CATÓLICA
FACULDADE DE MEDICINA DENTÁRIA
VISEU

THE EFFECT OF INCREASING THREAD DEPTH ON THE INITIAL STABILITY OF DENTAL IMPLANTS. AN IN VITRO STUDY.

Dissertação apresentada à Universidade Católica Portuguesa
para obtenção do grau de Mestre em Medicina Dentária

Por:
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Orientador: Professor Doutor Bruno Leitão de Almeida
Coorientador: Professor Doutor Tiago Gonçalves Ferreira Borges

Viseu, 2024

QUOTE

"Nec spe, nec metu."
- Locuzione latina attribuita alla filosofia stoica

DEDICATION

Alla mia famiglia,

la misura di tutte le cose.

Con immenso amore e gratitudine.

ACKNOWLEDGMENTS

Desidero esprimere la mia riconoscenza a coloro che hanno contribuito, in modo consapevole o meno, al successo di questa tesi nel corso dell'ultimo anno.

Ringrazio mio padre, la mia roccia, il mio più grande esempio di determinazione e dedizione. Lo ringrazio per aver reso tutto questo possibile e per aver sempre creduto in me, per trasmettermi il senso di passione che ripone nella vita e la capacità di sognare in grande.

Ringrazio mia madre, per tutto l'amore e l'impegno che ci dedica. La donna che ammiro e ringrazio per essere stata al mio fianco, dimostrandomi il suo affetto in ogni istante. Colei che mi ha aiutato e supportato ogni giorno, rendendo più semplice il mio cammino.

Mia sorella, che rappresenta per me un modello di estrema forza e coraggio. La ringrazio per spronarmi e per avermi insegnato a trovare la bellezza anche nei momenti peggiori.

Ringrazio i miei nipoti, che sono la mia grande motivazione e fine ultimo. Li ringrazio per essere i bambini meravigliosi che sono e per tutta l'allegria e amore che sanno trasmettere.

Ringrazio i miei nonni, per il loro amore incondizionato. Anche se lontani o non più con me, rimangono i miei principali sostenitori, i miei pilastri, sempre presenti nel mio cuore.

Un ringraziamento speciale va alla mia collega Donatella, con la quale ho condiviso ogni istante degli ultimi cinque anni, colei che più mi conosce e senza la quale tante cose non sarebbero state le stesse. Per ogni nostro successo e insuccesso, ogni gioia, preoccupazione e avventura vissuti insieme. Grazie per tutto l'aiuto, la collaborazione e il sostegno. Al binomio 323 e alla nostra amicizia!

Ringrazio inoltre la mia collega Marta, per essere tanto simile a me, ma anche così diversa da riuscire a incoraggiarmi in quel modo che solo lei, è in grado di fare. Grazie per riuscire a strapparmi sempre un sorriso, per sostenermi e condividere con me ogni mio progetto.

Un sentito ringraziamento va anche alle mie amiche di sempre, che nonostante gli impegni e i chilometri di distanza, sono sempre state presenti per me.

Per ultimi, ma non per importanza, vorrei ringraziare i miei relatori, i Professori Bruno Leitão e Tiago Borges.

Al mio relatore Bruno va un grande ringraziamento per l'aiuto e la pazienza, per la disponibilità e la collaborazione. Da sempre mi ha trasmesso l'interesse per la sua materia e mi ha incoraggiato nel mio lavoro. A lui va tutta la mia stima e rispetto.

I wish to express my gratitude to those who have contributed, knowingly or unknowingly, to the success of this thesis over the past year.

I thank my father, my rock, my greatest example of determination and dedication. I thank him for making all of this possible and for always believing in me, for instilling in me a sense of passion for life and the ability to dream big.

I thank my mother for all the love and dedication she gives us. The woman I admire and thank for always being by my side, demonstrating her affection for me at every moment. She who has helped and supported me every day, making my path easier.

My sister, who represents for me a model of extreme strength and courage. I thank her for encouraging me and for teaching me to find beauty even in the worst moments.

I thank my nephews, who are my great motivation and ultimate purpose. I thank them for being the wonderful children they are and for all the joy and love they know how to convey.

I thank my grandparents for their unconditional love. Even if distant or no longer with me, they remain my main supporters, my pillars, always present in my heart.

A special thanks goes to my colleague Donatella, with whom I have shared every moment of the last five years, the one who knows me best and without whom many things would not have been the same. For every success and failure, every joy, worry, and adventure experienced together. Thank you for all the help, collaboration, and support. To the 323 and our friendship!

I also thank my colleague Marta for being so similar to me, yet so different in her ability to encourage me in ways only she can. Thank you for always making me smile, supporting me, and sharing in all my projects.

A heartfelt thanks also goes to my lifelong friends, who despite their commitments and kilometers of distance, have always been there for me.

Last, but not least, I would like to thank my advisors, Professors Bruno Leitão and Tiago Borges.

To my Professor Bruno, a big thank you for the help and patience, for the availability and collaboration. He has always instilled in me an interest in his subject and encouraged me in my work. He deserves all my esteem and respect.

Abstract

Background: the long-term success of dental implants largely depends on achieving primary stability, crucial to obtain osseointegration and for immediate loading protocols. Implant thread depths seem to be one of the key factors influencing primary stability, particularly in low-density bone. Insertion torque (IT) and resonance frequency analysis (RFA) are considered the most reliable tests to assess primary stability. We evaluated how different thread depths of dental implants of the same type and brand, affect primary stability in lower bone density. We also assessed the relationship between IT and ISQ.

Materials and Methods: *in vitro* study carried out at the University Clinic of the *Universidade Católica Portuguesa* of Viseu, between February 2024 and March 2024. Logistics were enabled by Megagen® Portugal, Bone Models™, SmartPeg™Osstell® and Precision Dental Medicine Platforms (CIIS-FMDUCP). 24 dental implants, divided into four groups of six implants each, with four different thread depths (Group A: 4mm, Group B: 4.5mm, Group C: 5mm, Group D: 5.5mm), were tested on three blocks of D3-type artificial bone. For each inserted implant, the IT and ISQ values were recorded. The results were statistically analyzed by calculating the mean values of IT and ISQ. The significance value was 5%.

Results: from the 24 implants tested, the highest mean IT values were obtained in Group D, with an average of 54.03±8.99 N/cm^2, while the lowest were in Group A with an average of 25.12±2.96 N/cm^2. The mean ISQ values were consistently higher in Group D for each analyzed point (ISQ V, P, M, and D), revealing an overall mean of 70.13±1.12.

Conclusions: implants with greater thread depth have been found to be more effective in achieving primary stability in lower bone density within the test conditions. Furthermore, a positive correlation has been observed between all IT and ISQ values, regardless of the thread depth.

Key words: Dental implants, Osseointegration, Torque, Resonance frequency analysis.

Resumo

Introdução: o sucesso a longo prazo dos implantes dentários depende principalmente da obtenção de estabilidade primária, crucial para obter a osseointegração e para protocolos de carga imediata. A profundidade das espiras do implante parece ser um dos fatores chave que influencia a estabilidade primária, especialmente em ossos pouco densos. O torque de inserção (IT) e a análise de frequência de ressonância (RFA) são considerados os testes mais fiáveis de estabilidade primária. Avaliámos como as diferentes profundidades das espiras de implantes dentários do mesmo tipo e marca, afetam a estabilidade primária em osso mole. Também analisámos a relação entre IT e ISQ.

Materiais e Métodos: estudo in vitro realizado na Clínica Universitária da Universidade Católica Portuguesa de Viseu, entre fevereiro e março de 2024. Logística facilitada por: Megagen® Portugal, Bone Models™, SmartPeg™Osstell® e Precision Dental Medicine Platforms (CIIS-FMDUCP). Foram testados 24 implantes dentários, divididos em quatro grupos de seis implantes cada, com quatro profundidades de espiras diferentes (Grupo A: 4mm, Grupo B: 4,5mm, Grupo C: 5mm, Grupo D: 5,5mm), em três blocos de osso artificial do tipo D3. Para cada implante inserido, foram registados os valores de IT e ISQ. Os resultados foram analisados estatisticamente através do cálculo dos valores médios de IT e ISQ. O valor de significância foi de 5%.

Resultados: dos 24 implantes testados, os valores médios de IT mais elevados foram obtidos no Grupo D, com 54.03±8.99 N/cm^2; os mais baixos foram no Grupo A com uma média de 25.12±2.96 N/cm^2. Os valores médios de ISQ foram consistentemente mais altos no Grupo D para cada ponto analisado (ISQ V, P, M e D), revelando uma média geral de 70,13±1,12.

Conclusões: implantes com maior profundidade das espiras demonstraram ser mais eficazes na obtenção da estabilidade primária em osso mole nas condições do teste. Uma correlação positiva foi observada entre todos os valores de IT e ISQ obtidos, independentemente da profundidade das espiras.

Palavras-chaves: Implantes dentários, Osseointegração, Torque, Análise da frequência de ressonância.

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LIST OF ABBREVIATIONS AND ACRONYMS

IT: insertion torque

RFA: resonance frequency analysis

ISQ: implant stability quotient

μm: micrometer

N/cm²: Newton per square centimeter

kHz: kilohertz

I. INTRODUCTION

I.1 Introduction

The art of implant rehabilitation now stands as a treatment of choice, renowned for its consistent predictability and significant rates of survival. (1,2)
Numerous studies have demonstrated that implants placed in the edentulous mandibular region achieve a long-term success rate exceeding 95%, whereas in areas with lower bone density, such as the maxillary region, the success rates decrease. (3)
An implant is deemed 'failed' when it needs to be removed or has already been lost. Conversely, success is contingent upon the presence of specific clinical conditions, including the absence of pain, mobility, crestal bone loss, and peri-implant diseases, as well as appropriate probing depth. (4)
Substantial efforts persist in optimizing the survival rates of implant treatments, with special attention in achieving the highest possible level of primary stability, that is essential to fulfill a favorable osseointegration outcome and eventually to perform an immediate loading protocol. (3,5)
Multiple factors contribute to the determination of primary stability, such as the surgical technique, patient´s characteristics and the dental implant macrogeometry. The macrogeometry appears to play a key role in influencing primary stability, including the thread depth, that is one of the specific aspects under scientific and literature review. (1,6)
Various noninvasive clinical testing methods to assess implant stability have been outlined, including visual evaluation, the Ping test (a percussion test involving tapping on the implant-abutment interface with a metallic instrument), insertion torque (IT), Periotest, and resonance frequency analysis (RFA). (1,3,5,7)
Even though the literature suggests employing multiple methods for a more comprehensive investigation when assessing the presence of primary stability, it also considers the IT and the RFA, that measures the implant stability quotient (ISQ), as the two most effective techniques, in addition to clinical and radiographic evaluations. (1,5,7)
Furthermore, the literature has also demonstrated a positive correlation between IT and ISQ. However, not all bone types have undergone uniform testing, hence the results remain inconclusive. (5,7)

I.2 History

Since time immemorial, human beings have shown interest and concern regarding the loss of teeth and their replacement. Initially, the desire to solve this issue was strictly related to survival, due to the inability to nourish oneself adequately. Nevertheless, throughout the centuries, as diverse food resources emerged to accommodate various consistencies and requirements, the lack of teeth evolved into a matter of aesthetics. (8)

What is now unanimously referred to as a "dental implant," which is an intraosseous metal post designed to mimic a missing tooth root and support a prosthetic component, has a long history of experimental development. (8,9)

In ancient times, dental implants consisted of a wide variety of materials, including animal bones or human teeth, embedded in the jawbones. These early implants aimed to closely simulate the anatomical appearance of a tooth while attempting to restore its function. (8,10,11)

The earliest documented evidence of this practice dates back to the ancient Egyptian civilization, which used shells and stones embedded in jawbones. (8,12,13)

In the 5th century B.C., the Etruscan people attempted to address tooth loss by replacing them with oxen bones.(11)

Around 600 A.D., the Maya people demonstrated great skill in creating the first actual mandibular pseudo-implants, as demonstrated by archaeological researches in the 1930s and the radiographic ones in the 1970s, conducted on a remnant of a mandible with three shells inserted in place of three lower incisors, around two of which excellent compact bone formation occurred. (11,13)

The practice of replacing missing teeth in Europe was characterized in the 17th century by the use of different materials or even animal components. In the 18th century, teeth obtained from deceased or less affluent individuals, who sold them out of necessity, became a common practice. In the 19th century, a wide range of materials such as gold, silver, porcelain, iridium and other metal alloys were experimented with. Up until then, every attempt at dental implantation was unsuccessful, resulting in inflammations and infections. (8,11)

In 1948, studies conducted by Dr. Norman Goldberg and Dr. Aaron Gershkoff were of fundamental importance. They placed the first subperiosteal cobalt-chromium-molybdenum implant, achieving excellent results and thus initiating the dissertation of implantology knowledge in many dental schools. (11,13)

But the real turning point for modern implantology occurred in the 1960s, when Swedish orthopedic surgeon Branemark identified and experimented with the enormous potential of pure titanium implants. (11–14)
Indeed, in 1965, he placed four pure titanium implants in the mandible of a 34-year-old man, and they integrated seamlessly with the surrounding bone, remaining in situ and without any side effects until the patient's death 40 years later. (11,13)

I.3 Osseointegration

The term "osseointegration" was coined by Branemark and is still accepted and used to describe “a direct structural and functional connection between ordered, living bone, and the surface of a load carrying implant”. (11,14,15)
This concept was accidentally discovered by Branemark in 1952, during research on blood flow in rabbits. By implanting titanium chambers in the femurs of these animals, he observed that the living bone could become perfectly anchored to the titanium oxide layer, growing around it to the extent that separation was impossible without causing fracture. (11,15)
This groundbreaking discovery was soon applied to the dental field, shifting the focus from what had until now been almost purely mechanical interlocking implant research to more biochemical and macrogeometric compatibility research. This paved the way for a wide range of endosseous implant designs. (12)
The direct contact between bone and implant, without the interposition of nonbony tissue, is regarded as a measure of bone integration and consequently, the long-term success of the prosthetic unit. (15,16)
This is an intricate process of bone remodeling that occurs throughout the patient's life, triggered as a physiological healing response to medical treatment that the body recognizes as a bone fracture. (16)
New bone undergoes appositional growth towards the implant at the bone-implant interface, until the latter is completely covered by it. Currently, osseointegration can be described as a state where non-vital elements are consistently assimilated into living bone, maintaining this integration under normal loading conditions without any ongoing associated movement between the implant and the directly contacted bone. (15,16)

I.4 Primary and secondary stability

For osseointegration to occur, the presence of primary stability is necessary. (5–7,9,15,17) The concept of 'primary stability' pertains to the mechanical interlocking that takes place immediately after the implant insertion. It holds paramount importance during the initial week following surgery, subsequently exhibiting a substantial decrease to minimal levels around two weeks postoperatively. (9)

This interlocking involves the threads of the implant and the surrounding bone, creating a firm anchorage between the two, established without any slight distortion or excessive micromovements of the inserted element. (5,15)

Indeed, after the implantation, micromovements may occur, which are considered acceptable within a range of 50μm to 150μm. Beyond this parameter, the bone-implant interface may potentially be invaded by fibroblasts originating from the surrounding connective tissue, leading to implant encapsulation within fibrous tissue and subsequent failure of osseointegration, thereby increasing the risk of fractures. (1,7)

It has been observed that implants with insufficient initial stability experience a 32% higher rate of failure. (13)

Primary stability is influenced by a combination of factors, including the surgical protocol, as well as characteristics related to the implant and patient-specific variables. (1,5,6,15)

The topography of dental implant surfaces plays a critical role in fostering adhesion and facilitating the differentiation of osteoblasts throughout the initial stage of osseointegration and in the extended process of bone remodeling. Systematically, dental implant topography can be distinguished across macro, micro, and nano-scales. (16)

Recent studies suggest that particularly the macrogeometric characteristics of the implant and the bone quality of the surgical site play a crucial role in the long-term success of the treatment. (6)(18)

The macrogeometry of an implant encompasses aspects such as its length, diameter, taper, thread depth, and pitch, that significantly influences its biomechanical attachment and functionality within the bone tissue. (9)

Thread depth represents the measurement of how far the coils extend outward from the core of the implant, or in other words, it refers to the measurement from the outermost part of the thread (major diameter) to the innermost part (minor diameter). (18)

It is commonly understood that implants with deeper threads have a larger surface area. This increased thread depth can provide benefits in regions with softer bone and more intense chewing forces, due to the expanded area of contact with the bone. (3)
An equally crucial parameter for the long-term success of implant treatment is secondary stability, which is closely related to the extent of new bone formation at the interface between the implant and the surrounding bone. (9,16)
A successful primary stability enables a proper process of bone healing and remodeling, leading to implant osseointegration and consequently achieving the so-called "secondary stability". (5)
The extent of secondary stability progressively rises over time, experiencing a more accelerated increase approximately 2.5 weeks post-implantation, ultimately reaching a plateau around 5-6 weeks post-implantation. The entire transitional period, shifting from the initially predominant primary stability phase to the ultimately dominant secondary stability phase, spans approximately 5–8 weeks. (9)
While the former pertains to a mechanical bone-implant relationship, the latter refers to a biological adaptation. However, the two aspects are closely interconnected. (17)

I.5 IT, RFA and bone quality and quantity

Currently IT and RFA are regarded as benchmarks for assessing *in vivo* implant primary stability. The first method is also commonly referred to as the measurement of cutting resistance, introduced by Johansson and Strid in 1994 and later enhanced by Frieberg. (1,5,7)
The torque applied during implant insertion gauges the frictional resistance experienced by the implant as it advances apically through a rotary motion on its axis. (7)
It is otherwise stated as the highest torque needed for placing an implant into the osteotomy site. (1,5)
Surgical techniques, implant design, and bone quality collectively impact this mechanical aspect. The IT force required, expressed in N/cm^2, offers valuable insights into primary stability and the density and quality of the bone. Elevated IT values signify a more robust anchorage, thereby indicating enhanced primary stability and denser bone.(1,5)
According to certain authors, an IT force of at least 30 N/cm^2 is proposed as the optimal minimum during insertion to achieve an ideal level of primary stability. (5)

While the IT allows for a single assessment of primary stability, the second method, the RFA, provides the opportunity for repeated evaluations over time. (1)
The RFA is a clinical approach presented by Meredith et al. in 1996, that offers non-invasive insights into the rigidity of the bone-implant connection. (1,5,7,19)
The resulting value is a combination of the contact at this junction and the density of the bone surrounding the implants. (1,19)
This method has been utilized to document changes in bone healing around the implant-bone interface. Moreover, it has been employed to assess the preparedness of implants for their final restoration or loading, as well as to identify implants carrying potential risks. (7,19)
The measurement is conducted by affixing a peg to the top of the inserted implant, which serves as a transducer, incorporating piezoelectric material within its structure. The peg is stimulated by approaching the Osstell® rod (a tool emitting magnetic impulses) and emits a sinusoidal wave within a range of 5–15 kilohertz (kHz). (7,9,19)
The recorded value is converted into a parameter known as the ISQ, ranging from 1 to 100, where 100 represents the maximum primary stability. (1,7,19)
Literature uniformly acknowledges that ISQ values below 45 indicate low primary stability, while values exceeding 65 indicate high primary stability. (17)
The long-term success of implant treatment is also directly proportional to the quality and quantity of bone. (13)
The bone quality at the implant site refers to the amount of cortical or cancellous bone present, while the quantity is related to the level of bone density that is currently present. (13,17)
Density is just one of the characteristics that define the quality of maxillary bones, along with bone metabolic processes, blood flow, mineral deposition, cell turnover, and maturation. Among all these aspects, density is more extensively studied, and the results in the literature suggest that it significantly influences the planning and long-term success of implant treatment. (20)
Implant failure may be linked to increased bone resorption and hindered healing processes, particularly in comparison to denser bone types. Clinical investigations have highlighted higher survival rates for dental implants in the mandible compared to those in the maxilla, particularly in the posterior maxilla. The underlying cause of this discrepancy has been attributed to differences in bone quality. In the posterior maxilla, there is typically thinner cortical bone coupled with thicker trabecular bone in contrast to the mandible. Clinically,

bones with lower densities, referred to as 'soft bones,' exhibit poor degrees of bone mineralization or limited resistance. (13)
From a strictly mechanical perspective, when the prosthetic unit is placed, low-density bone is unable to provide optimal support for the forces to which the implant is subjected, thus becoming more susceptible to microfractures at the interface. (21)

I.6 Misch’s classification

Misch outlined four distinct bone densities (D1, D2, D3, and D4) and their respective anatomical locations: D1 bone predominantly consists of dense cortical bone and is situated in the anterior region of the mandible; D2 bone exhibits dense to thick porous cortical bone at the crest, accompanied by coarse trabecular bone beneath. It is prevalent in the anterior maxilla, as well as both anterior and posterior regions of the mandible; D3 bone features a thinner porous cortical crest with fine trabecular bone. It is found in both the anterior and posterior regions of the maxilla, as well as the posterior mandible; D4 bone lacks significant crestal cortical bone, with fine trabecular bone constituting the majority of the volume. It is primarily located in the posterior region of the maxilla, specifically in the tuberosity region. (7)

I.7 Objectives

The primary objective of this study is:

- to evaluate how different thread depths, affect the initial stability of a dental implant placed in lower bone density.

The secondary objectives identified were:

- to evaluate the effect of thread depth in the IT and ISQ of dental implants placed in lower bone density;
- to evaluate the relation between IT and ISQ.

II. MATERIALS AND METHODS

The present research was conducted with an *in vitro* methodology, carried out at the University Clinic of the *Universidade Católica Portuguesa* of Viseu, during the period between February 2024 and March 2024, as part of this Master's Thesis in Dental Medicine. Logistics were facilitated by Megagen® Portugal (providing dental implants and surgical kits), Bone Models™ (type D3 artificial bone blocks), SmartPeg® Osstell® (SmartPeg® type 67) and Precision Dental Medicine Platforms (CIIS-FMDUCP) in terms of facilities and instruments (Set iChiropro Surgery, Micro-Series CA 20 handpiece Bien-air®, ISQ reader Osstell®).

II.1 Instruments and materials

- 24 implants (Anyridge®, MegaGen® Implant, Daegu, South Korea) **(Figure 1)**
- Surgical kit Anyridge® (Anyridge®, MegaGen® Implant, Daegu, South Korea) **(Figure 2)**
- 3 type D3 artificial bone blocks (Bone Models™, Castellon, Spain) **(Figure 3)**
- iChiropro Surgery Set (iChiropro, Bien-Air Dental® SA, Switzerland)
- ISQ reader Osstell Beacon® (Osstell®, Stampgatan 14, Sweden) **(Figure 4)**
- SmartPeg® type 67 (SmartPeg® Osstell®, Sweden) **(Figure 5)**

Fig 1. Anyridge® implant.

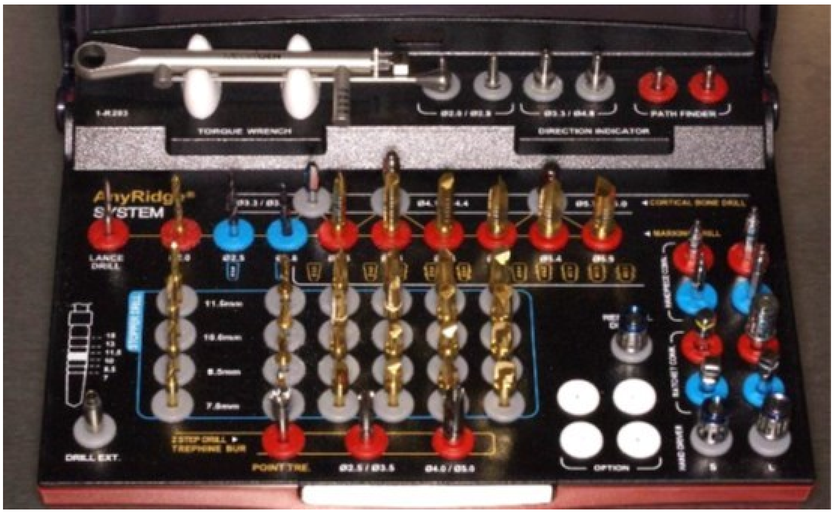

Fig 2. Anyridge® surgical kit.

Fig 3. Type D3 artificial bone block.

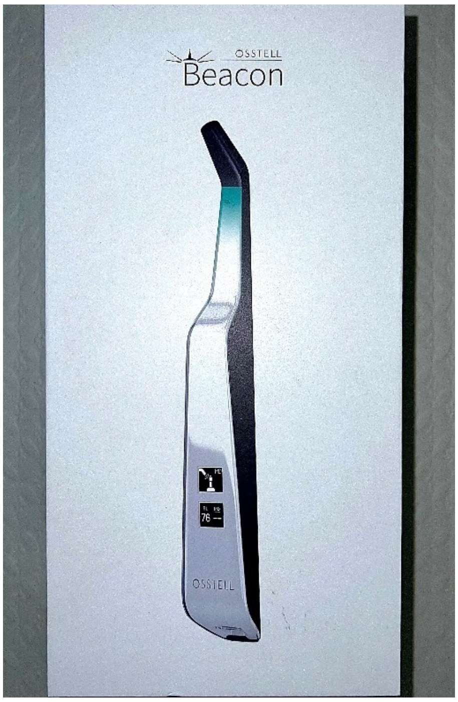

Fig 4. ISQ reader Osstell Beacon®.

Fig 5. SmartPeg® in place.

II.2 Groups under study

The implants (N=24) were distributed according to **figure 6** considering the 3.3mm inner core of the implant and the 10mm length, identical in all groups and the progressive increase in the threads determining final diameters of 4, 4.5, 5 and 5.5mm (**Figure 7**).

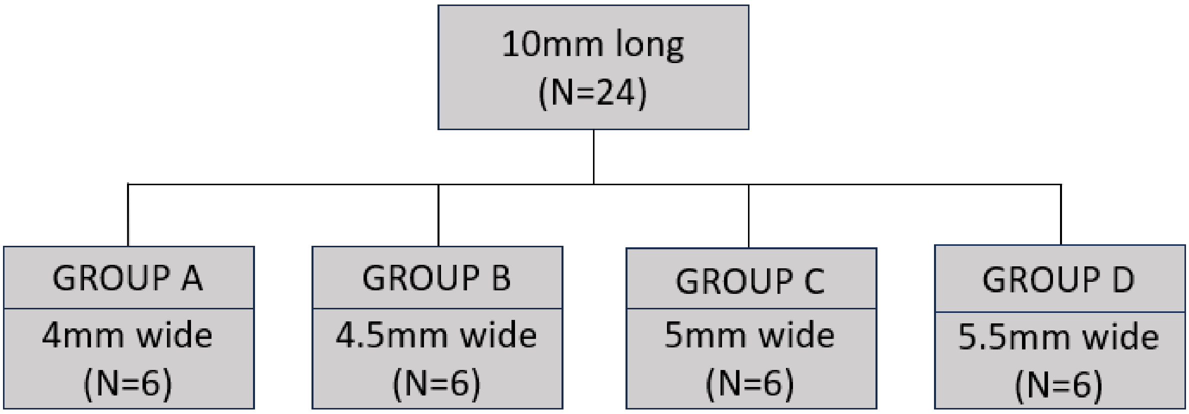

Fig 6. Implants groups under study.

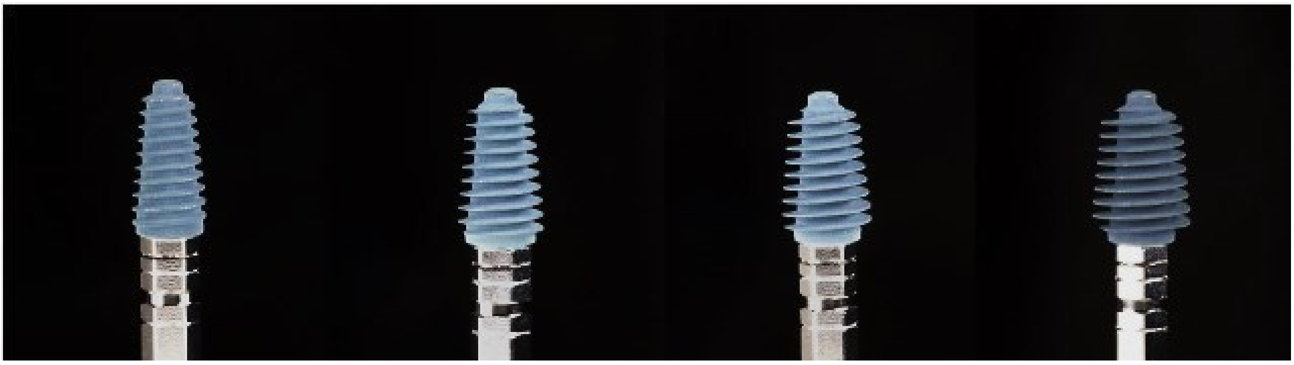

Fig 7. Example of implant samples used for our *in vitro* investigation. From left to right: implant 4mm (Group A), 4.5mm (Group B), 5mm (Group C), and 5.5mm (Group D) wide x 10 mm long.

II.3 In vitro implant placement procedure

Preparation of bone blocks (type D3 artificial bone blocks, Bone Models™): the bone blocks were divided graphically into 24 equal spaces and the center of the ridge in each space was identified and marked with a pencil. Then, keeping the drills perpendicular to the bone plane of the model, the implant beds were prepared up to the diameter of the implant core according to the manufacturer's instructions for placement in low-density bone.

II.4 Implant bed preparation sequence

1- Lance drill;
2- Drill 2mm in diameter, 10mm stopper drill;
3- Drill 2.8mm in diameter, 10mm stopper drill;
4- Drill 3.3mm in diameter, 10mm stopper drill;
5- Insertion of the implant using the implant driver until the implant platform is 1 mm below the bone level.

Using the surgical hand piece and the Anyridge® surgical kit **(fig.2)**, the initial perforation was performed with the lance drill bur **(fig.8)**, positioned at the central point of one of the 24 designated perforation sites. With the surgical motor (iChiropro) set at 1200 rpm and 20 N/cm², the bur was inserted perpendicularly up to the marked stop line. Subsequently, using the same surgical motor program, the osteotomy site was progressively enlarged. First, with the 2mm diameter drill bur **(fig.9)** with a stop at 10mm, then with the 2.8mm diameter drill **(fig.10)** bur with a stop at 10mm, and finally with the 3.3mm diameter drill bur **(fig.11)** with a stop at 10mm. The same perpendicular position relative to the bone was maintained for the insertion of all three drill burs. Once the osteotomy site preparation was completed, the respective implant was placed. For the implant insertion, the surgical motor was set at 35 rpm and 75 N/cm². Applying slight pressure, the implant was inserted up to 1mm below the bone level **(fig.12).** Once placed, the insertion torque (IT) value displayed on the surgical motor screen was immediately recorded in an Excel® data sheet (Microsoft® Excel® for Microsoft 365 MSO (Version 2407 Build 16.0.17830.20056) 64-bit). Subsequently, the SmartPeg® **(fig.5)** was manually screwed onto the implant until it was firmly attached. Four ISQ measurements simulating buccal (ISQ V), lingual (ISQ P), mesial (ISQ M) and distal (ISQ D) were taken (**fig.13**) and recorded in the Excel® data sheet. The same steps were repeated for all 24 samples.

Fig 8. Lance drill.

Fig 9. 2mm stopper drill

Fig 10. 2.8mm stopper drill

Fig 11. 3.3mm stopper drill

Fig 12. Implant 1mm below bone level.

Fig 13. ISQ measurement.

II.5 Statistics

For the descriptive analysis, frequency distributions and statistical measurements were used: minimum, maximum, mean and standard deviation, as well as graphical representations. All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 29.0.2.0 Armonk, NY: IBM Corp. In the inferential analysis, parametric tests were used: Student's t-test to compare means between two independent groups and the ANOVA test to compare means of at least three independent groups. The application of parametric tests presupposed the verification of the assumption of normality of distributions using the Kolmogorov-Smirnov test and also of homogeneity of variances (in the case of ANOVA). The significance value was of 5%. The study was based on a convenience sample comprising the 24 implants available. This number was not chosen arbitrarily but was dictated by the availability of cases. Consequently, our study included all possible cases, making our analysis exhaustive within the limits of the accessible data.

III. RESULTS

The results derived from the *in vitro* investigation and the related statistical analysis will be presented below through tables and figures, in order to make their interpretation clearer.

III.1 Study characteristics

The *in vitro* study was conducted on a sample of 24 dental implants (Anyridge®, MegaGen® Implant, Daegu, South Korea), divided into four groups of six implants each, characterized by four different thread depths (Group A: 4mm, Group B: 4.5mm, Group C: 5mm, Group D: 5.5mm). The implants were tested on three blocks of D3-type artificial bone (Bone Models™, Castellon, Spain). For each inserted implant, its IT and ISQ values were recorded **(Table 1)**.

Table 1. Results of mean values for IT and ISQ.

		IT (N/cm2)	ISQ V	ISQ P	ISQ M	ISQ D	Mean ISQ
4x10mm	Group A						
	Implant 1	27.4	70	70	63	64	66.75
	Implant 2	21.5	65	66	63	63	64.25
	Implant 3	25.5	68	68	65	65	66.5
	Implant 4	21.5	70	70	63	63	66.5
	Implant 5	26.4	64	64	63	63	63.5
	Implant 6	28.4	68	68	64	64	66
	Group B						
4.5x10mm	Implant 1	43.1	70	69	70	70	69.75
	Implant 2	47.0	71	71	69	69	70
	Implant 3	42.1	70	73	70	70	70.75
	Implant 4	40.1	70	70	68	68	69
	Implant 5	35.3	70	70	67	66	68.25
	Implant 6	37.2	65	65	68	68	66.5
	Group C						
5x10mm	Implant 1	52.9	70	70	69	68	69.25
	Implant 2	49.0	70	70	69	69	69.5
	Implant 3	39.2	63	63	63	63	63
	Implant 4	51.9	71	71	70	70	70.5
	Implant 5	52.9	70	70	70	70	70
	Implant 6	58.8	66	67	70	70	68.25
5.5 x 10mm	Group D						
	Implant 1	44.1	70	70	67	67	68.5
	Implant 2	49.0	72	72	70	70	71
	Implant 3	55.8	69	70	68	69	69
	Implant 4	52.9	72	72	70	70	71
	Implant 5	51.9	71	70	70	70	70.25
	Implant 6	70.5	72	72	70	70	71

III.2 Results of the statistical analysis

Table 2 presents the characterization of the following measures: IT, ISQ V, ISQ P, ISQ M, ISQ D, and mean ISQ by groups, along with the comparison for each measure between groups, the results of the non-parametric Kruskal-Wallis test and the results of multiple comparisons when statistically significant differences are detected.
Each group consists of six elements (implants) and differ in diameter (4 to 5.5 mm) while having the same length of 10 mm.

- Group A: 4mm wide x 10 mm long.
- Group B: 4.5mm wide x 10 mm long.
- Group C: 5mm wide x 10 mm long.
- Group D: 5.5mm wide x 10 mm long.

Table 2. Characterization and comparison of measurements.

	Group				Kruskal-Wallis test
	A	B	C	D	
IT					H=17,901
$\bar{X}$±s	25,12±2,96	40,80±4,22	50,78±6,51	54,03±8,99	(0,000) [a, b, c, d, e]
ISQ V					H =7,970
$\bar{X}$±s	67,50±2,51	69,33±2,16	68,33±3,14	71,00±1,26	(0,036) [c]
ISQ P					H=7,045
$\bar{X}$±s	67,67±2,34	69,67±2,66	68,50±3,02	71,00±1,10	(0,061)
ISQ M					H=12,284
$\bar{X}$±s	63,50±0,84	68,67±1,21	68,50±2,74	69,17±1,33	(0,002) [a, b, c]
ISQ D					H=12,316
$\bar{X}$±s	63,67±0,82	68,50±1,52	68,33±2,74	69,33±1,21	(0,002) [a, b, c]
Mean ISQ					H=11,751
$\bar{X}$±s	65,58±1,37	69,04±1,51	68,42±2,76	70,13±1,12	(0,002) [a, c]

$\bar{X}$±s – mean ± standard deviation; H – Kruskal-Wallis test statistic (significance level); a: Results between A and B significantly different; b: Results between A and C significantly different; c: Results between A and D significantly different; d: Results between B and C significantly different; e: Results between B and D significantly different;

III.3 IT results

Regarding IT, on average, the highest value is observed in Group D (5,5mm wide), at 54.03±8.99 N/cm², and the lowest in Group A (4mm wide), at 25.12±2.96 N/cm², as shown in **Figure 14**. The non-parametric Kruskal-Wallis test indicated that at least one group had significantly different results from the others ($H=17.901$; $p<0.01$). Multiple comparisons were then conducted using the Mann-Whitney test with Bonferroni correction, and it was found that Group A differs significantly from the other groups, as does group B, while Groups C and D yield statistically similar results.

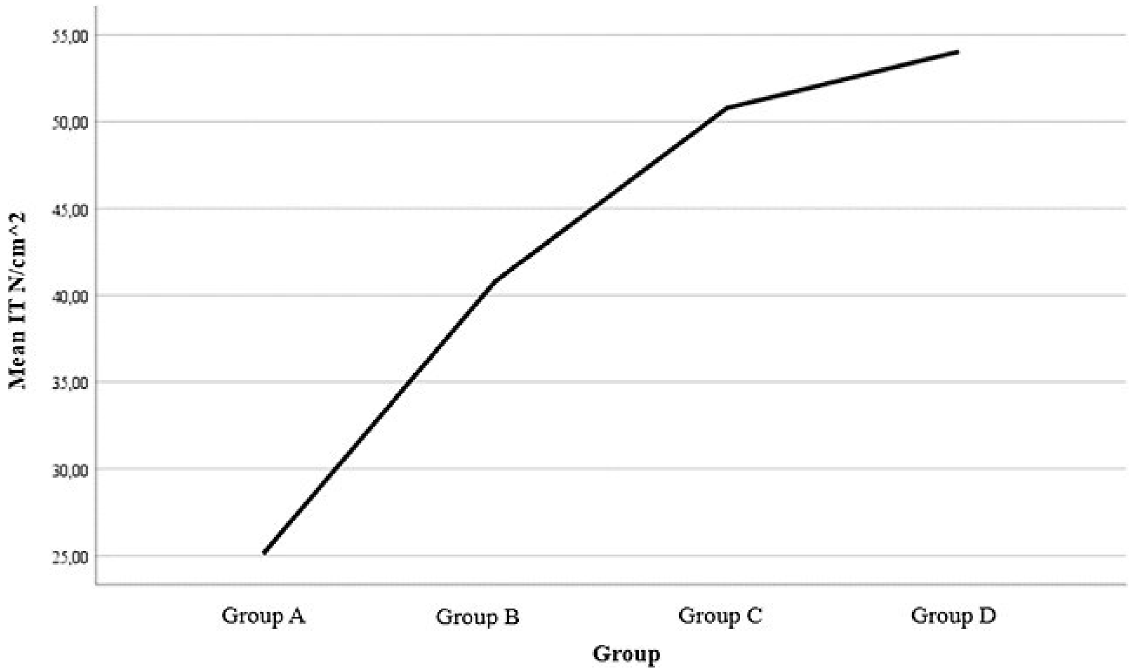

Fig 14. Correlation between IT and implant thread depth

III.4 ISQ results

As shown in **Figure 15**, regarding the ISQ V measurement, the highest average value was observed in Group D at 71.00±1.26, while the lowest was in Group A at 67.50±2.51. However, the results obtained for Groups B and C are relatively close. The non-parametric Kruskal-Wallis test indicated that at least one Group had significantly different results from the others ($H=7.970$; $p<0.05$).

Multiple comparisons were then conducted using the Mann-Whitney test with Bonferroni correction, and it was found that Group A differs significantly from Group D.

For the ISQ P measure, the results are similar across different groups, ranging from the lowest, 67.67±2.34 in group A, to the highest, 71.00±1.10 in Group D. The application of the non-parametric Kruskal-Wallis test concluded that there are no significant differences among the groups ($H=7.045$; $p=0.061$).

Regarding the results obtained for ISQ M and ISQ D, they are relatively similar, with the highest values observed in Group D and the lowest in Group A, while Groups B and C have values close to those of Group D in both cases. The application of the non-parametric Kruskal-Wallis test concluded that there is at least one group that shows significantly different results from the others ($p<0.01$) for both measures. Multiple comparisons were then conducted using the Mann-Whitney test with Bonferroni correction, and it was found that Group A differs significantly from the other groups for both measures.

As for the mean ISQ measure, on average, the highest value is observed in Group D, at 70.13±1.12, and the lowest in Group A, at 65.58±1.37. However, the results obtained for Groups B and C are relatively close. The non-parametric Kruskal-Wallis test concluded that there is at least one group that has significantly different results from the others ($H=11.751$; $p<0.01$). Multiple comparisons were then conducted using the Mann-Whitney test with Bonferroni correction, and it was found that Group A differs significantly from both Groups B and D.

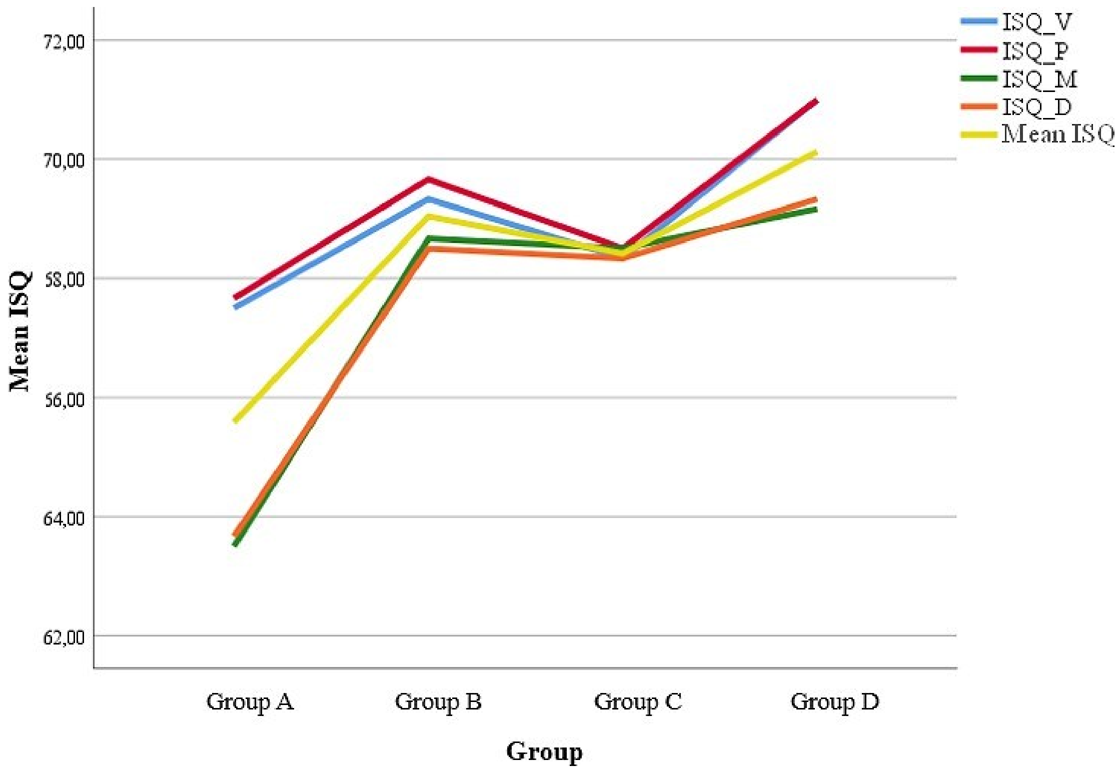

Fig 15. Correlation between implant thread depth and ISQ

III.5 IT and ISQ correlation results

Table 3 presents the Spearman correlation coefficients (as the distributions' normality was not verified) between the IT measure and the ISQ measures. It is observed that all correlation coefficients show statistical significance and a positive direction, indicating that if there is an increase in IT, there will also be an increase in ISQ measures. However, the strength of this increase, i.e., the correlation intensity, varies among the ISQ measures. Specifically, the correlation is weak between IT and ISQ V and ISQ P, and moderate to strong with the remaining ISQ measures.

Table 3. Spearman correlation between IT and ISQ measures.

	ISQ V	ISQ P	ISQ M	ISQ D	Média ISQ
IT	0,499*	0,479*	0,795**	0,803**	0,716**

*-significant at 5%; **-significant at 1%

IV. DISCUSSION

Through this investigative study, we aimed to understand how dental implants of the same type and brand, but with varying thread depths, can affect the degree of primary implant stability, the IT and the ISQ when the implant is placed in a low-density bone tissue. Additionally, we aimed to clarify the correlation between IT and ISQ. This study was conducted to improve the predictability and success rates of implant therapy.

IV.1 Discussion

The key to success in implant treatment is to make it highly predictable. Properly diagnosing the type of bone density at the surgical site in question is crucial. While predicting the outcome is relatively straightforward with jawbones of densities D1 and D2, it becomes more contentious when dealing with lower-density bones such as D3 and D4. (20,21)
The literature converges in considering primary stability as the *condicio sine qua non* for achieving successful implant treatment. (3,19,22,23)
Much of the literature generally agrees that the failure rates of an implant placed in low-density bone are higher due to lower primary stability. However, other factors are also related to the treatment outcome, so a comprehensive preliminary analysis of the patient and a personalized treatment plan are always required. (13)
Therefore, considering the previous literature, we wanted to examine whether it is possible to improve and make the outcome of implant placement in low-density bone more predictable.
According to various studies, using dental implants with greater thread depth improves the achievement of primary stability and osseointegration in soft bones, where a larger anchoring surface at the bone-implant interface and better force distribution are needed. (3,23)
The two most commonly used parameters for measuring primary stability are IT and RFA (expressed in ISQ). (3,18,21)

IV.2 IT results discussion

In a clinical setting, greater primary stability would be expected from achieving higher IT values at the time of placement. (5,17,23,24)

Ribeiro-Rotta et al. observed that higher trabecular bone density corresponded to increased IT values. (25)
However, our research has highlighted an interesting phenomenon: by inserting implants with varying thread depths into low-density bone, we obtained significantly varying IT data. This suggests that, despite the traditional correlation between bone density and IT values, the depth of implant threads can significantly influence the results. Statistical analysis revealed that, on average, the highest IT values were in Group D, with a result of 54.03±8.99 N/cm^2, while the lowest were in Group A, with 25.12±2.96 N/cm^2.
A comparable study conducted by Lee et al., utilized implants from the same company but with different dimensions, tested on polyurethane blocks of various densities and with multiple drilling protocols. Their data are interesting, as progressively greater thread depths produced progressively higher torque values across all three block densities: 0.16 g/cm^3, 0.24 g/cm^3, and 0.32 g/cm^3. However density did not have a significant impact on the relationship between thread depth and torque values. Similarly, in our study, greater thread depths corresponded to higher torque results. Specifically, Group D, consisting of implants with a diameter of 5.5 mm, exhibited higher torque values compared to Group A, which contains implants with a diameter of 4 mm. However, our test involved only the D3 density. (3)
According to the studies by Sarfaraz et al., good primary stability corresponds to IT values between 30 and 60 N/cm^2. Therefore, implants with increasing thread depth, belonging to Groups B, C, and D and inserted into soft bone, seem to have a better adaptation compared to group A, which has the shallowest thread depth. (5,7)
Furthermore, the threads of group C (5mm wide) and group D (5.5mm wide) yielded statistically equivalent and significant IT results.
Yet, a high IT value does not always imply implant osseointegration. Other studies suggest that values exceeding 50 N/cm^2 may indeed be detrimental both to bone remodeling and to the implant structures. (23)
Studies like Herekar et al. support the results of our research. Their findings revealed a lack of correlation between IT values and the different types of bone density examined, attributing primary stability to changes in the surgical technique and the implant structure. (21)

IV.3 ISQ results discussion

We subsequently also recorded the ISQ values using a manually tightened SmartPeg and an ISQ reader.

All the analyzed data yielded the same result, indicating that Group A (4mm wide) consistently recorded the lowest values among the four groups, whether comparing the means of individual values (ISQ V, P, M, and D) or comparing the overall average of the four ISQ values among the groups. Notably, Group A, with the shallowest thread depth, always differed significantly from Group D, which had the deepest thread depth. The mean ISQ of Group A was found to be 65.58±1.37, compared to that of Group D, which was 70.13±1.12. Nearly similar results between the mean ISQ values of Groups B (69.04±1.51) and C (68.42±2.76) could be attributed to various factors. There might be minimal variation in the data due to the limited sample size, or there could be local variations in the density or structure of the bone block used in the different tests. These variations could affect the ISQ measurements, hindering the observation of a positive trend between the two groups.

In general, observing **Table 2**, we can notice that no implant was found to be at risk of failure, both considering the literature, which deems 45 ISQ the minimum threshold for implant success, and considering the Osstell® guidelines, which have set the minimum threshold at 60 ISQ. (7,17)

However, the investigation revealed that primary stability in soft bone can be enhanced by preferring implants with deeper threads.

Makary et al. also found that implants with larger diameters tend to have higher ISQ values compared to those with smaller diameters when observed during healing phases after 3 and 6 weeks. (26)

Tözüm et al. contribute to substantiate our thesis, demonstrating how 12 implants with different diameters, inserted into acrylic resin blocks simulating the mandible, generated positive and significant results between implant width and its corresponding ISQ. (27)

On the other hand, Ohta et al. noticed a positive correlation between these factors, but not one that was truly significant, likely due to the experimental conditions of the swine bone model used. Other variables, such as the lack of contact between the implant base and the lesion, played a disadvantageous role. (28)

IV.4 IT and ISQ correlation results discussion

The question of whether there is a correlation between IT and ISQ values remains a matter of debate. (7,9)

All our IT values, when compared with all ISQ values, showed a directly proportional relationship, whereby as the former increased, the latter also increased.

According to Lages et al., the two parameters have no correlation and cannot be used in conjunction. However, the outcome might have depended on the different factors in each clinical case analyzed. (29)

Ito et al. also stated that the lack of correlation is understandable, as the two tests examine different aspects: while the IT is a mechanical factor influenced by the entire rotational insertion of the implant, the ISQ relates more to the contact between the implant's collar and the bone. (30)

However, there is also another part of the literature that revealed data supporting a positive correlation between IT test values and RFA values, possibly due to more standardized research, such as in the study conducted by Farronato et al. on polyurethane blocks. (5,7,9,23)

Makary et al., in their comparative study of standard and ultrasonic drilling protocols, also observed a relationship between IT and ISQ, as well as with bone quality. (31)

Turkyilmaz et al., by placing 230 implants in surgical sites with known bone density, observed a positive correlation among all examined factors: IT and bone density, ISQ and bone density, and IT and ISQ, thus confirming their previous studies. (32)

A favorable aspect of our investigation was the adoption of a surgical protocol tailored to soft bone types. The implants we used were placed in accordance with the manufacturer's instructions, which recommended a final drilling diameter of 3.3 mm for low-density bone, thus smaller than the diameter of the implant to be inserted. By doing so, we created an undersized or “misfit” surgical site, which actually allows for a better bone-implant interface. (3,22,23)

According to Dedigi et al., adequate undersizing should not be less than 10%, which aligns with our protocol. (33)

The results met the expectations, supporting the notion that the primary stability of a dental implant and thus its long-term success can indeed be improved and made more predictable,

even in delicate situations such as with bone that is of low density or otherwise compromised.
Despite the multiple variables to consider for each of our individual patients, our results support that by adopting the appropriate surgical protocol and choosing the most suitable implant design, it is possible to achieve successful initial stability even in less favorable conditions.
Our study does not claim to provide definitive theories about the choice of daily clinical procedures in surgery, but aims to contribute to improving knowledge in the field.

V. Limitations

Our study is subject to limitations because: the bone blocks did not have perfectly identical bone density among them and at each point; the implants were tested on only one type of density and not on four different types of density; we experimented with only one drilling protocol and not multiple protocols for comparison; we did not use a standardized SmartPeg screwing system, but rather a manual one; in the literature, there is a lack of studies comparing our exact same values and the sample size was constrained by the availability of implants.
We intend to undertake a more comprehensive investigation in future research to address the limitations identified in our study.

VI. CONCLUSION

VI.1 Conclusion

Mean IT values increased significantly when comparing the 4mm and 4.5mm wide implants to the 5 and 5.5m wide implants.

The 4mm wide group has the lowest mean individual and total ISQ values and a significant ISQ increase was observed between this group and the 5.5mm group.

Additionally, a strong statistically positive correlation was revealed between IT and ISQ parameters.

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