bed without bone loss. Denshan burs rotate at 800-1500 RPM in a counterclockwise direction, increasing bone density and promoting the formation of new bone tissue.


Figure 1


Figure 2


Figure 3


Figure 4

Case Description

- Patient treated in the Posgraduate program in Implant Dentistry (CESPU) for rehabilitation of edentulous space in the first upper right molar(16) **(Fig. 1 and 2).**
- The amount of remanescent bone was 4.5mm (**Fig. 3 and 4).**
- Sinus bone graft elevation with Densah burs® and immediate implant placement was planned.
- Bio-Oss small particle size was the bone graft material used and pushed with Versah Burs rotating in counterclockwise 150RPM without irrigation until 12mm **(Fig 5 to 8)**
- After sinus bone grafting, a implant Straumann BLT® de 4,1mmx10mm was placed in the surgical site with Platelet rich fibrin (PRF). The primary stability achieved was 60N/cm **(Fig. 9 to 12)**.
- The postoperative radiographic imaging shows a vertical gain of bone height **(Fig. 13)**
- Implant after the healing period **(Fig 14)**.
- The access to screw was closed with silver plug **(Fig 15)**
- After 5 months, the 2nd surgical phase was performed, with removal of the healing cap, exposure of the implant and impression for making a screwed zirconia crown, placed 15 days later. The Osstell measure after a 5-month healing period displays an implant coefficient stability value of 81 **(Fig 15 to 17).**


Figure 5


Figure 6


Figure 7


Figure 8


Figure 9


Figure 10

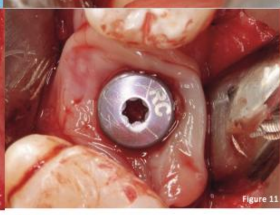
Figure 11


Figure 12


Figure 13


Figure 14


Figure 15


Figure 16


Figure 17

Discussion

Osseodensification, more than a technique, is a concept that has changed the way the implant bed is prepared, where through the geometry and cutting direction of the drills used, there is a promotion of bone condensation and consequent expansion and densification. The application of this technique brought a new approach to maxillary sinus lift, simpler, safer, with high predictability and less morbidity for the patient.

Conclusion

The maxillary sinus floor elevation using oseodensification is a valid solution to restore available bone quantity and also increases bone quality in cases of insufficient bone height under the maxillary sinus.

REFERENCES

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Annex 5. First Article published in Journal of Clinical Medicine (MDPI, Q1)

Journal of
Clinical Medicine

MDPI

Systematic Review

Osseodensification: An Alternative to Conventional Osteotomy in Implant Site Preparation: A Systematic Review

João Fontes Pereira [1,2], Rosana Costa [1,2], Miguel Nunes Vasques [1,2], Filomena Salazar [1,2], José Manuel Mendes [2] and Marco Infante da Câmara [1,2,*]

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Abstract: Osseodensification is an innovative method of preparing the implant osteotomy using drills that promote bone self-compaction. The main objective of this technique is to promote peri-implant bone densification and compaction of autologous bone and to increase the primary stability of the implant due to the viscoelastic characteristics of the alveolar bone using Densah® burs in a counterclockwise direction at a speed of 800 to 1500 rpm. The objective of this review is the analysis of the scientific literature regarding the applicability of the osseodensification technique in oral implantology. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines were used and registered at PROSPERO. The search strategy included electronic databases from 2016 to 2023 and was performed by two independent reviewers. The results demonstrate the advantage of the osseodensification technique in relation to conventional drilling, allowing an increase in the bone density and primary stability of the implant, bone density, and bone–implant contact. The osseodensification technique can be applied in different clinical situations: sub-antral bone grafts, narrow alveolar bone crests, low-density bone areas, and immediate implant placement in post-extraction sockets.

Keywords: dental implant; osteotomy; osseodensification; sub-antral bone grafts; bone density

check for updates

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1. Introduction

The development of the concept of osseointegration by Branemark PI et al. [1] revolutionised the rehabilitation of total and partial edentulous individuals, providing stability and long-term, high success rates in dental implants [1–5]. Osseointegration corresponds to the stable and functional union between the bone and the implant surface, which is crucial for its stability and success [6,7].

Primary stability is considered one of the most important factors for implant success, which is related to the bone density, surgical protocol, type, and geometry of the implant [6,7]. There are methods such as Resonance Frequency Analysis (RFA) or Periotest and insertion torque that can determine implant stability and osseointegration [8–10].

In the atrophic posterior maxilla, there is often insufficient residual alveolar bone, which is why it is necessary to increase the base of the maxillary sinus to obtain an adequate volume for the insertion of dental implants. Maxillary sinus elevation was first described by Boyne PV in 1980 [3].

In 1994, Summers R described a technique using a crestal approach using progressive diameter osteotomes that increased the density of the maxillary bone by compaction, allowing the insertion of implants with a high primary stability and the atraumatic elevation of the sinus membrane [4].

Preparation of the implant site can be carried out using the conventional technique of cylindrical or conical drills capable of cutting and extracting bone tissue for the subsequent placement of the implant [11]. However, in 2013, Huwais S introduced an atraumatic osteotomy preparation procedure known as osseodensification (OD) [6]. OD promotes an increase in peri-implant bone density, compaction of autologous bone, plastic deformation of the bone, and increased primary stability of the implant due to the viscoelastic characteristics of the alveolar bone using Densah® drills (2000 Spring Arbor Rd Suite D, Jackson, MI, USA) in a counterclockwise direction at a speed of 800 to 1500 rpm [7]. This technique is indicated in the posterior maxilla in cases of low bone density type IV, sub-antral bone grafts, and in the expansion of narrow bone crests and post-extraction implants [12,13].

The main objective of this systematic review is the analysis of the osseodensification technique as used in sub-antral bone grafts, low-density bone areas, narrow bone crests, and immediate implant placement in post-extraction sockets.

2. Materials and Methods

This systematic review was conducted between November 2022 and July 2023 in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines (PRISMA) [14], using the MEDLINE database via PubMed, Cochrane Library, Scopus, and Web of Science (from 2013 to 2023) referring to the last 10 years. Studies carried out with humans and animals were included.

The following search strategy used was: (dental implant [MeSH Terms]) AND (osteotomy [MeSH Terms]); ((osteotomy) OR (osseodensification)) AND (dental implants).

The articles were analysed by title, abstract, and full text. The studies included in this review matched all the predefined criteria according to PICOS ("Population", "Intervention", "Comparison", "Results", "Type of study") (Table 1).

Table 1. PICO'S strategy.

P	Population	Patients who need sub-antral bone grafts or have narrow bone ridges, low-density bone (type IV), and post-extraction implants.
I	Intervention	Use of the OD technique in implant placement.
C	Comparison	Implants placed using other conventional techniques.
O	Outcomes	To analyse the OD technique in oral implantology.

The study protocol for this systematic review was registered in the International Prospective of Systematic Reviews (PROSPERO) under the number CRD42023417202.

The eligibility criteria were organised using the PICO method as follows:

The inclusion criteria were articles in English, clinical or experimental studies that compared OD with conventional osteotomy techniques (SD) for the placement of dental implants in humans or animals, and studies that evaluated the performance and safety of OD, such as bone density increase, primary stability, bone–implant contact, success rate, or implant survival. The exclusion criteria were articles with no abstract, studies that did not involve the placement of dental implants, and studies that did not use OD as an intervention.

2.1. Extracting Sample Data

The data collected were analysed using a table of results, considering the author, study objective, eligibility criteria, study group and duration, number of implants, osteotomy sequence, anatomical area, and results.

2.2. Study Quality and Risk of Bias

To assess the methodological quality of a study and determine the risk of bias in its performance, conduct, or analysis, we used the SYRCLE guidelines for animal studies and the Joanna Briggs Institute (JBI) 2017 guidelines for other studies. For each type of study, a form was filled out using the answers Yes (Y), No (N), Uncertain (UN), and Not

Applicable (NA). Two independent examiners (J.F.P/M.I.C) were used to demonstrate intra- and inter-examiner reliability, and the Kappa coefficient test applied in this study resulted in almost perfect agreement (0.81–0.99). The degree of quality of the studies on the relational index used and the number of positive responses to the questions was mostly high, including five articles [6,13,15–17], although we also found five studies with moderate evidence [2,12,18–20] and seven of low quality [7,8,20–25].

2.3. Sample Characteristics for Study Quality

To assess the methodological quality of a study and to determine the extent to which a study addressed the possibility of bias in its design, conduct, and analysis, we used the SYRCLE checklist for animal studies and Joanna Briggs Institute (JBI) guidance 2017 for each type of human studies (Case–Control and randomised controlled trials) (Tables 2–4). For each type of study, a different questionnaire was conducted using the answers Yes (Y), No (N), Unclear (UN), and Not Applicable (NA).

Table 2. SYRCLE Checklist for animal studies.

	Was the Attribution Sequence Generated and Applied Properly?	Were the Groups Similar at Baseline, or Were They Adjusted for Confounding Factors in the Analysis?	Has the Distribution of the Different Groups Been Adequately Concealed?	Were the Animals Housed Randomly during the Experiment?	Were the Carers and/or Researchers Blind to the Intervention of Each Animal Received during the Experiment?	Were the Animals Randomly Selected to Evaluate the Results?	Were the Results Assessed or Blind?	Have Incomplete Results Data Been Handled Appropriately?	Are the Study Reports Exempt from Selective Results Reporting?	Was the Study Apparently Free of Other Problems that Could Result in a High Risk of Bias?
Lahens et al. [21], 2016	N	Y	UN	N	N	N	UN	Y	N	N
Trisi et al. [18], 2016	N	Y	UN	N	Y	N	Y	Y	Y	Y
Huwais and Meyer [8], 2017	N	Y	N	UN	N	N	N	N	N	N
Lopez et al. [22], 2017	N	Y	UN	N	N	N	N	N	UN	N
Alifarag et al. [19], 2018	N	Y	N	UN	N	N	N	Y	Y	N
Slete et al. [2], 2018	N	Y	UN	N	N	N	Y	Y	N	N
Oliveira et al. [7], 2018	UN	Y	UN	UN	N	UNr	UN	UN	N	N
Tian et al. [23], 2019	N	Y	UN	UN	N	N	N	Y	UN	UN
Witek et al. [20] 2019	N	Y	N	Y	N	N	N	Y	N	N
Lahens et al. [21], 2019	N	Y	N	UN	N	N	N	Y	N	N
Torroni et al. [25], 2021	N	Y	UN	N	N	N	N	N	N	N

Table 3. Joanna Briggs Institute Critical Appraisal Checklist for case reports.

	Have the Demographic Characteristics Been Clearly Described?	Was the Patient's History Clearly Described and Presented as a Timeline?	Was the Patient's Current Clinical Condition at the Time of Presentation Clearly Described?	Have the Diagnostic Tests or Methods and the Results Been Clearly Described?	Was the Intervention or Treatment Procedure Clearly Described?	Was the Post-Intervention Clinical State Clearly Described?	Have Adverse Events or Unforeseen Events Been Identified and Described?	Does the Case Report Provide Relevant Data to Draw from?
Mello-Machado et al. [15], 2018	Y	Y	Y	Y	Y	Y	NA	Y
Huwais et al. [16], 2018	N	Y	Y	Y	Y	Y	N	Y
da Rosa et al. [13], 2019	N	N	N	Y	Y	Y	N	Y
Salgar et al. [17], 2021	Y	Y	Y	Y	Y	Y	Y	Y

Table 4. Joanna Briggs Institute Critical Appraisal Checklist for randomised controlled clinical trials.

	Was the Randomisation Method Appropriate?	Was the Allocation Method Appropriate?	Were the Groups Similar at the Start of the Study?	Were the Participants Blinded?	Were the Professionals Who Administered the Interventions Blinded?	Were the Outcome Assessors Blinded?	Were the Interventions Clearly Described and Applied Equally to the Groups?	Was the Primary Outcome Clearly Defined and Measured?	Was there an Intention-to-Treat Analysis?	Have Losses and Exclusions Been Described?	Were there any Complications or Adverse Events Reported?	Were the Results of the Study Accurate and Reliable?	Were the Results of the Study Relevant to Clinical Practice?
Jarikian et al. [6], 2021	Y	Y	Y	N	N	Y	Y	Y	Y	N	Y	UN	UN
Mello-Machado et al. [12], 2021	UN	UN	Y	N	N	Y	Y	Y	N	Y	N	UN	UN

3. Results

3.1. Search Results

A total of 3009 articles were initially identified. After excluding duplicates and reading the title and abstract, the remaining articles were analysed in full.

Finally, 17 articles were included. The characteristics of all the studies are included in Table 5.

Figure 1 shows the detailed article selection strategy.

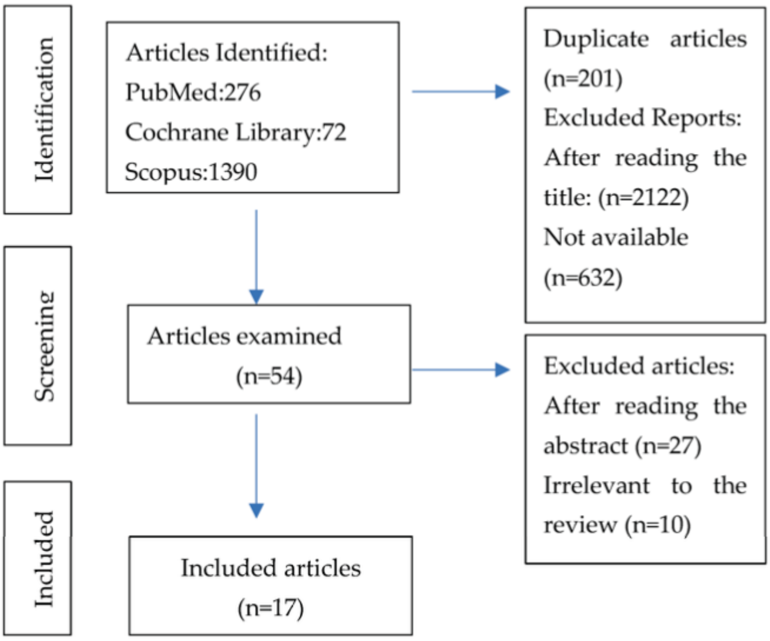

Figure 1. PRISMA flow diagram of study selection.

3.2. Characteristics of the Included Studies

From each eligible study included in this systematic review, data were collected on general characteristics such as the type of study and objectives, inclusion and exclusion criteria, the study group, and the duration of the study. Data were also collected on the number of implants placed, the anatomical areas where they were placed, and the results obtained (Table 5).

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Table 5. The main characteristics of the included studies.

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Lahens et al. [21], 2016	Experimental study	NR	NR	To investigate the effect of osseodensification on the initial stability and early osseointegration of implants in low-density bone.	Sheep	NR	30	Group SD: Pilot drill 2.0 mm; Twist drill 3.2 mm; Twist drill 3.8 mm. Group OD with *Densah® burs:* CW and CCW Pilot drill 2.0 mm; Drill 2.8 mm; Drill 3.8 mm.	Iliac bone	The OD technique showed greater primary stability and greater bone density around the implants compared to the SD technique. Statistical analysis showed that the osseodensification technique promoted a significant increase in the primary stability of the implants ($p < 0.05$). The OD technique showed a higher BIC compared to the SD technique ($p < 0.05$) (±70% and ±50%, respectively). No statistically significant difference in BAFO compared to traditional osteotomy technique ($p = 0.22$); cylindrical implant showed statistically high levels of BAFO compared to conical implants ($p = 0001$).

Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Trisi et al. [18], 2016	Experimental study	NR	NR	To evaluate a new surgical technique for preparing the implant bed that would improve bone density, ridge width, and secondary implant stability.	Sheep	2 months	20	Group SD: Drilling sequence recommended by the manufacturer. Group OD with *Densah® burs:* Pilot drill 2.0 mm; Drill 2.8 mm; Drill 3.8 mm.	Iliac crest	The OD technique (test group) showed greater primary stability than the SD technique (control group). There was no statistically significant difference in % BIC between the control and test groups (46.19 ± 3.98 vs. 49.58 ± 3.19; $p > 0.05$). Analysis of % BV revealed an increase in bone density of approximately 30 per cent in the test group compared to the control group (37.63 ± 4.25 vs. 28.28 ± 4.74; $p < 0.05$). The test group showed significantly better biomechanical performance (around 30 to 40 per cent higher) than the control group in the parameters assessed, such as RTV (172.70 ± 16.07 vs. 126.63 ± 9.52, $p < 0.05$) and VAM (60.45 ± 5.29 vs. 94.88 ± 10.94, $p < 0.05$).

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Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Huwais and Meyer. [8], 2017	Experimental study	NR	NR	To study the hypothesis that the OD technique would increase primary stability, bone density, and % BIC.	Pigs	NR	72	Group SD: Pilot drill 1.7 mm; Drill 2.2 mm; Drill 3.2 mm; Drill 4.2 mm; Drill 5.2 mm. Group ED: Tapered, multi-fluted bur design. OD group: Pilot drill 1.7 mm; Drill 2.8 mm; Drill 3.8 mm; Drill 4.8 mm; Drill 5.8 mm.	Tibial plateau bone samples	The OD technique showed greater primary stability, bone density, and % BIC compared to the SD and ED techniques. The % BIC was increased by approximately three times for osteotomies prepared with OD compared to SD and ED.
Lopez et al. [22], 2017	Experimental study	NR	NR	To investigate the effectiveness of OD in improving the fixation of spinal surgical material.	Sheep	6 Weeks	36	Group SD (left-sided vertebral body): Pilot drill 2.0 mm; Drill 3.2 mm; Drill 3.8 mm. Group OD (right-sided vertebral body): *Densah® burs* Drill 2.8 mm Drill 3.8 mm	C2, C3, and C4 vertebral bodies	Pullout strength demonstrated that osseodensification drilling provided superior anchoring when compared to the SD group collapsed over time with statistical significance ($p < 0.01$). % BIC analysis demonstrated an OD group with significantly higher values relative to the SD group ($p < 0.01$). % BAFO presented significantly higher values for the OD group compared to the SD group ($p = 0.024$).

Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Huwais et al. [16], 2018	Multicenter retrospective clinical study	Atrophic partially edentulous posterior maxilla requiring dental implant placement. All patients had crestal sinus augmentation utilising OD and implant placement. Routine: A minimum subsinus vertical bone height of 2 mm. Patients with a minimum of 6 months follow-up from time of augmentation	Sinus pathology that precludes routine sinus augmentation, such as acute sinusitis, history of previous sinus surgery, and bisphosphonate or chronic steroid medications.	To evaluate the effectiveness and predictability of the osseous densification instrumentation method and its ability to facilitate transcrestal sinus elevation with simultaneous implant placement.	115 women, 107 men	May 2012 and September 2017	261	*Densah® drills:* Pilot drill 1.7 mm; 3.0 mm drill.	Posterior maxilla	The baseline subsinus residual bone height was 5.4 mm (range: 2–10 mm). Sinus graft augmentation procedure achieved a significant vertical increase of 7 mm (SD: 2.49; $p < 0.05$). No sinus complications were found, such as membrane perforations, and late implant failure was observed in the follow-up period from 6 to 64 months. The cumulative implant survival rate was 97%.
Alifarag et al. [19], 2018	Experimental study	NR	NR	To investigate the effects of OD drilling techniques on implant stability and osseointegration using TM and TSV implants in low-density bone.	Sheep	NR	72:36 TM; 36 TSV.	Group SD: Drill 2.0 mm; Drill 2.8 mm; Drill 3.4 mm. Group OD with *Densah® burs:* Pilot drill 1.7 mm; Drill 2.8 mm; Drill 3.8 mm.	Ilia	TM implants yielded a significantly lower IT (Ncm) relative to the TSV implants ($p = 0.002$). No statistically significant differences across surgical techniques within the TM group despite higher mean values were observed for the OD (CCW and CW) techniques relative to SD. The IT as a function of drilling technique showed implants subjected to SD drilling yielded a significantly lower IT relative to samples implanted in OD (CW/CCW) sites ($p < 0.05$). Histomorphometric analysis showed that OD presented significantly greater values of BIC and BAFO ($p < 0.05$).

Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Slete et al. [2], 2018	Experimental study	NR	NR	To compare the histomorphometric structure of SD, SO, and a new osteotomy method without bone removal called OD.	Pigs	NR	18	Group SD: Pilot drill 1.7 mm; Manufacturer's sequence for the appropriate implant size (4.7 mm). Group SO: Pilot drill 1.7 mm; Instrumentation sizes I, II, and III of the set. Group OD with *Densah*® *burs*: Pilot drill 1.7 mm; Drill 2.5 mm; Drill 3.5 mm; Drill 4.5 mm.	Tibia	OD preparation produced 60.3% of BIC, SO 40.7%, and SD 16.3% of implant perimeter in contact with bone. % BV within 2 mm of implant produced was 62% for OD, 49% for SO. and 54% for SD (compared to SO (40.7%) and SD (16.3%)), with a statistically significant value ($p < 0.05$).

Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Oliveira et al. [7], 2018	Experimental study	NR	NR	To investigate the effect of OD on the primary stability and osseointegration of machined and acid-etched implants in low-density bone.	Goats	6 Weeks	60	Group SD: Pilot drill 2.0 mm; Drill 3.2 mm; Drill 3.8 mm. Group OD with *Densah® burs* CW and CCW: Pilot drill 2.0 mm; Drill 2.8 mm; Drill 3.8 mm.	Iliac bone	The IT values were approximately 10 Ncm for the SD technique and showed subsequent increases for CW (~53 Ncm) and CCW (~78 Ncm), with statistically significant data as a result of the technique (CCW > CW > SD, $p < 0.005$), regardless of implant surface. % BIC as a function of time (3 vs. 6 weeks); no statistical significance was noted ($p = 0.577$). % BAFO values showed a significant increase in values from 3 to 6 weeks in vivo ($p = 0.014$). Results demonstrated that BIC values for the CCW and CW groups were comparable to all acid-etched implant drilling groups, while the SD drilling for machined groups resulted in significantly lower % BIC values ($p < 0.01$). No significant differences were depicted between acid-etched and machined surfaces when % BAFO values collapsed over time and drilling technique was assessed ($p = 0.053$). Regardless of implant surface, insertion torque significantly increased when OD drilling was used in low-density bone.

Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Mello-Machado et al. [15], 2018	Case report	NR	NR	To observe whether the clinical and radiographic results obtained could support the hypothesis of gaining primary stability, as well as whether a compaction graft can be achieved using this technique.	Humans	NR	1	*Densah® burs* Pilot drill 1.7 mm; Drill 2.3 mm; Drill 3.0 mm; Drill 3.3 mm.	Maxilla	The OD served to increase primary stability and enhance BIC. The implant was adequately placed and with a sufficient stability, reflected in the ISQ (≥70), which is an indicator of an immediate provisional protocol.
Witek et al. [20], 2019	Case report	NR	NR	To qualitatively and quantitatively evaluate the effect of osteotomy preparation by conventional (control group) or OD (OD group) instrumentation on osteotomy healing.	Sheep	NR	15	Group SD: Pilot drill 2, 3.2, and 3.8 mm twist drills. Group OD *Densah® Burs* OD-CW: Pilot drill 2.0, 2.8 and 3.8 mm multi-fluted tapered burs. OD-CCW: Pilot drill 2.0, 2.8, and 3.8 mm multi-fluted tapered burs.	Left ilium	The mean % BAFO for SD instrumentation was ~11.5%, while both OD techniques (OD-CW and OD-CCW) resulted in statistically homogeneous values: 11.3% and 9.1%, respectively ($p = 0.78$). BAFO values confirmed that there were no healing differences when utilising different instrumentations.

Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Tian et al. [23], 2019	Experimental study	NR	NR	Comparing the osseointegration of implants placed in atrophic mandibular alveolar ridges with the alveolar ridge expansion surgical protocol.	Pigs	12 + 4 Weeks	12	Conventional osteotomes *Densah® Burs*	Atrophic jaw	The mean % BIC value was approximately 62.5% in the osseodensification group and 31.4% in the regular instrumentation group. Statistical analysis showed a significant effect of the drilling technique ($p = 0.018$). There was no statistical difference in BAFO as a function of drilling technique ($p = 0.198$).
da Rosa et al. [13], 2019	Case report	NR	NR	To describe whether the combined use of IDR and osteotomy through the RE can improve the primary stability of the immediate implant in periodontally compromised extraction sites.	Humans	2 years	2	NR	Maxilla	The combination of the IDR technique with the osseodensification implant site preparation method allowed for an increase in implant primary stability, as demonstrated by the higher insertion torque achieved.

Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Lahens et al. [24], 2019	Experimental study	NR	NR	To investigate the effects of OD osteotomy on the stability and osseointegration of implants in low-density bone.	Sheep	12 Weeks	72	Group SD: Pilot drill 2.0 mm; Twist drill 3.2 mm; Twist drill 3.8 mm. Group OD *Densah® Burs* (CW and CCW): Pilot drill 2.0 mm; Drill 2.8 mm; Drill 3.8 mm.	Iliac Crest	OD insertion torque was higher in the CCW and CW drilling compared to the SD ($p < 0.001$). BIC was significantly higher for CW ($p = 0.024$) and CCW drilling ($p = 0.006$) compared to the SD technique. BIC values were significantly lower for the SD surgical technique relative to the CCW and CW surgical techniques ($p < 0.024$). The acid-etched surface treatment yielded a significantly higher % BIC than the machine-cut implants ($p < 0.001$). No statistical difference in the BIC as a function of time between the 3-week and 12-week time points ($p > 0.5$). Osseodensification drilling techniques (CW and CCW) yielded significantly higher % BAFO than the SD technique for the acid-etched implants ($p < 0.01$), while in the machine cut implant, the CCW drilling technique yielded a significantly higher BAFO than the SD technique ($p < 0.01$). In low-density bone, OD drilling presented higher stability and no osseointegration impairments compared to the SD technique, regardless of evaluation time or implant surface.

Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Jarikian et al. [6], 2021	Randomised controlled clinical trial	Good oral hygiene; presence of an edentulous site with an initial width of the alveolar crest between 4 and 5 mm with a minimum of 2 mm of trabecular bone core between the cortical plates.	Uncontrolled systemic conditions or systemic disorders that could compromise osseointegration;consumption of medication that could affect bone metabolism.	To compare the ridge expansion obtained using two different techniques, the OD technique and TET.	Humans	NR	40	TET Group: Pilot drill 1.7 mm; Expander 2.5 mm; Expander 3.1 mm; Expander 3.6 mm. Group OD: *Densah® Burs* Pilot drill 1.7 mm; Drill 2.0 mm; Drill 2.3 mm; Drill 3.3 mm; Drill 3.5 mm.	Alveolar bone	Both techniques were useful in achieving expansion, and all implants placed were successful. The amount of achieved expansion was significantly higher in the OD group, where the average expansion was 2.36 mm (2.36 ± 0.31, $p < 0.05$), while the average amount of expansion in the threaded expanders group was 1.5 mm (1.5 ± 0.28, $p < 0.05$). The Densah bur drilling was superior to manually threaded expanders.
Salgar et al. [17], 2021	Case report	Healthy, non-smoking individuals; requires maxillary sinus augmentation;maximum residual bone height of 1.5 mm.	NR	Presentation of a minimally invasive technique that facilitates bone graft augmentation of the maxillary sinus.	Humans	4 months	5	Group OD: *Densah® Burs* Drill 3.0 mm; Drill 4.0 mm; Drill 5.0 mm; Drill 5.3 mm.	Maxilla	The vertical increase in sinus bone height ranged from 10.3 to 13.6 mm.The rise in bone height is comparable to that obtained with lateral window procedures. The osseodensified crestal sinus window technique may be proposed as a possible alternative procedure for the lateral sinus window technique for maxillary sinus bone augmentation.

Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Torroni et al. [25], 2021	Case-controlled split model	NR	NR	Comparison of conventional instrumentation vs. OD osteotomy instrumentation in posterior lumbar fixation in an ovine model to determine the feasibility and potential advantages of the OD drilling technique in terms of mechanical and histomorphology outcomes.	Sheep	6 to 12 months	64	Group SD: Pilot drill; Twist drill 4.0 mm. Group OD: *Densah® Burs* Drill 2.8 mm; Drill 3.8 mm.	Lumbar region (spinous processes of L2 to L5)	Considerable mechanical stability differences were observed between OD and SD groups at 6- (387 N vs. 292 N) and 12-week (312 N vs. 212 N) time points. The % BAFO did not yield any significant differences when evaluated as a function of the insertion technique (OD vs. SD (p = 0.457)) and time in vivo (p = 0.957) The histometric analysis showed no statistical differences in BAFO between SD and OD groups. Mechanical pullout testing demonstrated that OD drilling provided greater degrees of implant anchoring as a function of time, whereas a significant reduction was observed for the SD group.

Table 5. *Cont.*

Authors	Study Design	Inclusion Criteria	Exclusion Criteria	Study Aim	Study Group	Study Duration	No. Implants	Osteotomy Sequence	Anatomical Zone	Results
Mello-Machado et al. [12], 2021	Randomised controlled trial	Patients older than 18 years of age requiring oral rehabilitation of the upper jaw.	Insufficient bone for implant placement; lack of primary stability at implant insertion; metabolic diseases; impeded/ hampered hygiene motor difficulties; pregnancy; uncontrolled periodontal disease.; smoking habits, radio-therapy, and use of bisphosphonates.	To compare the stability of dental implants placed in low-quality bone prepared for the healing chamber with the osseodensification technique and a standard undersized drilling.	Humans	7 months	55	Group SD: Pilot drill 2.0 mm; Drill 2.5 mm; Drill 2.8 mm. Group OD: *Densah® Burs* Pilot drill 1.6 mm; Drill 2.3 mm; Drill 3.0 mm; Drill 3.3 mm.	Upper jaw	The OD group showed higher IT (39.0 ± 6.4 Ncm) than the SD group (32.0 ± 3.4 Ncm) ($p < 0.001$). ISQ values were similar ($p > 0.05$) at the implant insertion (67.1 ± 3.2 and 65.5 ± 2.7, OD vs. SD, respectively). After six months of healing, implant survival was equally comparable in both groups ($p > 0.05$), and ISQ values were greater than those of implant insertion ($p < 0.001$) but similar ($p > 0.05$) for both groups (74.0 ± 3.6 and 73.3 ± 3.2 for OD and SD, respectively) OD instrumentation allowed for the bone-healing chamber concept in low-quality bone without any reduction in implant stability and success rate.

Legend: OD- Osseodensification; BAFO—Bone area fraction occupancy; BIC—Bone-to-implant contact; BV—Bone volume; CCW—Counterclockwise; CW—Clockwise; ED—Extraction drilling; IDR—Immediate dentoalveolar restauration; ISQ—Implant stability quotient; IT—Insertion torque; NR—Non-referred; SO—Summers' osteotome; RTV—Removal torque value; SD—Conventional osteotomy; TET—Threaded expander surgical technique; TM implants—Trabecular metal implants; TSV implants—Twisted screw-vent implants; VAM- Value of the actual micromotion.

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4. Discussion

According to the results obtained, the OD technique has advantages over the SD and osteotome techniques in terms of primary implant stability, bone density, BIC, and clinical success of the implants [7,12,15,18,20,21]. The OD technique achieved a greater bone density around implants, greater bone–implant contact, and a higher implant success rate after healing when compared to conventional techniques [2,7,8,18,19,21,24,25]. These results can be explained by the fact that the OD technique preserves and increases the bone matrix during the implant site preparation, which ultimately favours the osseointegration of the implants, as well as allowing additional procedures such as the elevation of the maxillary sinus, the expansion of narrow alveolar ridges, and the prevention of cortical collapse [2,6,13,21,24,26]. These results are in line with the existing literature, which suggests that the OD technique can be a very viable and minimally invasive option for optimising the implant site preparation [17,23,25].

The results obtained in the studies analysed using the technique suggest a better prognosis for dental implants placed in different clinical situations: low-density bone (type IV), narrow alveolar ridges, maxillary sinus grafts, and post-extraction implants [7,8,15].

4.1. Insertion Torque and Primary Stability

Several studies have investigated and compared the OD technique and the SD techniques in the context of the primary stability of dental implants. According to Lahens et al. [21], Trisi et al. [18], Huwais and Meyer [8], Alifarag et al. [19], Oliveira et al. [7], Torroni et al. [25], and Mello-Machado et al. [12], OD promotes significantly greater primary stability when compared to SD techniques.

Specifically, when analysing the results related to insertion torque, which is a measure of primary stability, the studies reported that OD had higher insertion torque values compared to SD osteotomy. According to Lahens et al. [21], they observed an average increase of 30% in insertion torque with OD compared to the SD technique, with an average insertion torque value for the SD technique of approximately 10 Ncm and for the OD techniques (CW and CCW) it was significantly higher, with values of over 50 Ncm for CW and around 80 Ncm for CCW. Similarly, Huwais and Meyer [8] reported an average 25% increase in insertion torque with OD.

Alifarag et al. [19] carried out a comparative study and observed an average insertion torque of 45 Ncm with the OD, while the SD technique showed an average insertion torque of only 30 Ncm. In a study by Oliveira et al. [7], similar results were found, with an average insertion torque of 40 Ncm using OD osteotomy and 25 Ncm using the SD technique.

In a study carried out by Trisi et al. [18], statistically significant values of approximately 30% to 40% higher ($p < 0.05$) were observed in relation to primary stability when comparing the OD technique with the SD technique. Mello-Machado et al. [15] obtained an insertion torque of 45 Ncm and an ISQ > 70 when placing the implant using the OD technique, while Mele et al. [26] obtained an ISQ of 74 using the technique in felines.

Oliveira et al. [7], Trisi et al. [18], and Alifarag et al. [19] consistently report that osseodensification is a promising surgical technique that improves the primary stability of dental implants. The osseodensification technique has shown favourable results, measured by insertion torque, indicating greater implant strength and stability in bone tissue compared to conventional osteotomy techniques. These findings highlight the importance and clinical potential of osseodensification in optimising osseointegration [7,18,19].

4.2. Bone-to-Implant Contact (BIC) and Bone Area Fraction Occupancy (BAFO)

The osteogenic parameters along the surface of the implants were evaluated by measuring the BIC and the bone growth in the space between the implant spirals as a percentage called BAFO. Animal and human studies have also confirmed that these values tend to increase when using the OD technique.

Tian et al. [23], Trisi et al. [18], Huwais and Meyer [8], Lopez et al. [22], Slete et al. [2], Oliveira et al. [7], Lahens et al. [24], Torroni et al. [25], and Mello-Machado et al. [12]

compared the BIC and BAFO values between the OD technique and other SD techniques. The results showed that OD has higher BIC and BAFO values compared to SD osteotomy, although there are variations in the values obtained depending on the implant surface, healing time, and study methodology.

According to Tian et al. [23], OD showed an average BIC value of 80% and BAFO of 70.5%, while with SD osteotomy, the average values were 60% for BIC and 47.5% for BAFO ($p = 0.018$ and $p = 0.198$, respectively). However, according to Torroni et al. [25], there was no significant difference in BIC or BAFO when comparing the different techniques.

Another factor that can influence BIC and BAFO is the type and surface treatment of the implant, as can be seen in the studies carried out by Lahens et al. [21], Alifarag et al. [19], and Oliveira et al. [7]. There are different types of implant designs (parallel, conical), which can be manufactured using different materials (titanium, zirconia, or titanium-zirconia). In addition, there are different implant surface treatments, such as alumina, magnesium oxide, or anodising. According to Oliveira et al. [7], surface treatment with magnesium oxide showed significantly higher BIC and BAFO values than implants with alumina surface treatment in all the osteotomy techniques analysed ($p < 0.05$ BIC and BAFO). The same was found in the study by Lahens et al. [21].

Considering the above, the OD technique improves BIC and BAFO compared to the SD osteotomy techniques.

4.3. Osseointegration

Placing implants in the posterior region of the maxilla is a challenge when faced with bone resorption and pneumatisation of the maxillary sinus. To overcome this problem, there are various bone grafting techniques that aim to increase the height and width of the alveolar ridge and prevent the collapse of the buccal cortex. OD is a predictable and advantageous alternative for maxillary sinus elevation and alveolar ridge expansion, improving bone density, primary stability, and osseointegration of dental implants [6,18,24].

The results obtained in the studies suggest that dental implants placed using the OD technique in areas of low bone density or with bone defects have a better prognosis and may reduce the time needed for the implant to achieve osseointegration [7,13,19,21].

OD has emerged as a promising technique in various procedures, especially in clinical situations involving low-density bone. Lahens et al. [21] demonstrated that OD acts as a compacted autotransplant, improving the primary stability of the implant and bone–implant contact. However, further research is needed to better understand the osseointegration process using this technique. Similarly, Lahens et al. [24] highlighted the benefits of OD, indicating that this technique directly influences insertion torque values and improves the stability and osseointegration of endosseous implants in low-density bone, as observed in studies carried out on sheep.

Jarikian et al. [6] emphasised the importance of bone expansion in patients with narrow alveolar ridges, using the OD technique as an effective and less invasive option for increasing the width of the alveolar ridge. Compared to the bone expansion technique with SO, both methods appear to be effective. However, the OD technique was considered more predictable and less invasive. This discussion highlights the importance of proper treatment planning and careful patient assessment to ensure predictable results and minimise complications.

OD has also proved to be a promising technique for maxillary sinus elevation, as described by Salgar et al. [17], whose application of the technique in three patients with difficult clinical situations demonstrated an average increase in bone height of 10.3 mm. OD was able to overcome the limitations of traditional crestal approaches in terms of residual bone height and the limit of vertical height increase, proving to be a minimally invasive option with satisfactory results.

All the results obtained should be analysed and observed with caution since the studies have several limitations and risks of bias, such as the sample size and the short follow-up period. Therefore, more studies with greater methodological rigour and longer follow-up

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periods are needed to confirm the benefits of the OD technique in oral implantology. In future clinical human trials, it would be worthwhile to perform digitally guided OD in order to evaluate if it improves the promising results of the technique even further [27].

5. Conclusions

The studies analysed showed that the OD technique has advantages when used in low-density bone (type IV) by increasing primary stability, bone–implant contact, and clinical success.

In addition, the OD technique can allow for additional procedures such as maxillary sinus elevation, narrow alveolar ridge expansion, and post-extraction implants.

However, these results should be interpreted with caution, as the studies had some limitations and biases. Therefore, more studies with greater methodological rigour and external validity are needed to confirm the benefits of the OD technique in oral implantology.

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The Effectiveness of Osseodensification Drilling versus the Conventional Surgical Technique on Implant Stability: A Clinical Trial

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Abstract: Background/Objective: To ensure that implants are able to support prosthetic rehabilitation, a stable and functional union between the bone and the implant surface is crucial to its stability and success. To increase bone volume and density and excel bone-implant contact, a novel drilling method, called osseodensification (OD), was performed. To assess the effectiveness of the osseodensification drilling protocol versus the conventional surgical technique on implant stability. **Methods:** Bone Level Tapered Straumann implants were placed side-by-side with both OD and subtractive conventional drilling (SD) in 90 patients from CESPU—Famalicão clinical unit. IT was measured using a manual torque wrench, and the Implant stability quotient (ISQ) value was registered using the Osstell® IDX. **Results:** According to the multifactorial ANOVA, there were statistically significant differences in the mean IT values due to the arch only (F(1.270) = 4.702, *p*-value = 0.031 < 0.05). Regarding the length of the implant, there were statistically significant differences in the mean IT in the OD group ($p = 0.041$), with significantly lower mean IT values for the Regular implants compared to the Long. With respect to the arch, the analyses of the overall ISQ values showed an upward trend in both groups in the maxilla and mandible. High levels of IT also showed high ISQ values, which represent good indicators of primary stability. **Conclusions:** OD does not have a negative influence on osseointegration compared to conventional subtractive osteotomy.

Keywords: osseodensification; low bone density; implant stability; osseointegration; resonance frequency analysis; insertion torque

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1. Introduction

The placement of dental implants to restore the oral cavity has been incorporated into daily dental practice as a dental treatment alternative since Branemark PI et al. [1] revolutionized the total and partial rehabilitation of edentulous individuals. To ensure that implants are able to support prosthetic rehabilitation, a stable and functional union between the bone and the implant surface is crucial to its stability and success [2–4].

An established primary stability, which is characterized as sufficient contact between the implant and bone at their interface upon instrumentation and subsequent implant placement, is needed for successful osseointegration. Strong primary stability is therefore linked to increased osseointegration [5,6]. In dental implants, primary stability is a crucial factor for successful osseointegration, and the surgical procedure and bone density are important factors in achieving this stability. The dimensions of the osteotomy, the implant design, and the amount of bone strain imposed determine the degree of primary stability [2–4,7,8].

Insertion torque (IT), resonance frequency analysis (RFA), and the patient's bone density are also related to the success of the implant's primary stability. Thus, a high insertion torque significantly increases primary stability compared to an implant inserted with low insertion torque values [7]. As seen in the human jaw, for example, low-density bone can lead to poor contact between the bone and the implant, which can negatively affect primary stability and secondary stability. Thus, an adequate volume of bone in the implant site preparation is crucial to ensure osseointegration and long-term implant stability [2,9].

Secondary stability is also necessary for osseointegration, which is established over time due to bone remodeling around the implant during the healing period [2,10].

In order to increase the bone volume and density, which are essential for achieving bio-mechanically stable bone–implant contact, Huwais S. introduced a novel drilling method in 2013, called osseodensification (OD), which has revolutionized the world of implantology [9]. Conventional drilling protocols have employed a clockwise (subtractive) cutting technique with a positive angle of inclination, which has resulted in the absence of bone debris in the osteotomy. However, the non-cutting (additive) drilling technique, osseodensification, has been shown to compact the walls of the osteotomy site through lateral displacement of the bone, increasing primary stability. Moreover, the compacting of residual bone remains, which function as nucleating surfaces for osteoblasts after the implant, acts as an autograft that promotes osteointegration [10,11]. Thus, OD promotes an increase in peri-implant bone density, autologous bone compaction, plastic bone deformation, and an increase in the primary stability of the implant due to the viscoelastic characteristics of the alveolar bone, using a specific set of Densah® Burs (Versah® LLC, Jackson, MI, USA) in a counterclockwise direction at a speed of 800 to 1500 rpm [12,13]. This benefit can be crucial for decreasing implant micromovement during osseointegration and achieving high success rates in low-density bone. Another advantage is the reduction in the size of the osteotomies when the drills are removed, called the spring-back effect, due to the viscoelastic part of the bone deformation. In addition, it promotes higher insertion torques and, thus, enables immediate loading in comparison with conventional subtractive drilling techniques [9]. For this purpose, insertion torque (IT) and resonance frequency analyses were measured at three different times: (i) surgical phase of implant placement (T1); (ii) 6 months after implant placement (T2); and (iii) 1-year follow-up (T3).

2. Materials and Methods

2.1. Study Design

This study was designed as a clinical trial study according to CONSORT guidelines [14]. The interventions were approved by the Ethical Committee of the of the University Institute of Health Sciences (reference: 02/CE-IUCS/2019), and conducted in compliance with the provisions of the declaration of Helsinki. The study was registered in the ISRCTN registry (registration number ISRCTN15797074).

2.2. Patient Selection

All patients underwent a preliminary assessment that included a careful analysis of their medical and dental histories and a detailed clinical examination. Patients were thoroughly informed, by means of oral and written explanations, about the purpose and procedures of the study, and informed consent was obtained from all participants.

For inclusion, participants must be at least eighteen years old, have healed edentulous sites on the posterior maxillae region with at least 3 months of postextraction period; need to receive at least two dental implants; and have sufficient residual bone volume for implant placement without the need for bone augmentation where the minimum ridge height and width should be ≥8 and ≥6 mm, respectively. The exclusion criteria were: alcoholism, drug abuse, diabetes, heart disease, bleeding disorders, weakened immune

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systems, radiation exposure, past or ongoing use of steroids or bisphosphonates, and previous bone regenerative or augmentation procedures.

From 6 February to 10 March 2019, 120 patients from the CESPU—Famalicão clinical unit were screened from this patient pool, 90 of whom met the study's inclusion criteria and were selected to participate.

In order to perform a comparison between osseodensification (OD) and subtractive conventional drilling (SD), the implants were placed side by side or contralateral, with both techniques to establish a comparison in RFA and torque values. In some patients, two implants were placed, but in other patients, they had between 3 and 4 implants.

Two independent examiners (J.F.P/M.I.C) were used to demonstrate intra- and inter-examiner reliability, measurements of the clinical parameters of implant primary stability were repeated in 50% of the sample.

2.3. Pre-Operative Radiographic Planning

The pre-operative radiographic examination: panoramic X-ray (and a cone beam computed tomography (CBCT, New Tom® Go 3D, CEFLA S.C., Imola (BO) Italy) were used for initial participants screening. CBCT was crucial in order to provide a guide for assessing the condition of the Schneiderian membrane, ostium patency, presence of antral septa, and other pathologies that may influence the alveolar bone and the degree of sinus pneumatization and thickness of Schneiderian membrane.

2.4. Presurgical Phase

All patients underwent scaling 8 days prior to implant surgery. During this phase, preoperative instructions were given:

- To eat a light diet, avoiding fatty, fried, laxative and fermentable foods (milk, cheese, bananas) on the day of surgery.
- Not to wear jewelry or make-up, in the case of women.
- Avoid smoking in the 72 h before and 30 days after surgery, to avoid anesthetic and surgical complications, as well as contributing to better tissue healing.
- Not to take medication based on acetylsalicylic acid (aspirin) in the 4 days before surgery.
- Start antibiotic therapy 48 h before surgery (875 mg of amoxicillin and 125 mg of clavulanic acid) twice daily for 8 days.

2.5. Surgical Phase

2.5.1. Implant Design and Surface Characteristics

Bone Level Tapered (BLT) Straumann® implants (Basel, Switzerland) with a CrossFit® connection (Basel, Switzerland) 3.3.mm diameter (Narrow connection—NC) or 4.1/4.8 mm diameter (Regular connection—RC) were used. These implants feature a tapered, self-cutting design with a 0.8 mm thread pitch, and are designed for excellent primary stability. BLT implants are available in lengths of short (8 mm), Regular (10 mm, 12 mm, 14 mm) and Long (16 mm, 18 mm). The implant surface SLA® (Basel, Switzerland), Sandblasted, large grit, acid-etched is a type of surface treatment that creates surface roughness with the goal of enhancing osseointegration through greater bone-to-implant contact (BIC).

2.5.2. Conventional Protocol

Patients were prepared and long-acting local anesthesia was administered (4% articaine with 1:100.000 adrenaline).

A mid crestal incision was made and a full thickness mucoperiosteal flap was raised. The anterior region of the edentulous area was prepared using subtractive conventional drilling, according to the Straumann guidelines of RPM values. Independent of the type of implant diameter selected for the site (Ø 3.3 mm, 4.1 mm or 4.8 mm), the narrower drill (pilot drill Ø 2.2 mm, 800 rpm) was used until reached the desired depth under abundant saline irrigation. All drills were used in clockwise rotation. The drilling sequence is shown in Tables 1–3. After using the drill sequence, the BLT implant delivered in the implant bed.

Table 1. Conventional drilling sequence for Ø 3.3 mm BLT implant.

Straumann® BLT			Drilling Sequence				
Geometry	**Implant Diameter**	**Type of Bone**	**Needle Drill Ø 1.6 mm (800 rpm)**	**Pilot Drill Ø 2.2 mm (800 rpm)**	**BLT Drill Ø 2.8 mm (600 rpm)**	**Profile Drill Ø 3.3 mm (300 rpm)**	**BLT Tap Ø 3.3 mm (15 rpm)**
Tapered	Ø 3.3 mm	Type I	•	•	•	•	• *
		Type II	•	•	•	• *	
		Type III	•	•	• *		
		Type IV	•	• *			

• Performing the osteotomy; • * Osteotomy and implant placement.

Table 2. Conventional drilling sequence for Ø 4.1 mm BLT implant.

Straumann® BLT			Drilling Sequence					
Geometry	**Implant Diameter**	**Type of Bone**	**Needle Drill Ø 1.6 mm (800 rpm)**	**Pilot Drill Ø 2.2 mm (800 rpm)**	**BLT Drill Ø 2.8 mm (600 rpm)**	**BLT Drill Ø 3.5 mm (500 rpm)**	**Profile Drill Ø 4.1 mm (300 rpm)**	**BLT Tap Ø 4.1 mm (15 rpm)**
Tapered	Ø 4.1 mm	Type I	•	•	•	•	•	• *
		Type II	•	•	•	•	• *	
		Type III	•	•	•	• *		
		Type IV	•	•	•	• *		

• Performing the osteotomy; • * Osteotomy and implant placement.

Table 3. Conventional drilling sequence for Ø 4.8 mm BLT implant.

Straumann® BLT			Drilling Sequence						
Geometry	**Implant Diameter**	**Type of Bone**	**Needle Drill Ø 1.6 mm (800 rpm)**	**Pilot Drill Ø 2.2 mm (800 rpm)**	**BLT Drill Ø 2.8 mm (600 rpm)**	**BLT Drill Ø 3.5 mm (500 rpm)**	**BLT Drill Ø 4.2 mm (400 rpm)**	**Profile Drill Ø 4.8 mm (300 rpm)**	**BLT Tap Ø 4.8 mm (15 rpm)**
Tapered	Ø 4.8 mm	Type I	•	•	•	•	•	•	• *
		Type II	•	•	•	•	•	• *	
		Type III	•	•	•	•	• *		
		Type IV	•	•	•	• *			

• Performing the osteotomy; • * Osteotomy and implant placement.

2.5.3. Osseodensification Protocol

The posterior region of the edentulous area was prepared using the osseodensification procedure to test what has already been described in the literature, which is that this technique is especially used in situations of low-density bone (type III/IV) (which is typically found in the posterior region of the maxilla/mandible) in order to increase bone volume, percentage of bone to implant contact and, subsequentially, the primary stability of the implant.

Drilling was carried out to the desired depth using the pilot drill (clockwise drilling speed from 800 to 1500 rpm) with abundant saline irrigation. Depending on the implant diameter selected (Ø 3.3,4.1 or 4.8 mm), the narrower Densah® Bur (Bur 1 for each implant diameter- Table 4) was used in a counterclockwise direction (800 to 1500 rpm) with a pumping motion until reaching the desired depth under abundant irrigation. All drills were used in counterclockwise rotation. The drilling sequence is shown in Table 4.

Table 4. Drilling sequence of Densah® Burs.

Straumann®		Soft Bone (Type III and IV)			
Geometry	**Implant Diameter**	**Pilot**	**Bur 1**	**Bur 2**	**Bur 3**
Tapered	Ø 3.3 mm	Pilot drill	VT1828 * (2.3)	—	—
	Ø 4.1 mm	Pilot drill	VT1525 (2.0)	VT2535 * (3.0)	—
	Ø 4.8 mm	Pilot drill	VT1525 (2.0)	VT2535 (3.0)	VT3545 * (4.0)

* Implant placement.

After using the drill sequence, the osteotomy received a threaded Sandblast large grit acid-etched (SLA) implant. In some cases, we finished placing the implant with a ratchet wrench, when the drill motor that drives the implant into place has reached the maximum placement torque.

Figure 1 shows the final drill used for each group (SD and OD) and implant diameters (Ø 3.3 mm, Ø 4.1 mm, Ø 4.8 mm).

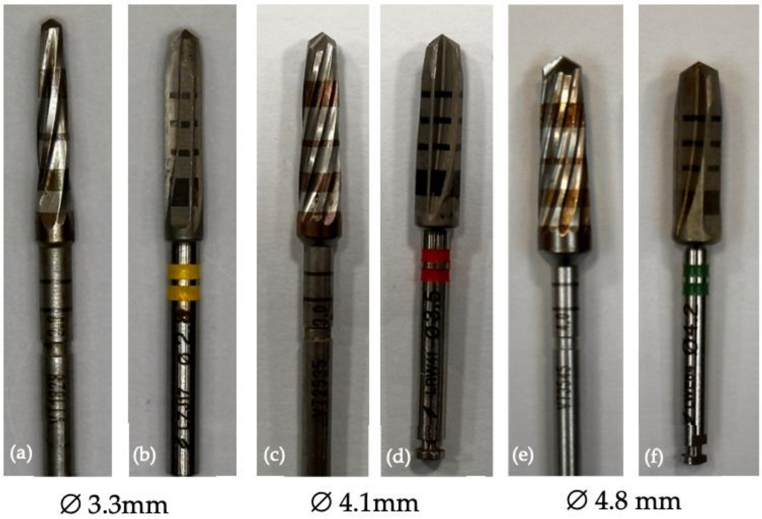

Figure 1. The configuration of the final drill used for each group (SD and OD). (**a**) VT1828; (**b**) Ø 2.8 BLT Drill; (**c**) VT2535; (**d**) Ø 3.5 BLT Drill; (**e**) VT3545; (**f**) Ø 4.2 BLT Drill.

2.5.4. Evaluation of Implant Stability Parameters

Immediately after implant placement, the IT was measured (T1) using a manual torque wrench (Straumann®, Basel, Switzerland), and the Implant stability quotient (ISQ) value was registered as the average of the buccal, lingual, mesial and distal readings using the Osstell® IDX (Osstell, W&H, Gothenburg, Sweden). IT and ISQ values were measured in all implants placed with the SD and OD technique.

A cover screw was placed in all implants.

Afterwards, the surgical site was closed with several interrupted sutures using a monofilament suture (Nylon, Resorba® 4.0, Nuremberg, Germany).

Figure 2 illustrates OD osteotomies.

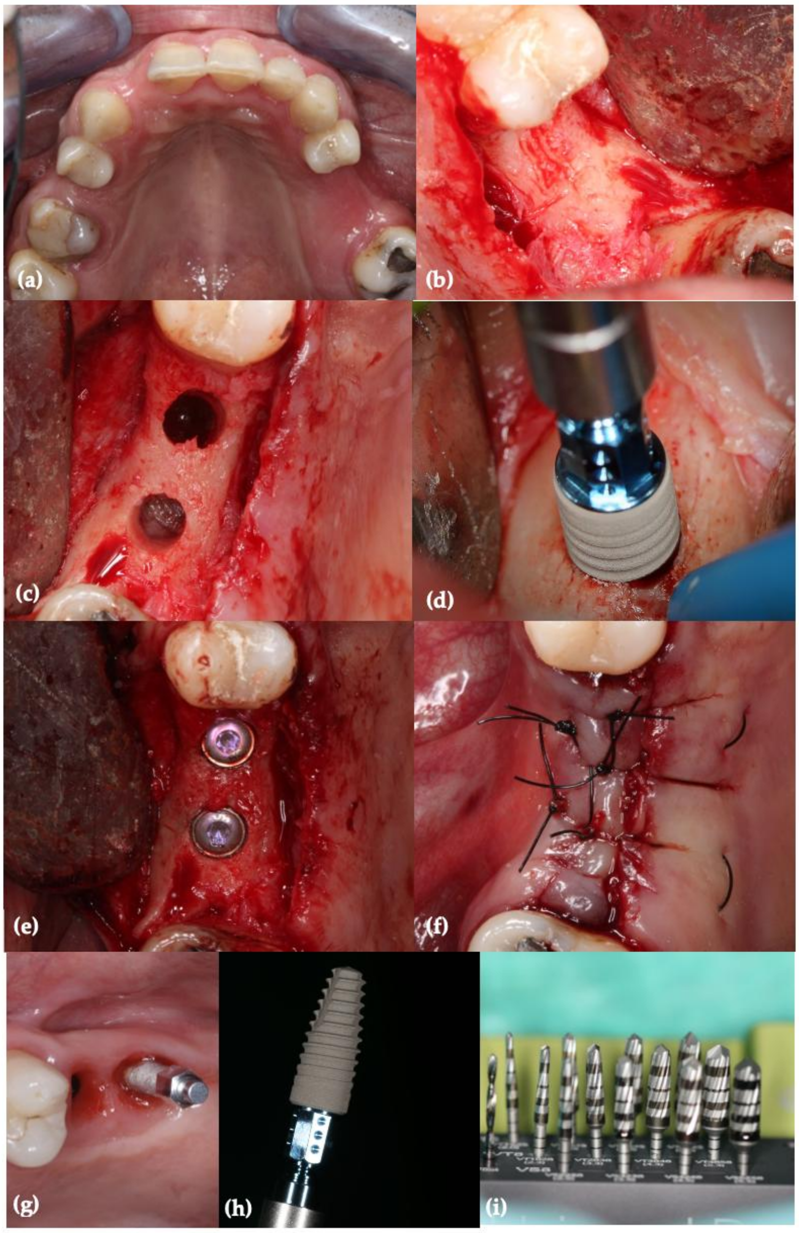

Figure 2. A visual representation of the surgery. (**a**) The initial case; (**b**) full thickness mucoperiosteal flap; (**c**) osteotomies; (**d**) implant placement (Ø 4.1 mm BLT); (**e**) a view of the cover screws; (**f**) the interrupted sutures using a monofilament suture (Nylon, Resorba®4.0); (**g**) SmartPeg placement for ISQ reading; (**h**) tapered implant design; (**i**) Densah Bur kit.

2.6. Postoperative Instructions

Postoperative instructions were given of some important actions to avoid increased edema (swelling), pain, bleeding and infections:

- To lie down for the first three days after surgery to stabilize the blood clot, as this is a critical period for a good post-operative result without complications.
- To continue the antibiotic therapy and to take Naproxen (500 mg) twice daily for a 3 day period.
- Paracetamol 1 g 3 times a day for pain control management.
- To use 0.12% chlorhexidine gluconate mouthwash (Bexident® Post Isdin, Barcelona, Spain) thrice daily for two weeks to reduce plaque formation.
- To apply ice to their faces in the first 6 to 8 h after surgery in order to significantly reduce facial edema, while also improving pain control and reducing local vascularization, thus preventing bleeding.
- To prepare a liquid/pasty and cold diet for 8 days.
- To bite on a piece of sterile gauze for 30 min to promote hemostasis.
- Not to spit, which could cause negative pressure in the mouth and dislodge the clot. Drinking liquids through straws is also contraindicated.
- Avoid vigorous mouthwashes.
- Not to smoke during the entire osseointegration process (especially during the first two weeks). Nicotine destroys vitamin C, which is essential for tissue regeneration, delaying the repair of the surgical wound.
- To refrain from physical activity or heavy lifting for three days after surgery.

After the post-operative indications were made, the patients were scheduled to have the sutures removed ten days after surgery.

2.7. Healing Abutment—6 Months

After six months of healing, the survival of the implants was verified, and the secondary stability was measured though ISQ values (T2), and an appropriate healing abutment was inserted considering the emergence profile and gingival height. Subsequently, the patients were scheduled for digital implant impressions with the 3Shape® scanner (Copenhagen, Denmark), and final ceramic crowns were manufactured.

2.8. One Year Follow-Up

Removal of screw-retained zirconia crowns and ISQ values were recorded (T3) using the Osstell® IDX.

2.9. Statistical Analysis

Descriptive statistics were calculated for each variable, including mean values and the corresponding 95% confidence interval (CI). The quantitative variables were assessed for normality using the Kolmogorov–Smirnov test and Normal probability graphical methods (QQ-plot), and the fit to the normal distribution was verified. The homogeneity of variances was assessed using Levene's test.

The factorial ANOVA model test and multiple comparison tests were carried out to compare torque/torque values. Repeated measures analysis of variance and the respective Tukey tests for multiple comparisons were used to analyze the ISQ data. Pearson's correlation test was applied to investigate the relationship between IT and immediate ISQ values for all the variables studied.

All analyses were carried out using IBM® Statistical Program for Social Sciences (SPSS®) Statistics software, version 29.0 for Windows, with a significance level of 5%.

3. Results

Of the 120 patients screened at the CESPU—Famalicão clinical unit, only 90 met the study's inclusion criteria and were selected to participate.

Figure 3 illustrates the design of the study in the form of a CONSORT diagram.

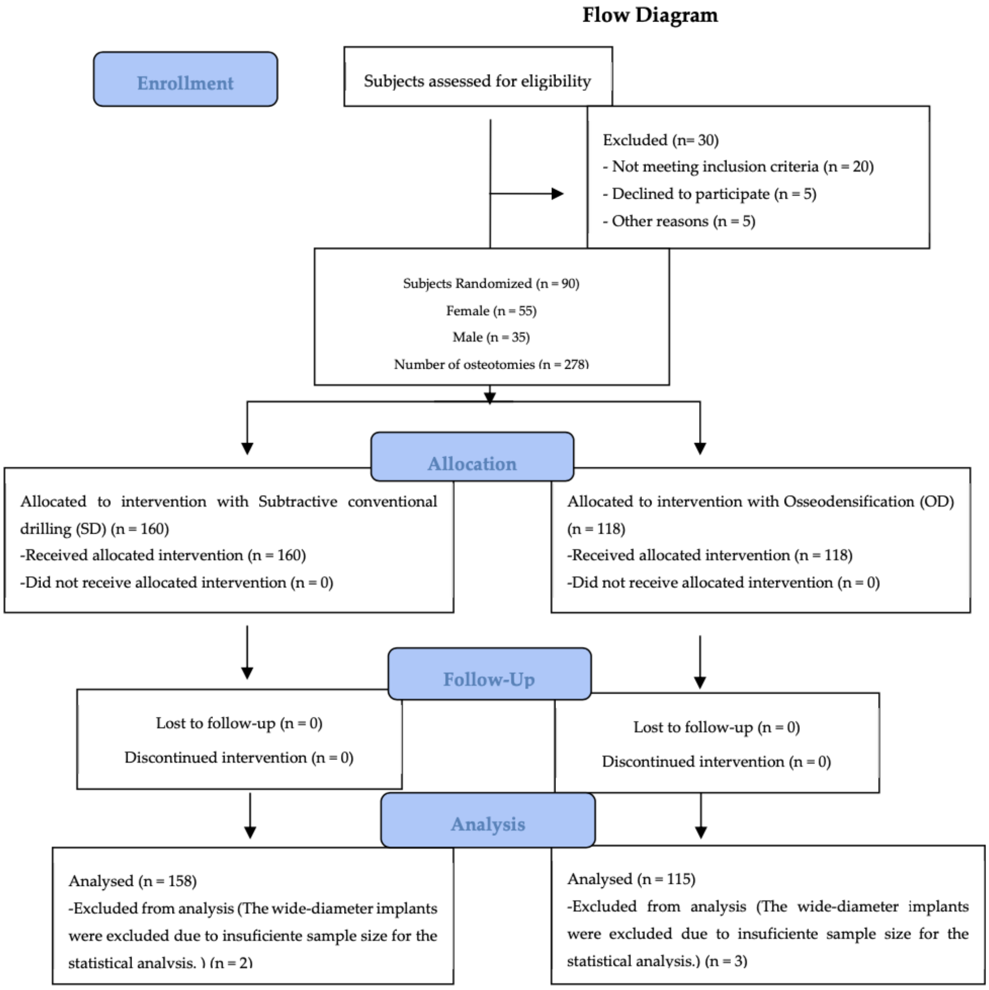

Figure 3. CONSORT flow chart.

As shown in Table 5, the total sample consists of 90 individuals, 55 of whom are female (61.1%) and the remaining 35 male (38.9%). The limits of the 95% confidence intervals are also shown.

Table 5. Distribution of members by gender.

Gender	n	%	CI 95.0%	
			LCL	UCL
F	55	61.1%	50.8%	70.7%
M	35	38.9%	29.3%	49.2%
Total	90	100.0%		

Note: F—female; M—male; n—number of subjects and percentages; LCL—Lower Control Limit; UCL—Upper Control Limit.

Table 6 shows the data characterizing the sample in terms of age by gender and overall.

Table 6. Summary statistics for age by gender.

		Gender		Total
		F	M	
Age	Mean	47.7	50.3	48.7
	Median	49.0	48.0	48.5
	Standard deviation	12.7	11.2	12.1
	Minimum	19.0	20.0	19.0
	Maximum	72.0	69.0	72.0
	Percentile 25	37.0	44.0	42.0
	Percentile 75	56.0	59.0	57.0

Note: F—female; M—male.

Table 7 shows the results of the characterization of the sample in terms of the characteristics of the individuals assessed, as well as the respective limits (Lower Control Limit (LCL) and Upper Control Limit (UCL)) of the 95% confidence intervals (CI).

Table 7. Summary statistics for the individual's characteristics.

		n	%	CI 95.0%	
				LCL	UCL
Smoker	N	74	82.2%	73.4%	89.0%
	Y	16	17.8%	11.0%	26.6%
	Total	90	100.0%		
Systemic Disease	N	71	78.9%	69.6%	86.3%
	Y	19	21.1%	13.7%	30.4%
	Total	90	100.0%		
Number of cigarettes/day	4	1	6.3%	0.7%	25.7%
	5	1	6.3%	0.7%	25.7%
	6	1	6.3%	0.7%	25.7%
	10	5	31.3%	13.1%	55.6%
	15	2	12.5%	2.7%	34.4%
	20	6	37.5%	17.4%	61.7%
	Total	16	100.0%		

Note: N—no; n—number of subjects and percentages; LCL—Lower Control Limit; UCL—Upper Control Limit; Y—yes.

Table 8 shows the sample characterization data regarding the implant for each surgical technique and as a whole.

To assess whether there are differences in IT, a multifactorial ANOVA was carried out, and it was found that there are statistically significant differences in the mean IT values due to the arch only ($F(1.270) = 4.702$, p-value = 0.031 < 0.05).

The results can be seen in the graphs in Figure 4.

Table 8. Implant-related characterization.

		Surgical Techniques											
		SD				OD				Total			
		n	%	CI 95.0% LCL for %	CI 95.0% UCL for %	n	%	CI 95.0% LCL for %	CI 95.0% UCL for %	n	%	CI 95.0% LCL for %	CI 95.0% UCL for %
Implant diameter (mm)	Narrow	26	16.3%	11.2%	22.5%	25	21.2%	14.6%	29.2%	51	18.3%	14.1%	23.2%
	Regular	132	82.4%	76.1%	87.8%	90	76.3%	68.0%	83.2%	222	79.9%	74.8%	84.2%
	Wide	2	1.3%	0.3%	3.9%	3	2.5%	0.7%	6.6%	5	1.8%	0.7%	3.9%
	Total	160	100%	.	.	118	100.0%	.	.	278	100.0%	.	.
Implant length (mm)	8	33	20.6%	14.9%	27.4%	30	25.4%	18.2%	33.8%	63	22.7%	18.0%	27.8%
	10	65	40.6%	33.2%	48.3%	51	43.2%	34.5%	52.2%	116	41.7%	36.0%	47.6%
	12	37	23.1%	17.1%	30.1%	25	21.2%	14.6%	29.2%	62	22.3%	17.7%	27.5%
	14	9	5.6%	2.8%	10.0%	7	5.9%	2.7%	11.3%	16	5.8%	3.5%	9.0%
	16	7	4.4%	2.0%	8.4%	3	2.5%	0.7%	6.6%	10	3.6%	1.9%	6.3%
	18	9	5.6%	2.8%	10.0%	2	1.7%	0.4%	5.3%	11	4.0%	2.1%	6.7%
	Total	160	100.0%	.	.	118	100.0%	.	.	278	100.0%	.	.
Arch	Maxilla	78	48.8%	41.1%	56.5%	86	72.9%	64.4%	80.3%	164	59.0%	53.1%	64.7%
	Mandible	82	51.3%	43.5%	58.9%	32	27.1%	19.7%	35.6%	114	41.0%	35.3%	46.9%
	Total	160	100.0%	.	.	118	100.0%	.	.	278	100.0%	.	.
Position	11	1	0.6%	0.1%	2.9%	0	0.0%	.	.	1	0.4%	0.0%	1.7%
	12	3	1.9%	0.5%	4.9%	2	1.7%	0.4%	5.3%	5	1.8%	0.7%	3.9%
	13	4	2.5%	0.8%	5.8%	2	1.7%	0.4%	5.3%	6	2.2%	0.9%	4.4%
	14	15	9.4%	5.6%	14.6%	6	5.1%	2.1%	10.2%	21	7.6%	4.9%	11.1%
	15	15	9.4%	5.6%	14.6%	13	11.0%	6.3%	17.6%	28	10.1%	6.9%	14.0%
	16	9	5.6%	2.8%	10.0%	14	11.9%	7.0%	18.6%	23	8.3%	5.5%	11.9%
	17	3	1.9%	0.5%	4.9%	3	2.5%	0.7%	6.6%	6	2.2%	0.9%	4.4%
	21	0	0.0%	.	.	1	0.8%	0.1%	3.9%	1	0.4%	0.0%	1.7%
	22	5	3.1%	1.2%	6.7%	2	1.7%	0.4%	5.3%	7	2.5%	1.1%	4.9%
	23	2	1.3%	0.3%	3.9%	2	1.7%	0.4%	5.3%	4	1.4%	0.5%	3.4%
	24	5	3.1%	1.2%	6.7%	12	10.2%	5.7%	16.6%	17	6.1%	3.7%	9.4%
	25	11	6.9%	3.7%	11.6%	11	9.3%	5.1%	15.6%	22	7.9%	5.2%	11.5%
	26	5	3.1%	1.2%	6.7%	13	11.0%	6.3%	17.6%	18	6.5%	4.0%	9.8%
	27	0	0.0%	.	.	5	4.2%	1.6%	9.0%	5	1.8%	0.7%	3.9%
	32	1	0.6%	0.1%	2.9%	2	1.7%	0.4%	5.3%	3	1.1%	0.3%	2.9%
	34	6	3.8%	1.6%	7.6%	1	0.8%	0.1%	3.9%	7	2.5%	1.1%	4.9%
	35	3	1.9%	0.5%	4.9%	2	1.7%	0.4%	5.3%	5	1.8%	0.7%	3.9%
	36	22	13.8%	9.1%	19.7%	4	3.4%	1.2%	7.9%	26	9.4%	6.3%	13.2%
	37	8	5.0%	2.4%	9.2%	3	2.5%	0.7%	6.6%	11	4.0%	2.1%	6.7%
	42	3	1.9%	0.5%	4.9%	0	0.0%	.	.	3	1.1%	0.3%	2.9%
	44	5	3.1%	1.2%	6.7%	2	1.7%	0.4%	5.3%	7	2.5%	1.1%	4.9%
	45	7	4.4%	2.0%	8.4%	7	5.9%	2.7%	11.3%	14	5.0%	2.9%	8.1%
	46	17	10.6%	6.6%	16.1%	9	7.6%	3.8%	13.5%	26	9.4%	6.3%	13.2%
	47	10	6.3%	3.3%	10.8%	2	1.7%	0.4%	5.3%	12	4.3%	2.4%	7.2%
	Total	160	100.0%	.	.	118	100.0%	.	.	278	100.0%	.	.
Operated Area	Anterior	19	11.9%	7.6%	17.6%	11	9.3%	5.1%	15.6%	30	10.8%	7.6%	14.8%
	Posterior	141	88.1%	82.4%	92.4%	107	90.7%	84.4%	94.9%	248	89.2%	85.2%	92.4%
	Total	160	100.0%	.	.	118	100.0%	.	.	278	100.0%	.	.

Note: n—number of implants and percentages; LCL—Lower Control Limit; OD—osseodensification; SD—subtractive conventional drilling; UCL—Upper Control Limit.

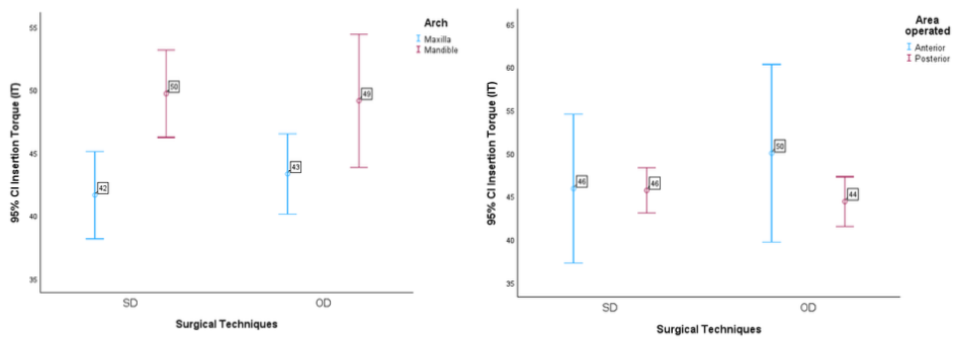

Figure 4. 95% CI insertion torque in relation to surgical technique as a function of arch (maxilla and mandible) and area operated on (anterior and posterior).

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Another multifactorial ANOVA procedure was carried out, and statistically significant differences were found in mean IT values due to the effects of implant length (F(2.261) = 3.243, *p*-value = 0.041 < 0.05), and due to the effects of the interaction between technique used and implant diameter (F(1.261) = 4.538, *p*-value = 0.041 < 0.05), in the sense that the mean IT value with the SD technique for the Narrow implant is significantly lower when compared to the Regular.

The multiple comparison tests showed that the differences in the mean IT values with length are significantly lower for the Regular implants when compared to the Long implants (*p* = 0.011 < 0.05).

These results are illustrated in the graphs in Figure 5.

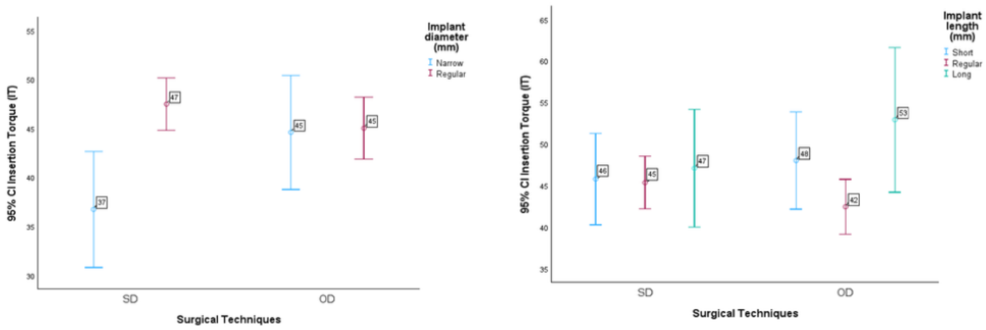

Figure 5. 95% CI insertion torque in relation to surgical technique as a function of implant diameter (Narrow and Regular) and implant length (Short, Regular, Long).

To evaluate the effect of the different factors (surgical technique, arch and area operated) in relation to ISQ over time, a repeated measures ANOVA (three times) was performed.

These results are illustrated in the graphs in Figures 6 and 7.

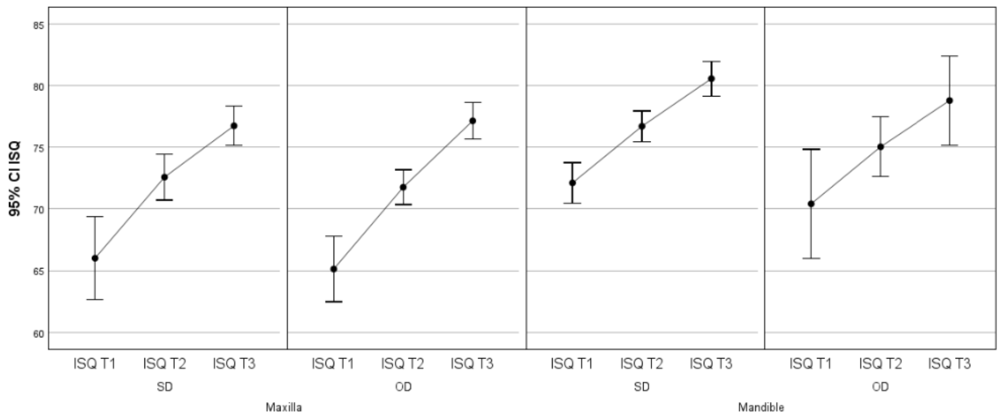

Figure 6. 95% CI implant stability quotient in relation to surgical technique (SD and OD) at three different times (T1, T2 AND T3) in relation to arch (maxilla and mandible).

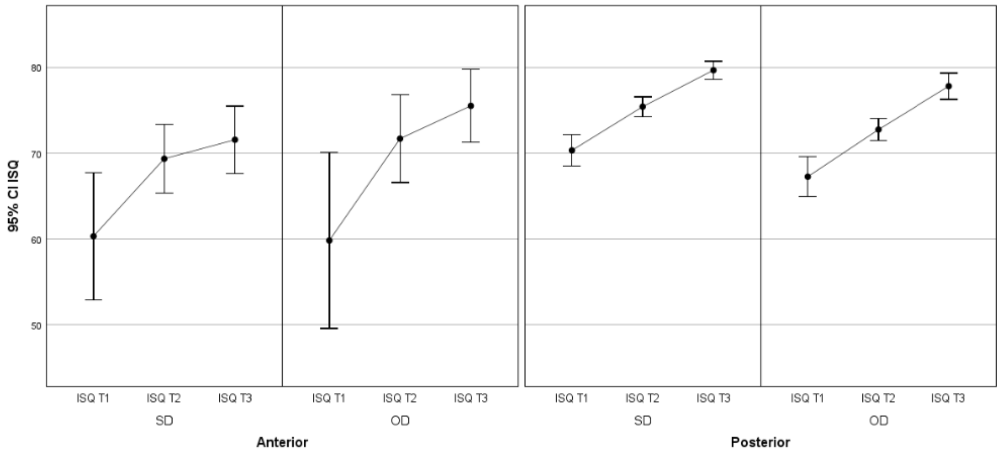

Figure 7. 95% CI implant stability quotient in relation to surgical technique (SD and OD) at three different times (T1, T2 AND T3) in relation to area operated (anterior and posterior).

Once the assumption of sphericity was tested using the Mauchly test (p-value < 0.05), the sphericity of the data was rejected. As the value of the epsilon estimate was less than 0.75, the Greenhouse–Geisser correction was used to interpret the results for intra-subject effects.

In this way, it was found that there are statistically significant differences in the average ISQ values in the different periods considered, i.e., there is significant variation in the average ISQ value over time, in the sense that it increases significantly over time (Figure 8). Statistically significant differences by multiple comparison tests ($p < 0.05$) were detected between all pairs (T1–T2, T1–T3 and T2–T3).

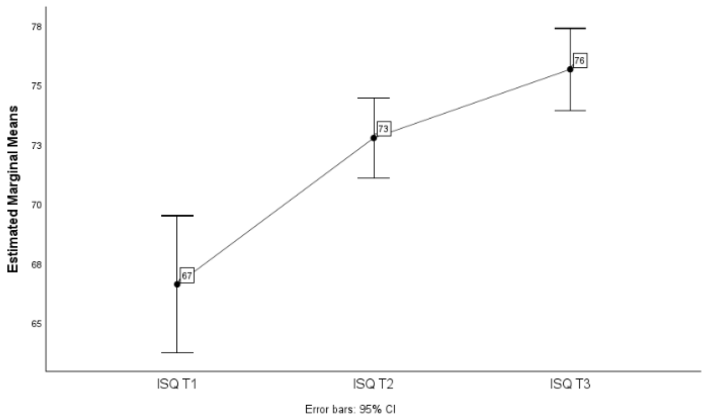

Figure 8. Distribution of mean ISQ values over time and respective 95% confidence intervals.

There were significant differences in the mean ISQ values due to the interaction of time and arch (F(1.438; 388.165) = 6.620, p-value < 0.05), which means that the means of the groups (maxilla and mandible) vary differently over the three times considered (T1, T2 and T3), i.e., the mean ISQ over time is not the same for the arches considered. This is reflected in the non-parallel lines in the graph in Figure 9.

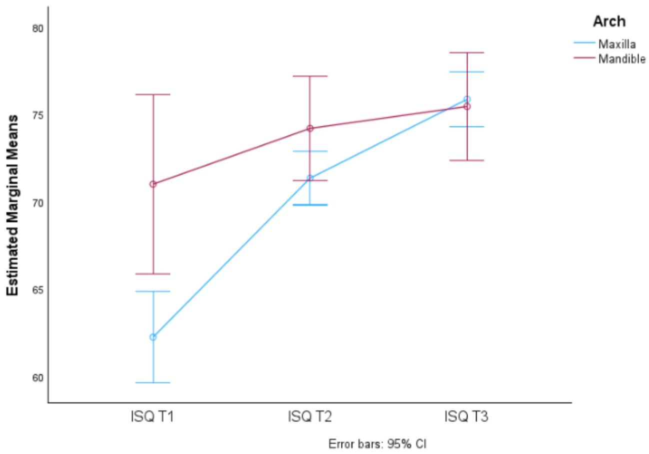

Figure 9. Distribution of mean ISQ values over time according to arch and respective 95% confidence intervals.

There were significant differences in the average ISQ values due to the interaction of time, arch and area (F(1.438; 388.165) = 4.553, *p*-value < 0.05), which means that the averages of the groups (maxilla and mandible) vary differently depending on the area of operation (posterior or anterior) in the three times considered, i.e., the average ISQ over time is not the same for the arch and area of operation considered. This is illustrated by the different behavior of the graphs in Figure 10.

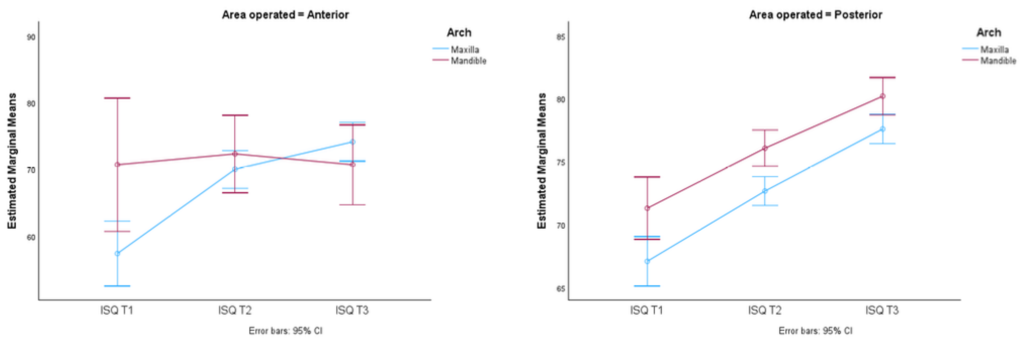

Figure 10. Distribution of mean ISQ values over time according to arch and area with respective 95% confidence intervals.

As in the previous situation, to evaluate the effect of the different factors (surgical technique, diameter, and length) in relation to the ISQ over time, an ANOVA with repeated measures (three times) was carried out.

Once the assumption of sphericity was tested using the Mauchly test (*p*-value < 0.05), the sphericity of the data was rejected. As the value of the epsilon estimate is less than 0.75, the Greenhouse–Geisser correction will be used to interpret the results for intra-subject effects.

As with the previous results, there were statistically significant differences in the mean ISQ values in the different periods considered; statistically significant differences by multiple comparison tests ($p < 0.05$) were detected between all pairs (T1–T2, T1–T3 and T2–T3).

There were no significant differences in the average ISQ values due to the interaction of time and technique used (F(1.438; 375.336) = 0.163, *p*-value > 0.05), meaning that the ISQ averages over time in the groups (SD and OD) did not vary. This is reflected in the almost overlapping lines in the graph in Figure 11.

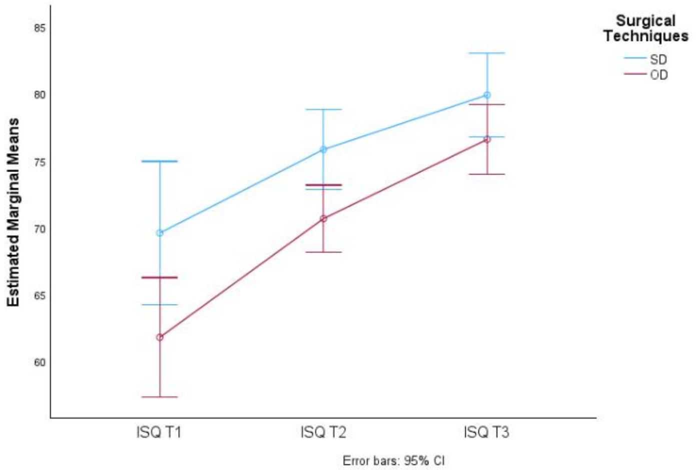

Figure 11. Distribution of mean ISQ values over time according to surgical procedure and respective 95% confidence intervals.

No significant differences were found in the average ISQ values due to the interaction of time and technique used (F(1.438; 375.336) = 0.685, *p*-value > 0.05), meaning that the ISQ averages over time in the diameters considered (Narrow and Regular) do not vary. This is reflected in the almost overlapping lines in the graph in Figure 12.

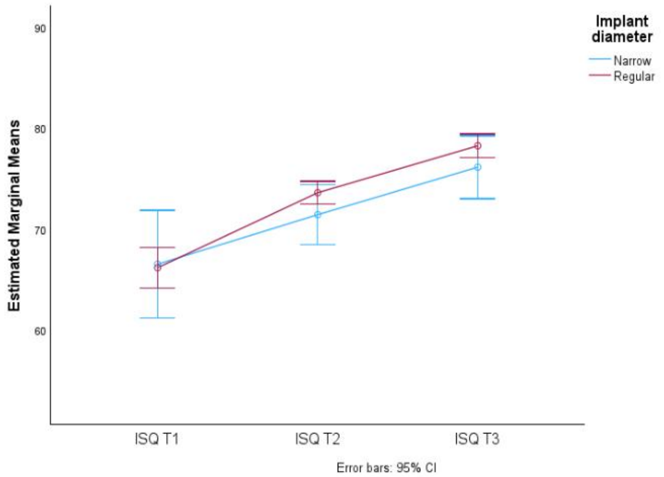

Figure 12. Distribution of mean ISQ values over time according to implant diameter and respective 95% confidence intervals.

There were no significant differences in the average ISQ values due to the interaction of time and technique used (F(2.876; 375.336) = 1.014, *p*-value > 0.05), meaning that the ISQ averages over time in the lengths considered (Short, Regular, and Long) do not vary. This is reflected in the lines and confidence limits, which are practically superimposed on the graph in Figures 13 and 14.

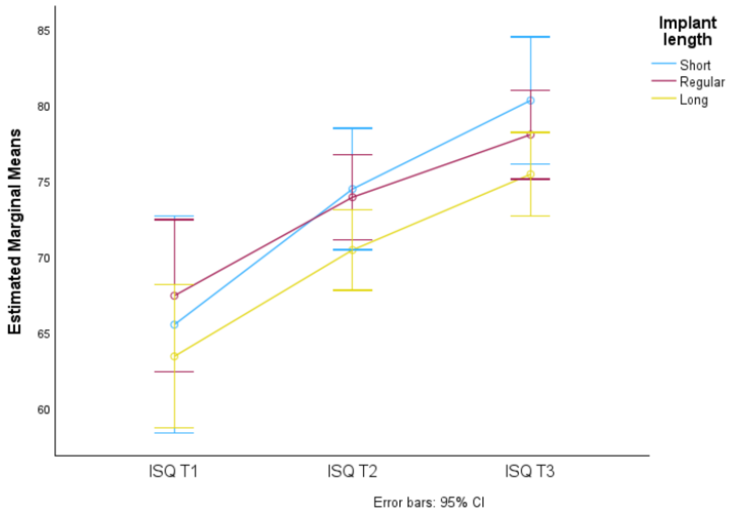

Figure 13. Distribution of mean ISQ values over time according to implant length and respective 95% confidence intervals.

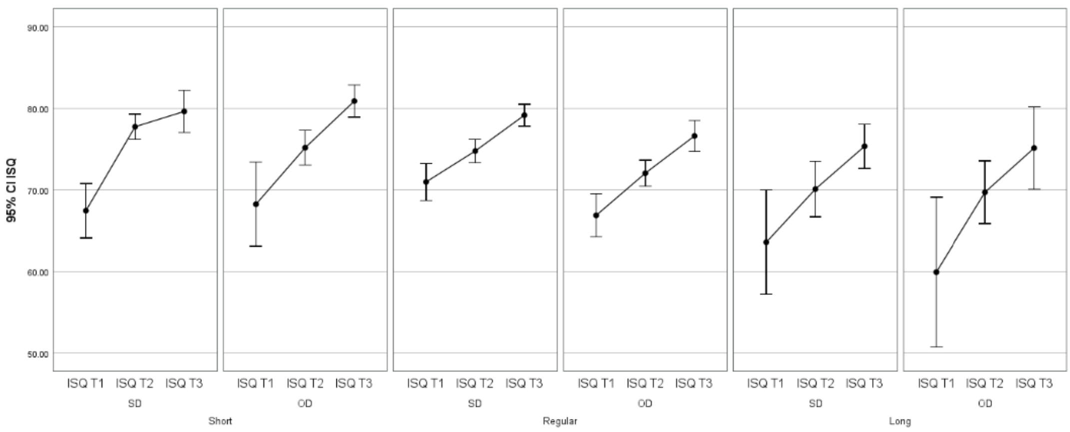

Figure 14. 95% CI Implant stability quotient in relation to surgical technique (SD and OD) at three different times (T1, T2 and T3) in relation to implant length (Short, Regular, and Long).

Table 9 shows the correlation beteen th IT and ISQ T1 values and the variables under study.

Table 9. Pearson correlation between the IT and ISQ T1 values and the variables under study.

	Maxilla ISQ T1	Mandible ISQ T1	Anterior ISQ T1	Posterior ISQ T1	Narrow ISQ T1	Regular ISQ T1	Wide ISQ T1	Short ISQ T1	Regular ISQ T1	Long ISQ T1	SD ISQ T1	OD ISQ T1	Total ISQ
Maxilla IT	r = 0.192 * p = 0.014												
Mandible IT		r = 0.315 * p < 0.001											
Anterior IT			r = −0.003 p = 0.988										
Posterior IT				r = 0.326 * p < 0.001									
Narrow IT					r = 0.195 p = 0.171								
Regular IT						r = 0.242 * p < 0.001							
Wide IT							r = 0.903 * p = 0.036						
Short IT								r = 0.413 * p < 0.001					
Regular IT									r = 0.310 * p < 0.001				
Long IT										r = 0.058 p = 0.734			
SD IT											r = 0.290 * p < 0.001		
OD IT												r = 0.221 * p = 0.016	
Total IT													r = 0.263 * p < 0.001

Note: ISQ T1—implant stability quotient in the surgical phase of implant placement; IT—insertion torque; OD—ossedensification; p = level of significance; SD—subtractive conventional drilling. * significant for the 5% decision rule used.

4. Discussion

Osseointegration and primary implant stability are objectives of critical importance because their impediments often lead to implant failure [15]. Implant primary stability is a crucial component of osseointegration, and is correlated with bone density, surgical drilling technique, implant surface texture, and geometry [4,16,17]. Besides primary stability, it is important for the implant to obtain secondary stability, which is achieved after bone production and maturation on the implant body [16]. For this reason, the application of tests to assess the primary and secondary stability of the implant has become extremely important in implant dentistry. These tests include determining the insertion torque (IT) and resonance frequency analysis (RFA) [17].

Previous studies focused on the analysis of OD effects on implant placement, the present study evaluated the OD drilling effects on healing in three different stages T1, T2 and T3 with different diameters and lengths placed in anterior and posterior regions of the maxilla and in the mandible. To assess the implant stability, insertion torque measurements and resonance frequency analysis were carried out.

The IT, initially developed by Johansson and Strid, is applied with a torque wrench, and is the measure of the frictional resistance obtained at the time of implant placement [17,18]. The maximum value of the insertion torque was recorded in Newton centimeter (Ncm) [16,18].

In 1996, Meredith et al. [19] developed a noninvasive clinical method to measure implant stability as RFA by using an Osstell® device that can be used for multiple times both intraoperatively and during the follow-up time [19]. The resonance frequencies vary according to the different levels of implant stability, which is presented through an implant stability quotient (ISQ). To measure de ISQ value, the inserted implant is attached to a transducer (SmartPeg). The Osstell® device is positioned 1 mm from the transducer and four SmartPeg points are measured (mesial, distal, buccal, and lingual/palatal). The ISQ value range from 1 to100. A value of ISQ < 60 represents low stability, ≥60 ISQ ≤ 69 represents medium stability and ISQ ≥ 70 high stability [16,18]. According to our results, there was a progressive increase in IT and ISQ over time, regardless of the technique used, SD or OD. These two independent variables indicate two different characteristics of primary stability; however, they "move" together [20,21]. These results are in line with the findings of our study, in which, overall, the higher the IT, the higher the ISQ. Another study conducted by Vale de Souza et al. [16] showed that there is a positive correlation between IT and initial ISQ (correlation: 0.457; $p = 0.022$), so that the greater the IT, the greater the initial ISQ (and vice versa). Therefore, increased IT and ISQ values are positive primary stability indicators, which can be critical for immediate loading and subsequently improving osseointegration.

According to previous studies, the use of the OD drilling technique increases bone mineral density due to the compaction-autografting and the elastic spring-back effect, which promotes increased bone to implant contact in relation to SD technique [11,22,23]. On the other hand, the conventional drilling technique limits the initial bone–implant interaction due to the excavation of nucleated bone remnants, the amount of which can vary due to factors such as drilling speed, time and the use of irrigation in the osteotomy [15]. Buchter et al. [24] argues that the osteotome technique hinders the bone remodeling unit, causing ultrastructural microdamage, which can significantly reduce biomechanical stability shortly after implant placement [25]. Several studies showed that the osteotomized group exhibited microfractures, which was evident histologically, and the measured removal torque values were significantly lower for the same group compared to the non-condensed group. Thus, it has been concluded that traumatic damage to the bone delays the achievement of secondary stability and extends the osseointegration period to repair bone tissue microdamage, which stimulates the activation of osteoclasts [26].

The results of our study showed that there were no statistical differences between OD and SD groups in which concerns the IT and ISQ overall values, which supports the null hypothesis that the drilling technique may not influence clinical parameters of implant primary stability up to 6 months after implant placement. Although most of the studies carried out support the opposite hypothesis, it is important to consider that most of them were carried out on animals. For this reason, more human studies are needed in order to make the comparison of results as reliable as possible.

With respect to the arch, the analyses of the overall ISQ values showed an upward trend in both groups in the maxilla and mandible. According to the evidence, higher ISQ values are expected in the mandible compared to the maxilla, which is in line with our results. However, there were no statistical differences among OD and SD groups, especially between T1 and T2. This can be explained by the increased bone to implant contact that occurs during the osseointegration [15].

Despite the results obtained, in general, we can state that although IT and ISQ are two independent variables, high levels of IT also showed high ISQ values, which represents good indicators of primary stability.

In accordance with the literature, the primary stability of the implant can be significantly influenced by the macrogeometry of the implant. Some studies showed that hybrid (apical cylindrical and crestal conical) and conical designs provided the greatest primary stability [27,28]. The growing popularity of tapered implants can be attributed to their simplicity of use in clinical settings, shorter drilling sequences, and the possibility of shorter healing times and less trauma during the osteotomy. The lateral compressive forces on the cortical bone may be a significant reason for their increased primary stability [29,30]. Studies conducted on animals suggested that a larger diameter were positively correlated with greater primary stability [31,32]. Thus, a larger implant diameter improves load distribution by increasing primary stability and functional surface area. Nonetheless, a large number of studies have demonstrated that, in lower-quality bone, implants with smaller diameters can still establish adequate primary stability [32]. Our findings are in accordance with this theory, in which statistically significant differences were seen between the mean IT value and the SD technique in relation to regular implants, which showed significantly higher values when compared to Narrow implants ($p = 0.034$). The average ISQ values did not vary, but always increased over time regardless of the technique used; this could be explained by the percentage of new bone formation over time.

An increase in IT and RFA (ISQ) values were also favorably correlated with implant length. It is well known that the use of a long, tilted implant is a method of improving the IT before immediate load rehabilitation [28]. In fact, it is directly correlated with the overall surface area in contact with the bone [28,29]. The results of the present study showed statistically significant differences in the mean IT values due to the length of the implant in the OD group (p = 0.041) with significantly lower mean IT values for the Regular implants compared to the Long. Regarding the ISQ, there were no differences in relation to the length of the implants considered, regardless of the technique used.

Some studies indicate that the availability of cortical and trabecular bone at the implant interface may affect the biomechanical stability of the implant and the bone healing response [4,28]. For this reason, it is important to understand the particularities, characteristics, and differences and anatomy of the maxilla and mandible. According to the Lekholm and Zarb (1985) classification (the most popular classification of bone quality), bone types are classified based on the amount of cortical versus trabecular bone from I to IV [33–35]. The biomechanical properties of osteoporotic bone are similar to those of type IV bone, and do not provide appropriate stability for implants. Another important aspect is bone density according to anatomical location which is characterized by the Norton and Gamble classification. Norton and Gamble described different bone density range according to their typical anatomical locations in the maxilla and mandible. All of the subjectively rated areas in each of the four qualities were subsequently grouped together so that a range of Houndsfield (HU) values could be assigned to each specific quality [36]. Low-density bone (type III and type IV), commonly seen in the posterior mandible, especially in elderly patients, represents a high percentage of those seeking implant treatment.

The results of the present study showed that there were statistical differences in relation to the arch and the type of osteotomy with respect to IT. IT and ISQ were higher in the mandible than in the maxilla for both the SD and OD techniques. These results are in line with the study by Turkyilmaz et al. [37], which found a strong relationship between bone density and ISQ values.

With regard to area, in general, the anterior region showed higher IT values compared to the posterior area for both techniques. These results can be explained by the bone density in the anterior region compared to the posterior region of the arch. However, in terms of technique, the anterior region of the OD group showed higher IT values compared to the SD. These results are in compliance with the study by Bergamo et.al. [23], with 150 implants, in which the anterior region showed increased IT in the OD group when compared to the SD group.

Although this was not the aim of the present study, in clinical practice, achieving high levels of biomechanical stability has become more necessary to support the current tendency toward early loading protocols. In a study by Trisi et al. [38], immediate loading can be performed when IT value is at least 45 Ncm and ISQ at least 68. Thus, according to the results, rehabilitation with immediate loading was a possible option for implants with an ISQ > 68, which can be especially useful for the posterior maxillary region, which has low-density bone that makes immediate loading protocols difficult.

A larger sample of wide implants would be necessary in order to understand whether there was a change in primary stability parameters between osseodensification and subtractive conventional drilling. Furthermore, more human studies are needed, especially on low-density bone (type III and IV), so that the results can be compared as reliably as possible. Most studies on this technique have been carried out on animals and not humans, which makes it difficult to compare the results.

5. Conclusions

The results strongly indicate that OD does not have a negative influence on osseointegration compared to conventional subtractive osteotomy. Furthermore, the tapered implant design may compensate for the low stability expected in soft bone, and dense bone may compensate for short implant length if required by the anatomical bone conditions.

Osseodensification appears to be a viable method for increasing bone quantity and quality, but the literature's results are inconclusive and should be read thoughtfully.

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Informed Consent Statement: Patients were carefully informed through oral and written explanations about the purpose and procedures of the study and an informed consent was obtained from all participants.

Data Availability Statement: The data can be accessed by contacting the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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