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

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MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

ASSESSMENT OF THE PALATAL BONE THICKNESS FOR TEMPORARY ANCHORAGE DEVICE INSERTION IN PORTUGUESE POPULATION: A RETROSPECTIVE STUDY.

Trabalho submetido por:

Anastasiia Ananieva

para obtenção do grau de Mestre em Medicina Dentária

julho de 2024

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Trabalho orientado por:

Prof. Doutora Iman Bugaighis

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RESUMO

Objetivo: Este estudo teve como objetivo investigar a espessura óssea palatina em uma coorte de pacientes portugueses de diferentes faixas etárias, para identificar locais favoráveis de inserção para estabilidade ideal de Micro-Implantes (MIs) ortodônticos e determinar possíveis variações relacionadas ao sexo na espessura óssea palatina, bem como entre diferentes grupos etários.

Materiais e Métodos: Foram analisadas cinquenta Tomografias Computadorizadas por Feixe Cônico (TCFC) de pacientes entre 12 e 51 anos (23 homens e 27 mulheres). As TCFCs foram classificadas com base em idade e sexo. A espessura do osso palatino foi medida a 4, 8, 12, 16 e 20 mm posterior ao forame incisivo (FI) e a 3, 6 e 9 mm lateral à sutura palatina mediana (SPM). Um total de 750 regiões de interesse (ROIs) foram avaliadas (15 para cada um dos 50 pacientes). A análise dos dados foi realizada com análise de variância (ANOVA) bidirecional e teste t de Student, com nível de significância de $p < 0,05$.

Resultados: O valor mais significativo da espessura óssea palatina foi determinado a 4 mm posterior ao FI e 9 mm lateral à SPM em todos os grupos investigados, com uma espessura média de 12,29 ± 2,00 mm para mulheres e 13,59 ± 2,31 mm para homens; 13,30 ± 2,38 mm para adolescentes e adultos jovens, e 12,27 ± 2,03 mm para adultos. Diferenças estatisticamente significativas foram observadas entre homens e mulheres e entre diferentes grupos etários ($p < 0,05$).

Conclusões: A espessura óssea palatina varia com sexo e idade, sendo necessário considerar esses fatores para a seleção dos MIs. As mulheres geralmente têm uma espessura óssea palatina menor em comparação aos homens. A espessura óssea palatina tende a ser significativamente maior no grupo de adolescentes e adultos jovens (12-25 anos) do que em adultos (27-51 anos). A espessura óssea diminui em direção posterior dentro de cada seção sagital.

Palavras-chave: Tomografia computadorizada por feixe cônico; Palato; Microimplante ortodôntico; Espessura óssea palatina.

ABSTRACT

Objective: This study aimed to investigate palatal bone thickness in a cohort of Portuguese patients of different age groups to identify favorable insertion sites for optimal stability of orthodontic Micro-Implants (MIs) and determine potential sex-related variations in palatal bone thickness, as well as across different age groups.

Materials and Methods: Fifty Cone Beam Computed Tomography (CBCT) scans of patients between 12 and 51 years old (23 males and 27 females) were analyzed. The CBCTs were classified based on age and sex. The thickness of the palatal bone was measured at 4, 8, 12, 16, and 20 mm posterior to the incisive foramen (IF) and at 3, 6, and 9 mm lateral to the midpalatal suture (MPS). A total of 750 (regions of interest) ROIs were evaluated (15 for each of 50 patients). Two-way analysis of variance (ANOVA) and Students *t-test* were used for data analysis, with a significance level of $p < 0.05$.

Results: The most significant value of palatal bone thickness was determined 4mm posterior to IF and 9 mm lateral to MPS in all investigated groups with a mean thickness of 12.29 ± 2.00 mm for females and 13.59 ± 2.31 mm for males; 13.30 ± 2.38 mm for adolescents and young adults, and 12.27 ± 2.03 mm for adults. Statistically significant differences were observed between males and females and between different age groups ($p < 0.05$).

Conclusions: Palatal bone thickness varies with sex and age, necessitating consideration of these factors for MIs length selection. Females generally have a thinner palatal bone compared to males. Palatal bone tended to be significantly thicker in the adolescents and young adults age group (12-25 years old) than in adults (27-51 years old). The bone thickness decreases in a posterior direction within each sagittal section.

Key-words: Cone-bean computed tomography; Palate; Orthodontic microimplant; Palatal bone thickness.

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LIST OF ABBREVIATIONS

2D – Two-Dimensional

3D - Three-Dimensional

AI - Artificial Intelligence

ALADA - As Low as Diagnostically Acceptable

ALADAIP - As Low as Diagnostically Acceptable being Indication-oriented and Patient-specific

ALARA - As Low as Reasonably Achievable

ANOVA - Analysis of Variance

BS - Buccal Shelf

CBCT - Cone Beam Computed Tomography

CT - Computed Tomography

CVM - Cervical Vertebra Maturation

DICOM - Digital Imaging and Communication in Medicine

FOV - Field of View

ICC - Intraclass Correlation Coefficient

ICRP - International Commission on Radiological Protection

IF - Incisive Foramen

IMF - Intermaxillary Fixation

IZC - Infra-Zygomatic Crest

MARPE – Micro-implant Assisted Rapid Palatal Expansion

MI (s)- Microimplant (s)

Micro-CT - Micro-Computed Tomography

MPS – Midpalatal Suture

MSE - Maxillary Skeletal Expander

NCRP - National Council on Radiation Protection and Measurements

OSA – Obstructive Sleep Apnea

PNS – Posterior Nasal Spine

ROI - Region of Interest

RPE - Rapid Palatal Expansion

SS - Stainless Steel

STROBE - Strengthening the Reporting of Observational studies in Epidemiology

TAD (s) - Temporary Anchorage Device (s)

TMJ – Temporo-Mandibular Joint

I. INTRODUCTION

1. Contextualisation and Justification of the Work

During the last three decades, three-dimensional (3D) CBCT has been widely used in orthodontics to assess 3D craniofacial anatomy, evaluate bone quality and correlate anatomical craniofacial structures. In specific cases, using CBCT becomes an essential diagnostic aid before determining a treatment planning, especially when additional appliances, like Temporary Anchorage Devices (TADs) are used. CBCT is beneficial for assessing the intended placement site both before and after insertion, as well as for managing TADs status (Abdelkarim, 2019; Kaasalainen et al., 2021).

According to the literature, there are several notions that define devices for temporary anchorage in orthodontics. Among them, there are not only TADs (a general notion that includes screws, plates, and extraoral anchorage), but also miniplates and mini-implants. In the present dissertation, the term microimplant (MI) is used as a basic concept.

Nowadays, orthodontic MIs and mini-plates play a significant role in dental practice by providing a reliable anchorage system for successful orthodontic treatment. While MIs have become a popular tool for achieving maximum skeletal anchorage, the ideal placement location within the hard palate remains debated. Literature suggests the hard palate as a favored site for MI placement due to its sufficient bone volume and keratinized gingival tissue. However, it is essential to analyze and consider each patient's individual characteristics. To achieve clinical success and prevent complications, it is crucial to account for parameters such as bone thickness, density, and facial patterns while ensuring optimal anchorage throughout the treatment process (Vidalón et al., 2021).

The utilization of CBCT imaging facilitates a precise 3D assessment of the craniofacial and bone anatomy, enabling clinicians to identify optimal sites for MIs placement. This targeted approach minimizes the risk of complications, such as damage to anatomical structures or inadequate anchorage, and contributes to successful orthodontic treatment outcomes.

Although several studies evaluated bone thickness of the hard palate, up to date, there is no study for Portuguese individuals. Therefore, this study aimed to evaluating the parameters of the palatal thickness in different possible MI insertion locations in Portuguese population.

2. Objectives

The primary aim of this retrospective observational study was to identify the optimal site for the insertion of orthodontic MIs in Portuguese patients. This was achieved by evaluating total palate bone thickness using CBCT scans and determining the region with the greatest palatal bone height.

A secondary objective of this study was to investigate potential differences in palatal bone thickness between patients of different age and sex.

3. Literature review

3.1. Human Palate

The human palate is a complex structure that serves as a barrier between the oral and nasal cavities. It forms the roof of the mouth and plays an important role in several vital physiological processes, including gestation, articulation, deglutition, and respiration.

The palate is anatomically partitioned into two distinct regions: the hard and soft palates.

The hard palate comprises the anterior two-thirds. It is immobile and consists of the maxillary's palatine processes and the horizontal plates of the palatine bones. The primary purpose of this structure is to provide anatomical reinforcement and act as a barrier separating the mouth from the nasal cavity. The posterior one-third, *the soft palate,* is muscular and mobile. This structure consists mainly of muscle and connective tissues, allowing for flexibility. The soft palate terminates in a protrusion called the uvula, which hangs at the back of the throat (Cho et al., 2013; Olszewska & Woodson, 2019).

3.1.1. Embryonic Development

The embryonic development process is illustrated schematically in Figure 1. During early embryonic development, the oral and nasal cavities exist as a single, continuous space. Palate formation, a key developmental process, gradually separates these cavities through the formation of primary and secondary palates. The primary palate, including the alveolar arch, develops in parallel with the external face between the fourth and sixth weeks, specifically arising from the fusion of medial nasal and maxillary processes during the sixth week. Subsequently, the secondary palate, comprising the hard and soft palate, develops between the sixth and twelfth weeks. Originating from the medial walls of the maxillary processes, the palatal shelves expand medially, facilitated by the downward movement of the tongue due to mandibular growth. By the ninth week, these shelves fuse with each other and the primary palate, culminating in the formation of the definitive palate (Dursun et al., 2018; Greene & Pisano, 2010).

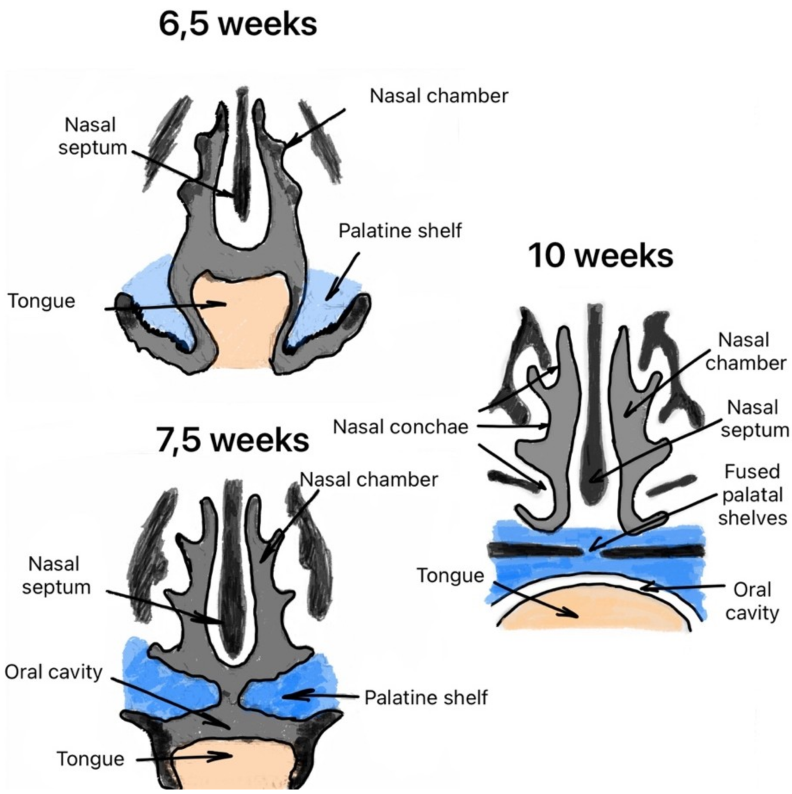


Figure 1. Human secondary palate development (adapted from Greene & Pisano, 2010).

3.1.2. Hard Palate Anatomy

The skeletal framework of the oral cavity is a complex structure, and its framework includes both paired and unpaired bones, each with specific contributions to the overall architecture. Among the paired bones are the maxillae, palatine bones, and temporal bones. Notably, the maxillae play a crucial role in shaping the roof of the oral cavity, primarily through their alveolar and palatine processes. The palatine process, a horizontal projection originating from the inner surface of each maxilla, extends towards the midline where it unites with its counterpart from the opposite side. This fusion results in the formation of the anterior three-quarters of the hard palate, a bony plate that serves as a barrier between the oral and nasal cavities (Figure 2).

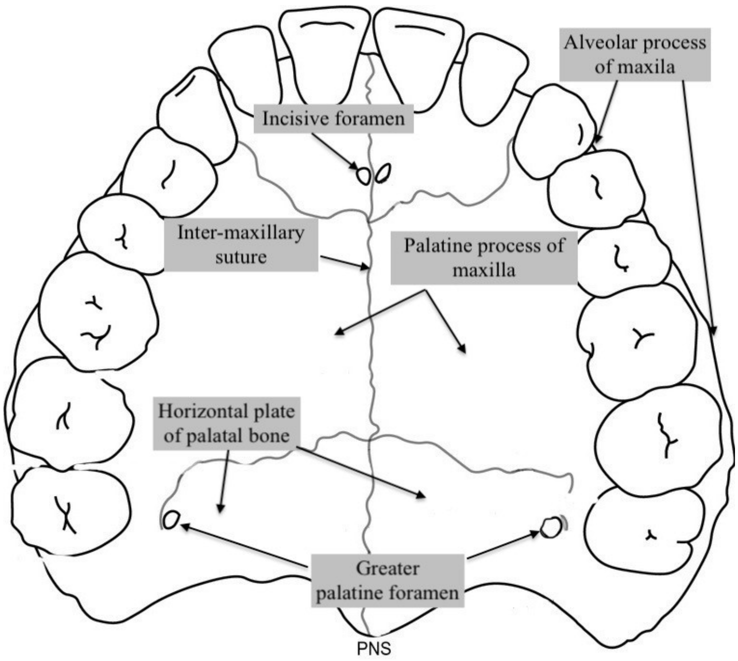


Figure 2. Schematic illustration of the hard palate anatomy (adapted from Atlas of human anatomy (6th ed.). (Netter, 2014)).

The hard palate itself is a multifaceted structure, composed of a bony foundation that is lined with distinct types of mucosae on its superior and inferior surfaces. The upper surface, facing the nasal cavity, is covered with respiratory mucosa, while the lower surface, forming the roof of the oral cavity, is lined with a tightly bound layer of oral mucosa. This mucosal lining is characterized by a series of transverse folds known as palatine rugae and a central longitudinal ridge called the palatine raphe. Additionally, there is a small oval elevation called the incisive papilla, which overlies the incisive fossa located between the horizontal plates of the maxillae. (Figure 3). The incisive fossa, situated in the midline on the inferior surface of the hard palate, is a significant landmark. It houses the openings of two incisive canals, one on each side, which ascend postero-superiorly to connect with the floor of the nasal cavity. These canals and fossae facilitate the passage of the greater palatine vessels and the nasopalatine nerves, contributing to the vascularization and innervation of the region.

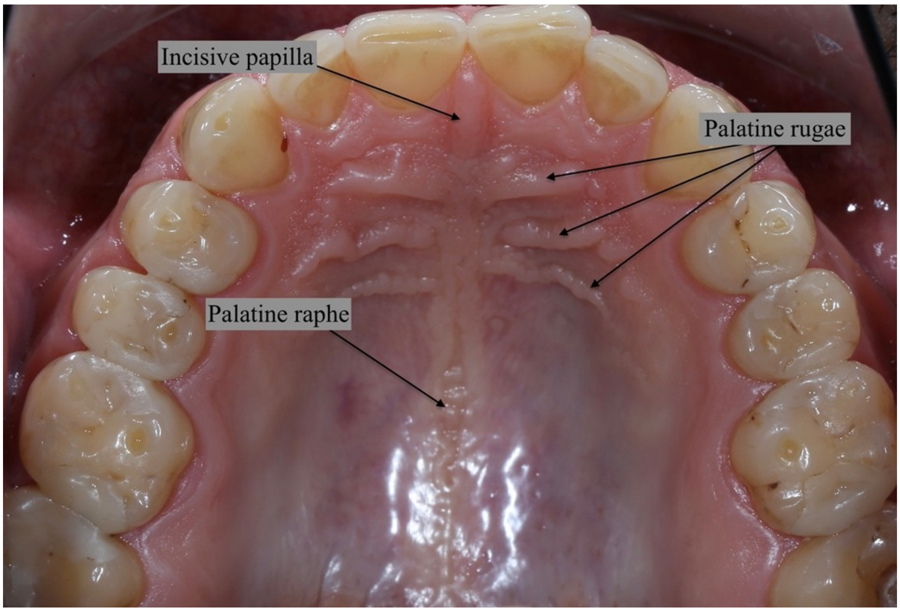


Figure 3. An intraoral photography showing the oral mucosa of the human hard palate.

The hard palate, a bony structure forming the roof of the mouth, contains three distinct anatomical landmarks that facilitate the passage of essential neurovascular structures:

- First, the incisive canal, positioned at the anterior midline of the maxilla just behind the central maxillary incisors, serves as a conduit for the nasopalatine nerve and the descending palatine artery.
- Second, the greater palatine foramen, located in the posterior region of the hard palate medial to the third molar, permits the transmission of the greater palatine vessels and nerve.
- Finally, the lesser palatine foramen, situated posterior to its larger counterpart on the base of the pyramidal process of the palatine bone, serves as a passageway for the lesser palatine nerve (Olszewska & Woodson, 2019).

3.2. 3D Imaging and CBCT in dentistry

Dental imaging has significantly evolved from the early 1900s, when the first dental radiograph was captured, until nowadays, where digital dental imaging has become an irreplaceable assessment tool in diagnosis, treatment planning and treatment evaluation. Dental radiography involves different types of X-rays capturing techniques. Imaging techniques for visualizing the oral and maxillofacial region can be broadly classified into two categories: planar methods and volumetric techniques. Planar methods, which produce two-dimensional images (2D), include intraoral radiographs, cephalometric radiographs, and orthopantomograms. Volumetric techniques, on the other hand, generate three-dimensional (3D) representations of the scanned region and include multi-slice Computed Tomography (CT) and Cone Beam CT (CBCT). Development of the medical imaging technology have helped overcome challenges in achieving high-quality 3D dental images, often referred to as CBCT (Kaasalainen et al., 2021).

Consequently, CBCT emerged as a valuable addition to dental medicine. It employs a conical X-ray beam and a corresponding detector that rotate around the patient, capturing comprehensive projection data in a single 360-degree sweep. This technology has significantly enhanced the diagnostic capabilities of dentists, allowing for more accurate assessments during treatment planning and providing detailed three-dimensional information about the craniofacial region (Nasseh & Al-Rawi, 2018).

3.2.1. Principle of Action

As a type of computed tomography, CBCT utilizes a cone-shaped X-ray beam that rotates 360 degrees around the patient's head, encompassing the region of interest (ROI). During this single rotation, digital detectors capture information about the shape and density of objects within the ROI from multiple angles. Specialized software then processes this imaging data to generate detailed tomographic images of the ROI in various anatomical planes. These include the standard coronal, axial, and sagittal planes (Figure 4), as well as their derivatives: the parasagittal, paracoronal, and para-axial planes (Abramovitch & Rice, 2014).

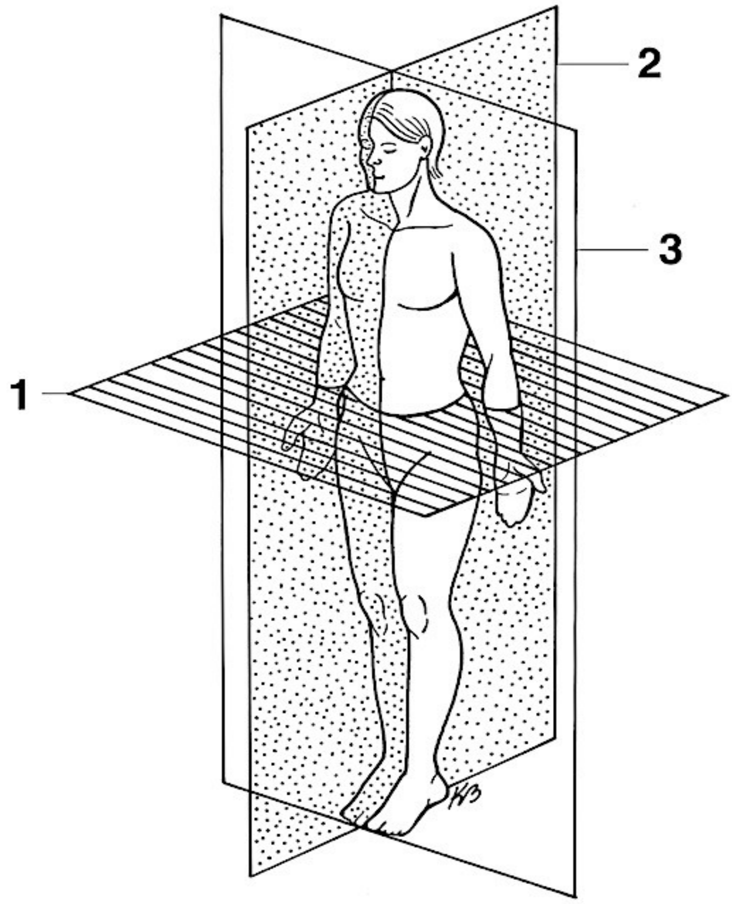


Figure 4. Standard anatomic planes:

1- Transverse plane; 2 – Sagittal plane; 3 – Coronal plane (https://www.dummies.com).

The core operating principle of CBCT relies on the rotational movement of a gantry containing both an X-ray source and an image detector. As this gantry rotates, a conical X-ray beam is emitted, passing through the patient, and encompassing the entire Field of View (FOV) during the scan. Within the rotational plane of the FOV, tissues are exposed in a sequential manner as the conical beam sweeps across the predetermined angular range. This systematic acquisition of raw-data projection images serves as the basis for the reconstruction of the final three-dimensional CBCT image dataset. (Kaasalainen et al., 2021).

Figure 5 introduces schematically the principle of CBCT: an X-ray tube projects a beam through the patient, and a detector positioned on the opposite side measures the radiation that have been attenuated by passing through the body's tissues.

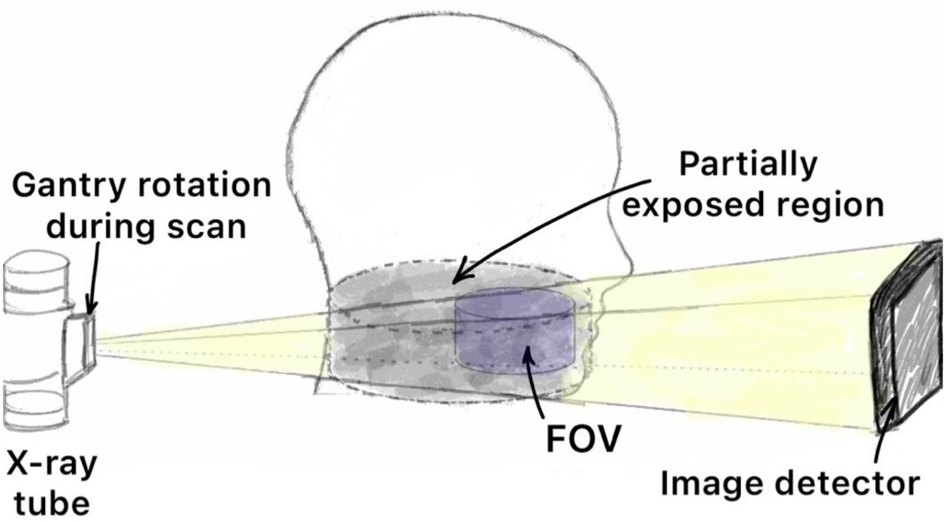


Figure 5. The principle of CBCT functioning (adapted from Kaasalainen et al., 2021).

3.2.2. Application, Radiation Dose

The increasing use of 3D imaging through CBCT in dental medicine, which exposes patients to higher radiation doses compared to traditional 2D imaging, has highlighted the need for radiation dose protection. This has become a significant focus in recent years. Significant variations in radiation dose levels exist among CBCT devices from different vendors and even within the same scanner models. Therefore, to achieve the best possible image quality while minimizing radiation exposure, the imaging protocol should be tailored to each individual patient. This involves considering various factors including the most suitable imaging modality, X-ray tube voltage and current, filtration, exposure time, field size, and voxel size. In modern devices, there is a growing trend towards adopting low-dose protocols. A key principle in radiation dose protection is the application of the "As Low as Reasonably Achievable (ALARA)" principle, introduced by the International Commission on Radiological Protection (ICRP) in 1977 (Abdelkarim, 2019).

In 2014, at the National Council on Radiation Protection and Measurements (NCRP) (https://ncrponline.org) Annual Meeting, Dr. Jerrold Bushberg proposed the concept of justifying the use and minimizing radiographic exposures to levels that are diagnostically acceptable. This suggests a shift from the traditional ALARA principle to ALADA, which stands for "As Low as Diagnostically Acceptable." It emphasizes the importance of dose optimization in medical diagnostic imaging (Yeung et al., 2019). Introduced in 2018, The European DIMITRA project (Dentomaxillofacial Paediatric Imaging: An Investigation Toward Low-Dose Radiation Induced Risks) focuses on enhancing pediatric doses and exploring strategies for optimizing dentomaxillofacial pediatric images. The DIMITRA consortium therefore proposes to move from ALARA and ALADA toward ALADAIP (As Low as Diagnostically Acceptable being Indication-oriented and Patient-specific) (Oenning et al., 2018).

CBCT systems provide diverse FOV options, each tailored to specific diagnostic needs. Broadly categorized as large, medium, or small. These FOVs determine the extent of anatomical coverage in the resulting 3D image. A large FOV, often exceeding 10 cm in diameter and height, encompasses maxillofacial structures beyond the oral cavity, such as the maxillary sinus floor. In contrast, a medium FOV, typically ranging from 8 cm x 5 cm to 10 cm x 10 cm, is designed for imaging dentoalveolar areas, capturing either one or both jaws. Lastly, a small FOV, usually less than 8 cm x 5 cm, is employed for localized imaging, concentrating on a few adjacent teeth and their surrounding bone (Yeung et al., 2019) (Table 1). The exact dimensions of each FOV category vary among CBCT devices and manufacturers.

Table 1. Fields of view and their basic characteristics.

Field of View (FOV)	Capturing size (diameter × height)	Description
Small FOV	below 8 × 5 cm	Focuses on a localized area, typically involving several adjacent teeth, periapical regions.
Medium FOV	ranging between 8 × 5 and 10 × 10 cm	Used for dentoalveolar regions, capturing one or both jaws.
Large FOV	exceeding 10 × 10 cm	Captures maxillofacial structures beyond the oral cavity (ex. maxillary sinus floor and surrounding areas).

Research investigating the effective radiation dose, measured in Sieverts, (Sv) from CBCT scans has revealed considerable variability depending on factors such as the FOV used and the patient's age. Studies indicate that large FOV scans, which encompass a broad area of the maxillofacial region, can result in effective doses ranging from 52 to 1410 μSv (micro SV). Medium FOV scans, typically used to image the dentoalveolar areas, deliver doses between 18 and 674 μSv. Conversely, small FOV scans, which focus on localized areas like a few teeth, expose patients to doses ranging from 11 to 252 μSv. Notably, CBCT scans conducted on children can lead to a wider range of effective doses, spanning from 7 to 769 μSv. When comparing these CBCT dose values to thoseassociated with traditional 2D dental radiography, it becomes evident that even the lowestrecorded CBCT dose (11 μSv) is comparable to a fraction of the dose from a panoramic or cephalometric image. This highlights the importance of careful consideration when selecting the appropriate FOV for a CBCT scan, balancing the diagnostic benefits with the associated radiation exposure (Table 2) (Yeung et al., 2019).

Table 2. Radiation doses (Abdelkarim, 2019; Yeung et al., 2019).

Imaging modalities	**Range of effective dose (μSv)**
Digital panoramic radiograph	6-38
Digital cephalometric radiograph	2-10
CBCT	
small FOV	11–252
medium FOV	18–674
large FOV	52–1410
child protocols	7–769

3.2.3. CBCT in Dental and Orthodontic Practice

CBCT enabling three-dimensional visualization of oral and maxillofacial structures, is a valuable asset in dentistry. Its ability to provide detailed 3D images contributes significantly to accurate and effective diagnose. As a result, CBCT has become a widely used diagnostic tool across various dental specialties.

- *In dental surgery* CBCT plays a pivotal role in implant treatment planning, enabling the assessment of bone quality and quantity, determining the need for augmentation procedures, and evaluating the health or pathology of the maxillary sinus. Incorporating of CBCT scans is recommended for precise planning of orthognathic surgeries and the assessment and planning of jaw asymmetry.

- CBCT imaging serves as a valuable supplement to traditional radiographs in *endodontics*, especially when periapical X-rays fail to provide a clear diagnosis. It is particularly useful for examining extensive dental injuries, evaluating complex root canal systems, and identifying calcifications within the canals.

- *Within periodontology* CBCT finds acceptance in assessing furcation defects, guiding the selection of appropriate treatment modalities and assessment of dentoalveolar vestibular bone thickness .

- *In orthodontics,* CBCT is widely used such in the evaluation of:

  a) 3D craniofacial anatomy including that of root morphology, angulation and inclination of the teeth;
  b) ankylosed, impacted and supernumerary teeth positions;
  c) buccal and lingual cortical plates;
  d) maxillary transverse dimensions and maxillary expansion;
  e) airway morphology;
  f) TMJ morphology and pathology contributing to malocclusion and facial asymmetry;
  g) proposed sites for the insertion of MIs (Abdelkarim, 2019; Kapila & Nervina, 2015).

3.2.4. Software

CBCT images can be analyzed in three dimensions using specialized software, either integrated with the CBCT device or activated through a separate key. The Digital Imaging and Communications in Medicine (DICOM) file format is commonly used to export

CBCT data, enabling these software applications to process and visualize the images in 3D, providing a comprehensive view of the patient's anatomy.

The market offers a wide variety of measurement tools for working with CBCT data, allowing practitioners to extract precise and relevant information for diagnosis and treatment planning. Some of the most popular software applications used in this context include:

- 3D SLICER 4.6® (USA)
- Blue Sky Plan (BlueSkyBio, New York City, USA)
- i-CAT (Imaging Hatfield, USA)
- ITK-Snap (PICSL, USA)
- NETFABB basic 5.0® (USA)
- OsiriX (Pixmeo, Switzerland)
- ProMax® 3D Max CBCT (Planmeca, Finland)

Each software application provides a distinct user experience and specific tools tailored for different dental specialties. For instance, ITK-SNAP focuses on image visualization and segmentation, enabling manual or semi-automatic outlining of specific anatomical structures, which is particularly useful for research purposes. OsiriX®, a versatile platform widely used in medical imaging, boasts a user-friendly interface and can reconstruct various types of 3D images, making it suitable for general diagnostic purposes. 3D SLICER 4.6®, another medical imaging software, facilitates 3D visualization and processing of images, allowing for detailed analysis of complex structures. NETFABB basic 5.0®, on the other hand, is specifically designed for repairing and printing 3D models, which can be used for surgical planning or patient education.

In the realm of dental implantology, Blue Sky Plan stands out as a free software solution for implant planning and surgical guide design. This software enables clinicians to virtually plan implant placement, assess bone quality and quantity, and design custom surgical guides based on the patient's CBCT data, ultimately improving the accuracy and predictability of implant surgeries (Abdelkarim, 2019; Asymal et al., 2022).

3.3. Orthodontic MIs

MIs are small, temporary devices used in orthodontic treatment to enhance anchorage, offering stability during tooth movement. In orthodontic treatment, applied forces on teeth generate opposing forces of equal magnitude. Managing these reciprocal forces is crucial, and MIs provide reliable anchors for orthodontic forces. Two primary anchorage methods utilize MIs:

- *Indirect anchorage:* In this method, MIs are strategically placed to support the teeth of the reactive unit – the teeth that would otherwise experience unwanted movement due to reciprocal forces. This approach minimizes unintended tooth movement, allowing for more controlled and predictable orthodontic corrections.

- *Direct anchorage:* In contrast, direct anchorage involves using MIs as independent anchors. By directly attaching orthodontic appliances to the MIs, the need for a reactive unit is eliminated altogether. This provides absolute anchorage, as the MIs are fixed to the bone and do not rely on the stability of other teeth (Nanda R et al., 2021).

3.3.1. Indications

Key indications for using MIs in clinical practice include:

- Providing anchorage for en-masse retraction and canine retraction.
- Molar distalization /mesialization; uprighting and extrusion of impacted molars.
- Intrusion of anterior or posterior teeth or the whole upper dental arch.
- Correction of occlusal cant and dental midline.
- Skeletal orthopedic correction of class 2 and class 3 malocclusions.

- Usage MIs with expansion appliances in patients who passed the age of using orthopedic expansion devices (sutural separation).

- Other different indications include intermaxillary fixation (IMF) during orthognathic surgeries (Umalkar et al., 2022).

3.3.2. Types and Structure

Orthodontic MIs are constructed from non-destructive, biocompatible materials, ensuring safe placement and temporary stability within bone tissue. Unlike dental implants, MIs rely on mechanical retention rather than osseointegration for anchorage. Their surfaces are highly polished to minimize bone bonding, facilitating easy removal after orthodontic treatment. While both Titanium Alloy (Ti-6Al-4V) and Stainless Steel (SS) are commonly used materials for MIs due to their lack of osseointegration properties, there is ongoing debate regarding their relative merits. Some researchers advocate for titanium alloys, while others favor surgical stainless steel for its superior modulus of elasticity, which enhances resistance to fracture (Nanda et al., 2021).

The majority of orthodontic MIs are composed of stainless steel and type IV or type V titanium alloy. Both stainless steel and titanium alloys have the potential to be clinically appropriate for infra-zygomatic crest (IZC) and buccal shelf (BS) implants with an overall success rate of 93.7% and both are able to achieve the basic biomechanical requirements. However, the occurrence of fracture during placement is greatly diminished by the distinctive structural properties of stainless-steel bone screws, including their exceptional ability to withstand bending forces and resist shearing. Predrilling is unnecessary before inserting the stainless-steel bone screw due to its pointed tips (Ghosh, 2018).

Table 3 demonstrates the key differences between Titanium Alloy and Stainless Steel when used as materials for orthodontic MIs.

Table 3. Comparison of Titanium Alloy and Stainless Steel as materials for microimplants.

Feature	Titanium Alloy (Ti-6Al-4V)	Stainless Steel (SS)
Biocompatibility	Yes	Yes
Osseointegration	No	No
Mechanical Retention	Yes	Yes
Surface Finish	Highly polished	Highly polished
Removal	Easy	Easy
Modulus of Elasticity	Lower	Higher
Fracture Resistance	Lower	Higher
Need for Predrilling	May be necessary	Not necessary

Orthodontic MIs are smaller in size compared to prosthetic dental implants, ranging from 1.15 mm to 2.5 mm in diameter and from 4 mm to 12 mm in length (Baxi et al., 2023). MI consists of three primary components: the head, neck, and screw thread (Figure 6). Each component serves a specific function, contributing to the overall efficacy of the MI in providing anchorage during orthodontic treatment.

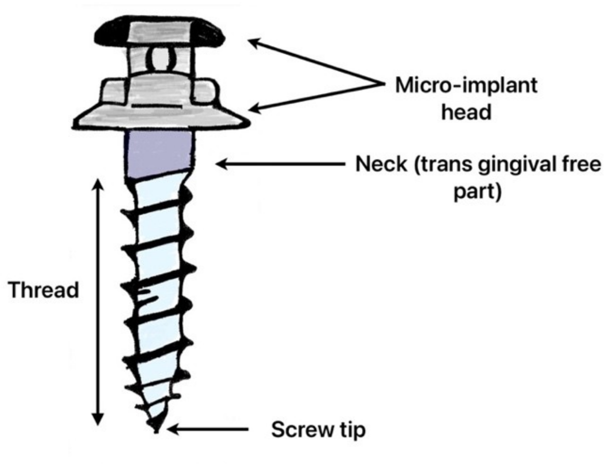


Figure. 6. Parts of orthodontic microimplant.

The MI head

A part of MI remains in the oral cavity above the gingival tissue and keeps the springs and rubber bands in place. The head provides a point of attachment to engage the MI driver during the installation procedure and to ligate elastics and wires. Various types of heads are available that provide different kinds of anchoring and prevent irritation of the soft tissues. The most widely used design is a button-like design with a sphere, double sphere-like or hexagonal shape. Depending on the specific clinical task, the most suitable shape of the MI head is selected. (Table 4). For direct anchorage, a hole of 0.8 mm diameter in the head or neck of the screw is typically preferred. Additionally, designs with a loop and a collared neck may be applied. This component varies depending on the manufacturer. Apart from that, the screw head has a collar or hole for various attachments (Baxi et al., 2023).

Table 4. Different head types of microimplants.

Head Type	**Characteristics**
Small head	Discreet and suitable for limited space scenarios.
Long head	Offers increased surface area for force distribution, enhancing stability.
Circle head	Provides versatility for force application from various angles.
Fixation head	Aids in securing auxiliary components and supporting complex orthodontic movements.
Bracket head	Allows direct attachment of archwires, mimicking traditional brackets for force application.
Hook head	Provides attachment points for elastics or other auxiliary elements, expanding treatment possibilities.

The MI neck

Also known as the transmucosal portion, it connects the head to the screw and extends through the soft tissue. Different neck lengths are available to suit varying mucosal thicknesses. The neck's surface is smooth and well-polished to avoid plaque buildup and debris accumulation. This region is critical as it forms the interface between the implant and the mucosa, and many implant failures and inflammatory problems originate from this area (Joseph et al., 2020).

MI Screw/Thread

The screw, a crucial structural component of the orthodontic MI, achieves retention through mechanical integration within either cortical or medullary bone. The stresses exerted during insertion, as well as the required amount of insertion torque, are directly influenced by the depth and angle of the screw's cutting edge, which is located on the thread encircling the main body or shank of the mini-screw. This cutting edge plays a pivotal role in facilitating the smooth and efficient placement of the MI into the bone. The screw's thread design can be either conical, resembling those found in dentalimplants, or parallel with a tapered end, a configuration unique to orthodontic MIs. The overall length of the MI is determined by summing the lengths of its components, including the head, neck, and screw. Screw pitch, defined as the distance between two adjacent threads, is a crucial factor influencing the MI's insertion characteristics. Threadsthat are widely spaced exhibit a high pitch, while closely spaced threads have a low pitch.Notably, screws with a higher pitch offer several advantages. They can be inserted morerapidly and efficiently, minimizing patient discomfort and reducing chair time for the clinician. Additionally, high-pitch screws tend to generate less heat during insertion, further enhancing patient comfort and reducing the risk of thermal injury to surroundingtissues (Joseph et al., 2020).

3.3.3. Anatomical sites for placement of MI

A critical factor in the successful application of MIs for orthodontic tooth movement is their surgical placement, which must avoid causing damage or injury to nearby structures. To achieve atraumatic insertion, various factors need to be meticulously considered, such as the condition of the soft tissue at the implant site, the underlying bone and tooth anatomy, the distance between tooth roots at the MI site, and the proximity to vital anatomical structures. The interradicular space between two teeth is a frequently chosen location for MI insertion due to its accessibility and favorable bone quality. However, other potential sites for MI placement have been proposed, including the palate, maxillary tuberosity, anterior ramus, and the retromolar areas of the mandible (Nanda R et al., 2021).

MIs can be placed in extra-alveolar sites like the IZC and BS. This technique not only reduces the risk of root contact but also enhances immediate stability due to the denser bone in these areas of the maxilla and mandible. However, this placement can lead to the implants being situated within the mobile alveolar mucosa. To address this issue, trans-mucosal attachments can be used, providing a more stable connection to the underlying bone and reducing the risk of implant mobility (Joseph et al., 2020).

3.3.4. Insertion technique of MI

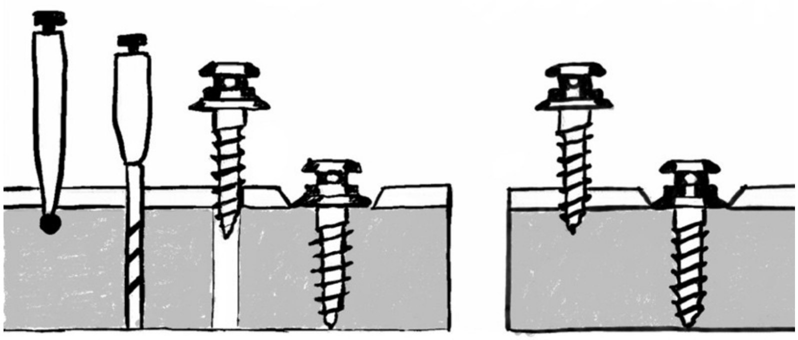
MIs can be categorized by their screw type, which dictates their insertion method. These can be self-drilling, which bore their own path, or self-tapping, which thread into pre-made holes (further subdivided into thread-forming and thread-cutting) (Table 5). Modern clinical practice has evolved to utilize advanced techniques for MI placement. This includes 3D CBCT imaging and the creation of personalized surgical guides through stereolithography, which significantly improves the accuracy of placing self-drilling MIs near sensitive structures like tooth roots and maxillary sinuses. Prior to implant placement, adjustable acrylic templates or surgical guides can be used to ensure proper positioning (Nanda R et al., 2021 ; Joseph et al., 2020; Miyazawa et al., 2010).

Table 5. Types of microimplants insertion techniques.

Screw Type	**Description**
Self-drilling	Incorporates a drill bit and can penetrate bone without pre-drilling
Self-tapping	Creates threads as they are inserted, aiding in stable fixation
Thread-forming	Shapes bone as they are inserted, optimizing implant stability
Thread-cutting	Engages with bone threads to enhance anchorage

MIs can be classified into two main types based on their insertion mechanism: self-tapping and self-drilling (Figure 7). Self-tapping MIs necessitate a pre-drilling step under local anesthesia to create a pilot hole. This procedure involves using a soft tissue punch to excise the tissue at the implant site, followed by a careful drilling of a pilot hole with a drill bit rotating at a speed not exceeding 1000 rpm. The pilot hole's depth is typically limited to 2-3mm, and its diameter should be 0.3mm smaller than that of the screw. Once the pilot hole is prepared, the self-tapping MI is inserted using an appropriate screwdriver.

In contrast, self-drilling MIs are designed with specialized tapered tips and cutting flutes that allow them to be directly inserted into the bone without the need for pre-drilling. This innovative design offers several advantages, including a reduced risk of complications such as damage to tooth roots or developing tooth germs. Additionally, it minimizes the chances of thermal necrosis of the bone, which can occur due to excessive heat generated during drilling. Furthermore, the self-drilling mechanism eliminates the risk of drill bit fracture during insertion, enhancing the overall safety and efficiency of the procedure (Kalra et al., 2013).



a) ***b)***

Figure 7. Self-taping (a) and self-drilling (b) microimplants (adapted from Joseph et al., 2020).

There are two primary methods for securing MIs in the jawbone: monocortical and bicortical. Monocortical placement involves anchoring the screw into either the vestibular or lingual cortical plate of the alveolar bone. In contrast, bicortical placement spans the entire width of the alveolus, engaging both cortical plates (Figure 8). Research suggests that the bicortical method provides orthodontists with greater anchorage resistance, reduced stress on the cortical bone, and improved stability compared to the monocortical technique (Brettin et al., 2008).

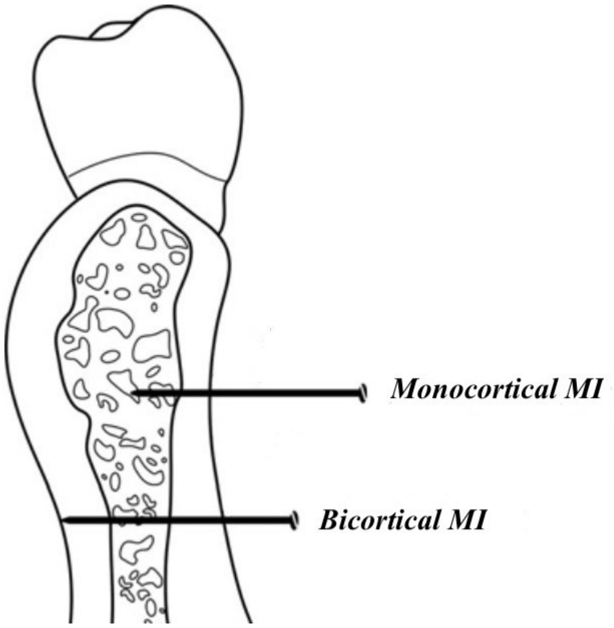


Figure 8. Mono- and bicortical microimplants placement (adapted from Brettin et al., 2008).

The choice between monocortical and bicortical MI insertion depends on various factors, including the desired degree of anchorage, bone quality and quantity at the implant site, and the complexity of the orthodontic treatment plan. However, each method offers distinct advantages and disadvantages that should be considered (Table 6).

Table 6. Comparison between mono- and bicortical microimplants insertion techniques.

Insertion Technique	Placement	Advantages	Disadvantages
Monocortical	Engages either facial or lingual cortical plate	Less invasive, reduced risk to vital structures, suitable for thinner bone	Lower primary stability, increased risk of loosening or failure under high loads
Bicortical	Engages both vestibular and lingual cortical plates	Superior primary stability, enhanced anchorage resistance, reduced stress on cortical bone	More invasive, requires sufficient bone thickness, slightly higher risk to vital structures

As the Table 6 illustrates, monocortical insertion is less invasive and poses a lower risk to vital structures, making it suitable for areas with thinner bone. However, it offers lower primary stability and may be more prone to loosening or failure under high orthodontic forces. On the other hand, bicortical insertion provides superior primary stability and anchorage resistance, reducing stress on the cortical bone. However, it is a more invasive procedure and requires adequate bone thickness for successful placement (Holberg et al., 2014; Yan et al., 2023).

The selection of monocortical versus bicortical insertion for orthodontic MIs is contingent upon multiple factors, including the anatomical location and the anticipated magnitude of force application. In regions such as the maxillary and mandibular buccal shelves and interradicular spaces monocortical insertion is frequently employed. These anatomical sites generally exhibit adequate cortical bone thickness to ensure sufficient primary stability upon MI placement. Conversely, bicortical insertion may be favored in regions like the IZC zone, hard palate, mandibular symphysis, and retromolar pad. These areas are often characterized by increased cortical bone density or necessitate higher force levels for effective orthodontic anchorage. Furthermore, the specific type of orthodontic tooth movement and the corresponding force system can also influence the choice between insertion techniques. For instance, movements requiring greater force vectors, such as molar intrusion or distalization, may necessitate bicortical anchorage for optimal stability and predictable outcomes. Consequently, clinicians should carefully consider the biomechanical implications of each insertion technique, selecting bicortical anchorage when greater force resistance and stability are paramount (Brettin et al., 2008; H. Chang & Tseng, 2014; Yan et al., 2023).

3.3.5. Success and failure rate

The success or failure rate of MIs can vary depending on several factors, such as the clinical case, the type of MI utilized, its specific location, and the precision of its placement. Achieving an optimal stability for MIs involves selecting a position with specific bone characteristics, particularly considering the thickness of the cortical and overall jawbone. This information is crucial as it highlights the significance of bone quality and quantity when choosing a MI placement site (Leo et al., 2016).

Dalessandri et al. (2014) highlighted the factors that could influence MIs stability and classified them as *patient-related, implant-related,* and *management-related* (Table 7).

Table 7. Factors influencing microimplant stability (Dalessandri et al., 2014; Zhao et al., 2023).

Factors	**Significance and Impact**
Patient-Related	
Age	Lower success rate in individuals below 20, potentially due to lower bone density and thinner cortical bone.
Bone density	Higher density contributes to better mechanical retention and stability of MIs.
Thickness of cortical bone	Thicker cortical bone enhances the mechanical retention of MIs.
Hygienic care	Inadequate care can lead to peri-implant inflammation and failure of MIs.
Smoking habit	Increases the risk of complications, including mucositis, peri-implantitis, and implant loss.
Implant-Related	
Type of MI	Mini-plates offer better stability but require flap surgery and can lead to postoperative complications.
Thread shape	Thread design significantly influences MI insertion torque and removal torque, an important indicator of its stability.
Management-Related	
Pre-drilling	When the pilot hole is narrower than the screw diameter, no failures were reported.
Oral microbiome	Differences in microorganisms on successful and failed MIs highlight the importance of controlling bacterial adhesion.

Statistical analysis has identified several factors influencing the success of Mis in orthodontics. Patient age, particularly under 20, is associated with lower success rates, likely due to the dependence of MI stability on mechanical retention, which is impacted by bone density and cortical thickness. Oral hygiene is crucial, as inadequate hygiene can lead to peri-implant inflammation and subsequent MI failure. Furthermore, smoking significantly increases the risk of complications like mucositis, peri- implantitis, and implant loss. In terms of implant-related factors, mini-plates offer superior stability compared to MIs, although their use necessitates flap surgery.

Regarding management-related factors, a notable finding from an animal study review by Cornelis et al. revealed that pre-drilling a pilot hole narrower than the screw diameter may improve success rates compared to direct screw insertion (Dalessandri et al., 2014).

The success of MIs is also influenced by the oral microbiome. Significant differences in the composition and function of microorganisms colonizing successful and failed MIs highlight the need for strategies to control bacterial colonization and improve clinical outcomes (Zhao et al., 2023). Furthermore, immediate loading of MIs has demonstrated superior success rates compared to delayed loading and can effectively withstand forces up to 250 grams with a high degree of success (Aly et al., 2018).

Proper MI placement is highly important for MIs clinical success during the orthodontic treatment process. To maximize the retention and effectiveness of palatal MIs, it's crucial to insert them perpendicular to the hard palate's surface while angling them towards the incisor roots. Moreover, palatal MIs should be inserted perpendicular to the hard palate and angled towards incisor roots for optimal retention and function. While the MPS may appear suitable due to its bone density, research findings on its efficacy are inconclusive. The median suture has a thick vertical bone layer, but its thickness can vary. Additionally, midpalatal MIs often fail in adolescents due to insufficient ossification and avoiding midpalatal regions in young patients is recommended. Conversely, anterior palate implants, both medial and paramedian to the midpaltine suture, showed considerable success. Wehrbein et al. introduced a successful implant system for the anterior palate, later demonstrating its effectiveness in complex orthodontic procedures like en-masse retraction of upper anterior teeth with a 100% success rate. Subsequent studies by Park and Wilmes et al. have further confirmed the high success rates and stability of MIs and miniplates in this region. Kim et al. reported a slightly lower success rate (88.2%) for MIs specifically placed within the palatal suture. Figure 9 illustrates the suitability of various palatal zones for MI insertion. Green zones indicate optimal sites, while yellow areas are restricted due to individual variations in bone thickness. Red zones are unsuitable due to the presence of thick mucosa or vascular bundles. The blue dot marks the incisive foramen (Ludwig et al., 2011).

Figure 9. Suitability of various palatal zones for microimplant insertion (Ludwig et al., 2011).

3.4. Palatal MIs

MIs are increasingly utilized in orthodontic practice due to their versatile biomechanics, minimal invasiveness, and cost-effectiveness. They offer innovative solutions for various treatment goals, such as molar distalization, mesialization, molar intrusion, extrusion of impacted teeth, midline correction, anterior and buccal anchorage etc. Despite their common insertion site being the alveolar process, which has an average failure rate of 16.1% due to variable bone and soft-tissue conditions, the anterior palate emerges as a favorable alternative. This location allows for the placement of a larger and a more stable MIs in an area characterized by high bone quality, thin, soft tissue, and minimal risk of root damage or interference with teeth (Wilmes et al., 2016).

3.4.1. Indications and contraindications for palatal expansion treatment with MIs

Palatal expansion with MIs is indicated in adolescence usually after 15 years of age. Orthopedic force for expansion is theoretically efficacious in patients up to 20 years of age exhibiting minimal suture obliteration (obliteration index ≤0.5). However, successful expansion may be achievable in patients up to 25 years of age when utilizing a 5% suture closure threshold. It is noteworthy that the rate of suture closure accelerates rapidly beyond 25 years of age. While skeletal and dental expansion ratios remained consistent between early and late adolescents (11-19 years of age), the contribution of skeletal expansion to overall treatment outcomes decreased with increasing age. Regarding the sex, there is no significant difference observed in the success rate of MPS opening between males and females (Jia et al., 2022).

Among the most common indications for palatal expansion with MIs are:

- molar distalization / mesialization
- molar intrusion / extrusion
- anterior en-masse retraction
- traction on impacted canines or premolars
- posterior cross bite
- V-shaped and constricted upper jaw
- Obstructed Sleep Apnea (OSA) in adults

Modern orthodontics proposes also a big variety of techniques and appliances which provide stable anchorage using palatal MIs for molar distalization, like *Frog appliance* or *Beneslider* (Figure 10) (Ludwig et al., 2011).

Figure 10. TADMAN ® Beneslider for molar distalization (https://www.tadman.de)

In addition, special attention should be paid to the OSA treatment. OSA, characterized by partial or complete upper airway blockage during sleep, leads to breathing interruptions and decreased oxygen levels. These disturbances can contribute to serious health issues such as hypertension, cardiovascular problems, mental health disorders, type 2 diabetes, kidney dysfunction, and even glaucoma. Prompt treatment is crucial upon diagnosis. RPE is an adjunctive therapy for pediatric OSA, effectively widening the nasal cavity and oropharynx by separating the MPS. This expansion, measured by rhinomanometry and acoustic rhinometry, has been shown to reduce airflow resistance and significantly improve breathing function (Brunetto et al., 2022).

In the context of the adult population, Surgically Assisted Rapid Palatal Expansion (SARPE) has demonstrated positive outcomes, including an augmentation in nasal cavity volume and functional enhancements in breathing. Recent research suggests that skeletal expansion, previously thought to require surgery, can also be achieved in young adults without surgical intervention. This non-surgical approach is known as MI Assisted Rapid Palatal Expansion (MARPE). Among the various MARPE techniques, Maxillary Skeletal Expansion (MSE) has emerged as a promising solution. Studies have demonstrated its effectiveness in correcting maxillary transverse deficiency in non-obese young adults, with a success rate of 85%. This non-surgical alternative offers a less invasive option for patients who may have previously required surgery to address this condition. Given its efficacy, MSE, either as a standalone treatment or in conjunction with other therapies, may be considered a valuable adjunctive treatment for OSA in non-obese young adults who also present with maxillary transverse deficiency (Brunetto et al., 2022; Cantarella et al., 2017).

The utilization of orthodontic MIs is subject to several contraindications that warrant careful consideration prior to their application. These include systemic conditions that may impair healing, such as uncontrolled diabetes or autoimmune disorders, as well as compromised immune function due to medication or underlying disease. Patients with bleeding disorders, poor bone quality or insufficient bone volume, and inadequate oral hygiene practices are also not ideal candidates for MI placement. Furthermore, lifestyle factors can significantly influence the success of MIs. Notably, heavy smoking has been identified as a major risk factor, as it can compromise vascularity and impede the healing process, leading to an increased likelihood of implant failure. Therefore, a thorough assessment of the patient's medical history, current health status, and lifestyle habits is essential to determine their suitability for MI therapy and to optimize treatment outcomes (H. P. Chang & Tseng, 2014).

3.4.2. MIs placement in the T-Zone

Wehrbein et al. (1996) first reported the placement of MIs in the T-zone, the area immediately posterior to the palatal rugae. This location has since been recommended as a preferred site for orthodontic MIs due to sufficient palatal bone height and keratinized gingiva. (Chang et al., 2021).

Wilmes et al. (2016) also identify T-zone as an ideal location for the insertion of MIs, highlighting the advantages of this region, such as bone volume, soft tissue thickness, and distance from vital structures. T-Zone has sufficient bone volume and high bone quality, which are crucial for the stability and retention of MIs. The soft tissue overlying the T-Zone is relatively thin, making the insertion procedure easier andreducing the risk of complications. This anatomical region of the palate is located away from critical structures like tooth roots, minimizing the risk of damage during insertion. The T-zone allows for both median and paramedian insertion of MIs, providing flexibilityin treatment planning depending on the specific orthodontic needs of the patient. Figure11 shows projection of the T-zone onto the palate, a region posterior to the third palatal rugae.

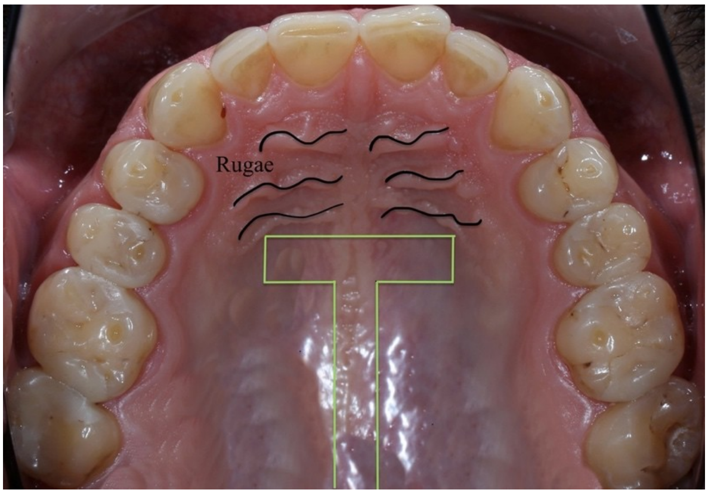


Figure 11. T-zone on the palate (highlighted with a green outline).

Insertion of the MIs in the anterior segment of the palate presents significant advantages. The favorable anatomical conditions, including the relative absence of vital anatomical structures, adequate bone volume, and sufficient keratinized gingiva, suggest a definitively lower failure rate for MIs insertion compared to inter-root insertion. (Iodice et al., 2022).

3.4.3 Midpalatal MIs

Orthodontic anchorage can be achieved by placing an immobile implant in the palatal midline or midpalatal zone between premolars, However, successful implant placement in the palatal midline requires adequate supporting bone. Schlegel et al. (2002) studied the ossification of the MPS in cadavers across three age groups: 12-22, 23-30, and 31-50 years. Their findings revealed that MPS ossification was not observed in any females, and the youngest male with ossification was 23 years old. Additionally, no synostosis was found in males under 23 years old. This suggests a potentially higher clinical failure rate for palatal implants in females. Moreover, the MPS tends to decrease in size with age due to ossification, starting no earlier than 17 years old, implying an increased risk of implant failure in patients under 17 (Chang et al., 2021).

3.4.4 MSE and MARPE

Transverse maxillary constriction, a prevalent dentofacial anomaly, is frequently characterized by a unilateral or bilateral posterior crossbite. This anatomical discrepancy can precipitate a cascade of complications, including a constricted and high-vaulted palate, dental crowding, excessive vertical alveolar development, prominent buccal corridors, dental attrition, periodontal compromise, and facial muscle imbalances. Rectifying this deficiency is paramount for establishing of optimal occlusion and a harmonious transverse skeletal relationship. Rapid Palatal Expansion (RPE) has demonstrated efficacy in ameliorating transverse maxillary constriction in pediatric and adolescent patients (under 15 years). The RPE-hyrax appliance exerts bilateral forces through an expansion screw to the maxillary first molars and premolars, indirectly inducing separation of the MPS, which remains malleable in this age cohort. However, treating late adolescents and adults necessitates a greater magnitude of force to achieve MPS disjunction due to the increased interdigitation that occurs with age. In these instances, using MARPE may be the preferred therapeutic modality. MARPE employs either a tooth-bone-borne or solely bone-borne RPE appliance with a rigid component that interfaces with palatal mini-implants. This configuration facilitates the direct transmission of the expansion force to the basal bone of the maxilla, thereby maximizing skeletal expansion while mitigating undesirable dental and alveolar effects (Kapetanović et al., 2021).

A multitude of appliance designs and protocols have been introduced to facilitate MARPE therapy. Recent investigations employing this approach documented a success rate of 86.96% in a cohort of young adult patients (mean age = 20.9 ± 2.9 years), with stability maintained over a 30-month follow-up period (Brunetto et al., 2017).

Among different types of appliances available for rapid palatal expansion used in non-growing patients, MSE, developed and improved by Dr. Won Moon and colleagues, has become a preferable method of treatment for orthodontists in daily practice (Figure 12).

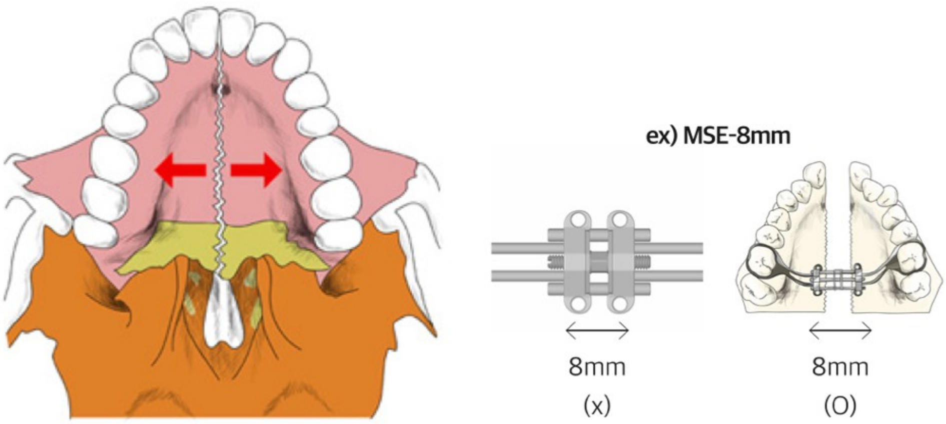


Figure 12. Maxillary Skeletal Expansion appliance, 8mm (https://www.moonmse.com)

The clinical steps (as well as the manufacturing process of the MSE appliance in the laboratory) closely resemble those of a conventional Hyrax expander (Table 8).

Table 8. Protocol for Maxillary Skeletal Expansion appliance insertion.

Appointment	Procedures
Initial	Comprehensive explanation of the procedure, placement of separator elastics on the maxillary first molars.
Second	Removal of separators, oral prophylaxis, placement of bands, alginate impression, reinsertion of separators.
Third	Removal of separators, topical anaesthetic application to the palate, cementation of the appliance, verification of vertical positioning, infiltrative anaesthesia, placement of self-drilling MIs with immediate expander activation, post-operative instructions.

Follow-up care for MSE necessitates more frequent appointments than conventional expansion due to potential difficulties with self-activation of the expander and the need for professional adjustment. Each visit should include an evaluation of the distance between the expander and mucosa, as close proximity can induce inflammation. Regular assessment of MI stability is imperative, and any mobile implants should be promptly removed. MARPE has demonstrated clinical efficacy in young adults with transverse maxillary deficiency, achieving 2mm of stable skeletal suture separation during retention (Brunetto et al., 2017; Choi et al., 2016).

3.5. Precedent studies

Table 9 shows the most important previously undertaken similar studies to the present investigation, that evaluated palatal bone thickness in different populations using CBCT scans. None of the studies is identical to the present research, however, there are some similar objectives and points, which are set out and summarized.

Following reviewing the literature, we found five studies addressing similar research questions to our study where the most suitable position for MIs placement in the palatal bone was assessed. Those studies were retrospective undertaken on orthodontic cohorts using CBCTs. None of the studies found investigated a Portuguese population.

Table 9. Summary of previous studies that evaluated the palatal bone thickness in the different populations using 3D imaging.

AUTHORS	OBJECTIVES	POPULATION INVESTIGATED	METHODOLOGY	RESULTS
Nakahara et al., (2012)	To assess optimal locations for orthodontic mini-implant placement in the palate, considering safety and stability.	Palates of five Japanese adult cadavers and 15 Japanese adult skulls.	3D measurements of the bony palate, cortical bone thickness, and internal bone structure analysis using micro-computed tomography (micro-CT).	The MPS region is ideal for MI placement due to its thickness. However, bone thickness decreases laterally, requiring caution when placing implants in the lateral MPS.
Jayakumar et al., (2012)	To evaluate the 3D mean palatal bone thickness, to determine the best location for mini-implant anchorage, compare palatal bone thickness differences between sexes and age groups.	60 Indian subjects (30 males, 30 females) divided into two age groups (15-24 years and 25-35 years).	3D reconstruction of CT scan data using "MIMICS" software. Measurements taken at various points on the palate in coronal view.	Significant variations were observed in the thickness of the palatal bone for both groups tested, with the anterior region at 4 mm behind the incisive papilla showing the maximum thickness.
Al-Hafidh et al., (2020)	To assess cortical bone thickness in the maxilla and mandible and investigate its	Eastern Mediterranean young adults. CT images of 50 patients aged 18-35 years (25	Measurement of buccal, palatal, and lingual cortical bone thickness at 2, 4, 6, and 8 mm from the cemento-	The value of palatal cortical bone thickness was found to be at the highest rate

	association with different orthodontic implant positions.	males, 25 females).	enamel junction at 26 inter-radicular sites using “BlueSky Plan 4” software. Statistical analysis performed using t-tests and Pearson correlation.	mesial to canine and first premolar in males and females respectively.
Jafar et al., (2016)	To measure labial and palatal alveolar bone thickness and height of the labial and palatal surfaces of maxillary anterior teeth in a Saudi population using CBCT.	108 maxillary CBCT scans from 30 Saudi patients.	|CBCT scans were used to measure labial and palatal alveolar bone thickness at three levels (cervical, middle, and apical) and vertical bone height (distance from cemento-enamel junction to alveolar crest).	Labial bone plate was thinner than palatal plate in all cases. Vertical bone loss was more severe on labial surfaces. Females had less bone thickness in the apical and middle thirds than males. Older patients (>40 years) had increased vertical bone loss compared to younger patients.
Suteerapon gpun et al., (2018)	To compare palatal bone thickness in Thai patients with Class I malocclusion and normal or open vertical skeletal configurations using CBCT.	30 Thai orthodontic patients (15-30 years old) with Class I malocclusion, divided into normal-bite and open-bite groups.	CBCT images were used to measure palatal bone thickness in a 3.0-mm grid pattern on both sides of the palate.	Palatal bone thickness was lower at almost all sites in patients with open bite compared to those with normal bite. Significant differences were found at 3,6, and 9 mm lateral to MPS.

The reviewed studies offer valuable insights into palatal bone thickness and its implications for orthodontic MIs placement. However, some studies have methodological limitations, such as small sample sizes (Nakahara et al., 2012; Suteerapongpun et al., 2018) and insufficient control for factors like age and sex (Al-Hafidh et al., 2020), which might had influenced the investigations results and limited the generalizability of the findings. Despite these limitations, the collective analysis of studies reveals that palatal bone thickness varies considerably among individuals and across different insertion sites.

Nakahara et al. (2012) investigated the palatal bone as a site for orthodontic MIs. The authors used micro-CT to take 3D measurements of the bony palate and cortical bone thickness in 5 Japanese adult cadavers and 15 Japanese adult skulls. The study found that the MPS region is ideal for MIs insertion. While this investigation provides valuable insights into the palatal bone for orthodontic MIs placement, it has some limitations. The sample size was small (n=20) and consisted of cadaver skulls, which may not accurately represent real patients. Al-Hafidh et al. (2020) investigated buccal, palatal and lingual cortical bone thicknesses in the alveolar process of the maxilla and mandible using CT scans in 50 Eastern Mediterranean patients aged 18-35 years. The sample size was limited to young adults, which may not be generalizable to other age groups. Finally, Alsaffar et al. (2016) and Suteerapongpun et al. (2018) both investigated bone thickness in the maxilla using CBCT. Alsaffar et al. (2016) focused on the alveolar bone surrounding the front teeth in a Saudi Arabian population, while Suteerapongpun et al. (2018) examined the palatal bone in Thai orthodontic patients. These studies provide valuable insights into bone thickness in specific populations and have clinical implications for MI placement in orthodontic practice. However, studies had small sample sizes (30 patients in each), which may limit the generalizability of their findings.

Additionally, previously undertaken similar studies review reveals a consistent methodological limitation in investigations assessing palatal bone thickness across diverse populations: the absence of rigorously calculated sample sizes. This deficiency raises significant concerns regarding the statistical power of those investigations, thereby undermining the confidence with which their findings can be generalized to broader populations.

II. MATERIALS AND METHODS

1. Investigation methodology

In order to carry out this research and its relevant bibliographic review the search strategy used the search engines and databases of PubMed and Google Scholar. Relevant books in the field of orthodontics were also used. Articles available in English and Portuguese were analyzed. The keywords used were: *CBCT in orthodontics, temporary anchorage devices, orthodontic miniscrews, palatal MI, assessment of the palatal bone thickness.*

The present study is part of an applied, quantitative, and descriptive primary investigation aimed at measuring the thickness of the hard palate across various parasagittal positions. It seeks to identify regions with the greatest bone thickness and investigate potential differences in thickness across age and sex groups.

The work comprises two components: a theoretical component, involving a narrative bibliographical review related to the research question, and an investigative component, which includes the assessment of data from CBCT images, its analysis, and interpretation.

This retrospective CBCT-scan-based observational study is reported according to the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines for observational studies. The research protocol was reviewed and approved by the Ethics Committee of the Egas Moniz School of Health and Science (PT-201/23 from 30.11.2023). Informed consent was obtained from all patients before the CBCT scans were performed.

1.1. Setting and participants

In the present investigation, available CBCT maxillary data from patients of various age groups and either sex, treated at Egas Moniz Dental Clinic between January 2023 and March 2024, were analyzed.

The following inclusion criteria were applied:

a) Portuguese patients checked by names and reading the patient records.

b) full upper arch permanent dentition

c) acceptable image quality

The exclusion criteria were patients with:

a) systemic illness or trauma history

b) craniofacial deformities involving the palate

c) cysts, impacted teeth, supernumerary teeth in the palate area

d) absence of upper first molar or a large metal restoration that might affect the quality of the image

e) images where the palate is not fully seen

Only 50 participants met the inclusion criteria. Thus, the study analysed 50 CBCT scans from 23 males and 27 females, between 12 and 51 years old, with permanent dentition. The CBCT images were selected, and samples were categorized into groups based on age and sex:

I. Regarding sex, the samples were divided into “Females” and “Males”.

II. Regarding age, “Adolescents and young adults” (males and females aged 12-25 years), and “Adults” (males and females aged 27 to 51 years).

1.2. Sample size calculation

The recommended minimum sample size for most analysis was 30 (power 80%, alpha=0.05). The achieved power (sensitivity for differences between the different points) with N=50 was practically 100%.

1.3. Image acquisition and processing

All CBCTs were obtained from Planmeca Viso G7 (Planmeca, Helsinki, Finland). The following settings were used: 120 kVp, 5 mA, large field of view (20 cm x 17 cm), exposure time of 30 seconds and slice thickness of 0.45 mm. The 3D images were constructed using the Planmeca Romexis Viewer, version 6.0 software (Helsinki, Finland).

1.4. Standardization and landmarks identification

Prior to analysis, all images were aligned to a standard position. The Incisive Foramen (IF) and Posterior Nasal Spine (PNS) were identified in the axial view, and a reference line was drawn across the MPS. A midsagittal reference line was then projected through the inferior distal margin of the IF and PNS. All following measurements were made perpendicular to this established reference line (Figure 13).

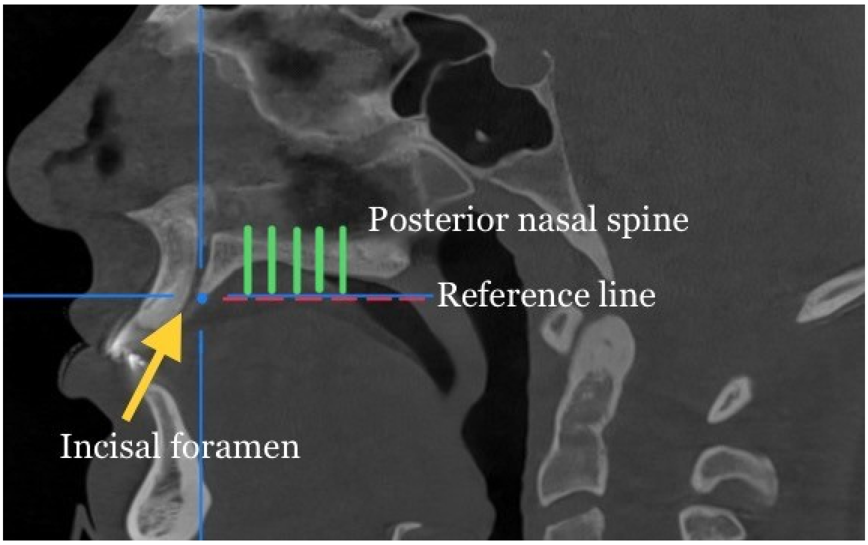


Figure 13. A midsagittal CBCT view illustrating the reference line placement.

Assessment of the palatal bone thickness was conducted in the coronal plane, whether the measurement points had to be defined in two planes: coronal and sagittal.

In the sagittal plane, measurement points were taken in the anterior region of the palate at 4 and 8 mm, and in the posterior region of the palate at 12, 16 and 20 mm distally from the IF. These points were designated as S4, S8, S12, S16, and S20 respectively. Vertical lines were drawn perpendicular to the reference line through these points (Figure 14).

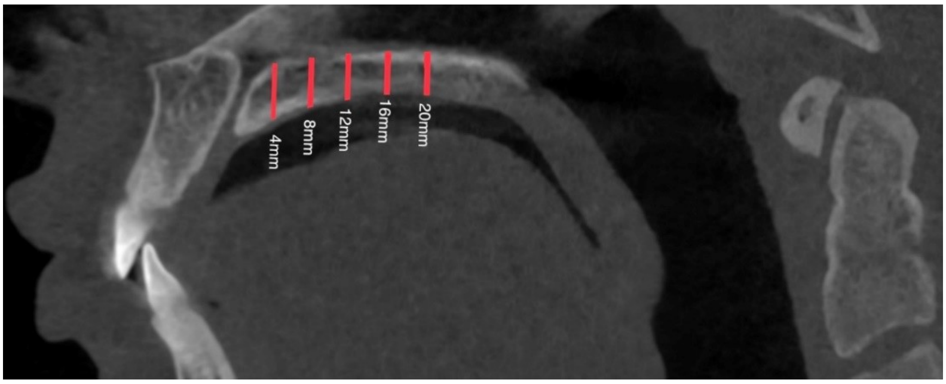


Figure 14. Measurement points located at 4, 8, 12, 16, and 20 mm posterior to the IF.

Further, starting from the point S4 (continuing then S8, S12, S16, S20) and switching it to the coronal view, the measurements were made only on the right side of each patient lateral to the midline at 3, 6 and 9 mm (measurement points were designated as C3, C6 and C9, respectively) (Figure 15). Earlier studies have reported that there are no differences in the palatal bone thickness between the right and left sides of the palate (Gracco et al., 2007).

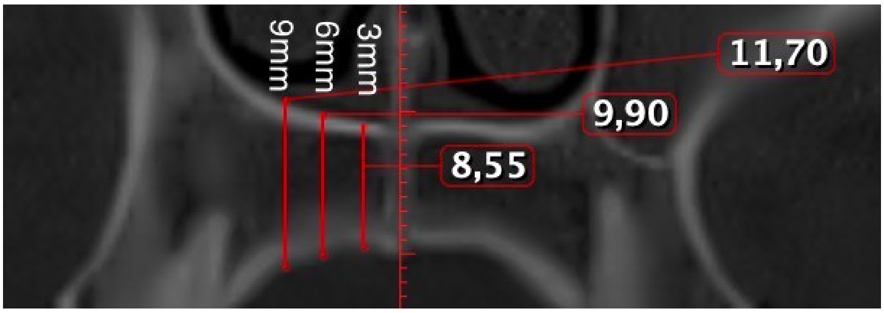


Figure 15. Measurements taken 4 mm posterior to the IF and 3, 6 and 9mm lateral to MPS.

A total of 750 measurements (15 for each of the 50 patients) were recorded (Figure 16). The points located 4 and 8 mm posterior to the IF and 3, 6, 9 mm lateral to the MPS were also designated as “anterior region”; the points located 12, 16 and 20 mm posterior to the IF and 3, 6, 9 mm lateral to the MPS were consequently named as “posterior region”. Each measurement was entered into an MS Excel® worksheet with the following statistical data analysis.

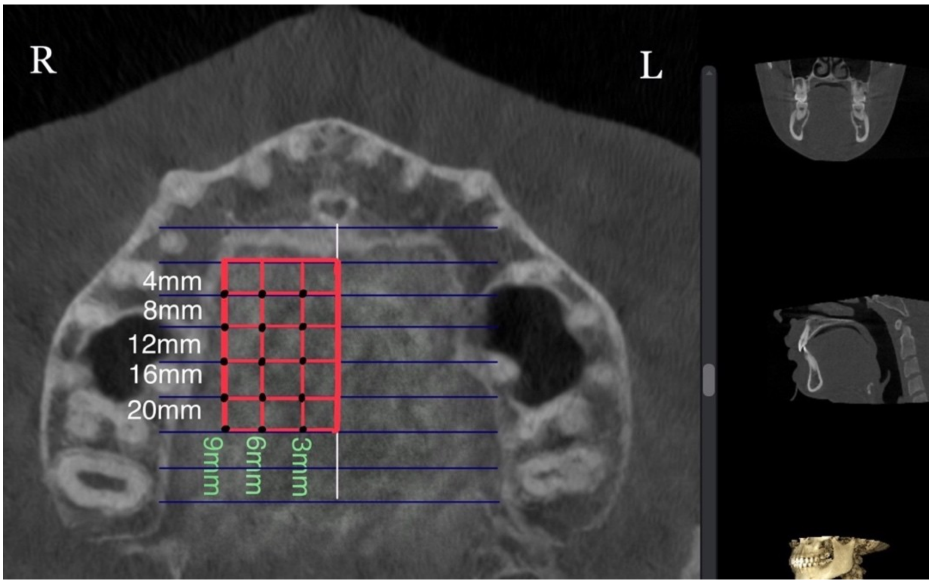


Figure 16. All measurement points located at 4, 8, 12, 16 and 20 mm posterior to the IF and 3, 6 and 9mm lateral to MPS (Right side, Axial view).

2. Research hypotheses

In this study, the following research questions were defined and subsequent null (H0) and alternative hypotheses (H1) were formulated:

1st Research Question: Are there significant differences in mean palatal bone thickness across different measurement points on the palate?

H0: There are no significant differences in mean palatal bone thickness across different measurement points on the palate.

H1: There are significant differences in mean palatal bone thickness across different measurement points on the palate.

2nd Research Question: Is there a significant difference in mean palatal bone thickness between *males* and *females* at the specific measurement points?

H0: There is no significant difference in mean palatal bone thickness between *males* and *females* at the specific measurement points.

H1: There is a significant difference in mean palatal bone thickness between *males* and *females* at the specific measurement points.

3rd Research Question: Is there a significant difference in mean palatal bone thickness between *adolescents and young adults* and *adults* at the specific measurement points?

H0: There is no significant difference in mean palatal bone thickness between *adolescents and young adults* and *adults* at the specific measurement points.

H1: There is a significant difference in mean palatal bone thickness between *adolescents and young adults* and *adults* at the specific measurement points.

3. Methodology of statistical analysis

The Statistical Package for the Social Sciences (SPSS Inc., Chicago, USA) version 28 was employed for the statistical analysis. The normality of the distribution and the homogeneity of variance of bone thickness across the different points were investigated using the Shapiro–Wilk and Levene's tests, respectively.

The performed descriptive statistics included the mean, standard deviation (SD), and 95% confidence intervals. The examiner re-evaluated 10 CBCT scans randomly selected with measurements of the same 150 ROIs obtained at 2-week intervals.

The reliability of the duplicated measurements was evaluated using Cronbach's Alpha. The Intraclass correlation (ICC) for consistency, or conformity, was employed to assess the degree of similarity between the measurements at the different points. Two forms of ICC were computed: the ICC for single measurements and the ICC for average measurements. Furthermore, Box's Test was applied to assess the assumption of equality of covariance matrices across the groups defined by age and sex. The test evaluated whether the observed covariance matrices of the dependent variables are equal across groups, which is a critical assumption for the validity of ANOVA.

A between-subjects ANOVA was conducted to evaluate the effect of age and sex on the average bone thickness. The analysis was performed using the Type III sum of squares method. The significance level was set at 0.05. The results tables employed a Student's t-test to determine significant measurement differences between age and sex groups. Finally, a hierarchic cluster analysis confirmed data homogeneity.

III. RESULTS AND DISCUSSION

1. Results

The results of the statistical analysis confirmed the homogeneity of the data. The Cronbach's coefficients (Cronbach's alpha = 0.937; Cronbach's alpha based on standardized items = 0.946) indicated excellent internal consistency and high reliability, demonstrating an acceptable intraobserver agreement of repeated measurements. The Box's Test revealed a non-significant difference ($p = 0.515$) between the covariance matrices of the groups. This suggests that the patterns of point thickness change in a similar manner across the different age and sex groups investigated.

The results of the two-way ANOVA test indicated the presence of significant between-subject effects ($p < 0.001$), suggesting that the mean measurements exhibited overall discrepancies across different points on the palate, regardless of age and sex. Further tests revealed that age did not have a significant effect on the measurements ($p > 0.05$). However, sex exhibited a significant effect ($p < 0.05$), indicating that the average measurements differed between males and females (Table 10).

Table 10. Tests of Between-Subjects Effects (p≤0,05)

Source	F	Sig.
Intercept	201.685	< .001
Age	2.759	.103
Sex	5.447	.024

The present investigation demonstrated that across all the samples analyzed, the greatest palatal bone thickness was in the anterior region of the palate (4-8mm distally to the IF). This thickness decreased in a posterior direction within each sagittal section.

The maximum palatal bone thickness was observed at a point 4mm posterior to the IF and 9mm lateral to the MPS, specifically at the S4/C9 coordinate. Mean thickness at this point was 12.29 ± 2.00 mm for females and 13.59 ± 2.31 mm for males. Notably, other points with high bone thickness values were identified, including S4/C3 (8.32 ± 1.46 mm for females, 9.77 ± 1.91 mm for males), S4/C6 (9.19 ± 1.66 mm for females, 10.75 ± 2.46 mm for males), and S8/C9 (7.12 ± 1.89 mm for females, 8.63 ± 1.95 mm for males), as detailed in Table 11.

Table 11. Mean and Standard Deviation of the palatal bone thickness by sex (distance in millimeters).

Points*	Mean (SD)		*t-test*
	Female	**Male**	
S4/C3	8.32 (1.46)	9.77 (1.91)	$p < 0.05$
S4/C6	9.19 (1.66)	10.75 (2.46)	$p < 0.05$
S4/C9	12.29 (2.00)	13.59 (2.31)	$p < 0.05$
S8/C3	5.16 (1.14)	6.13 (1.69)	$p < 0.05$
S8/C6	5.50 (1.25)	6.33 (1.88)	-
S8/C9	7.12 (1.89)	8.63 (1.95)	$p < 0.05$
S12/C3	3.75 (1.00)	4.44 (1.01)	$p < 0.05$
S12/C6	3.22 (.96)	4.14 (1.32)	$p < 0.05$
S12/C9	4.41 (1.48)	5.47 (1.52)	$p < 0.05$
S16/C3	3.38 (1.02)	3.52 (.96)	-
S16/C6	2.87 (.94)	3.23 (.91)	-
S16/C9	3.73 (1.51)	4.07 (1.23)	-
S20/C3	3.06 (1.03)	2.99 (.85)	-
S20/C6	2.63 (.71)	2.56 (.91)	-
S20/C9	3.05 (1.22)	3.31 (1.21)	-

*Red colour: anterior region, 4-8 mm posterior to the IF, 3-9mm lateral to the MPS (S4/C3- S8/C9); blue colour: posterior region, 12-20mm posterior to the IF, 3-9mm lateral to the MPS (S12/C3 - S20/C9).

Table 11 further demonstrates that males exhibited significantly greater average palatal bone thickness compared to females (p < 0.05). According to the t-test findings, statistically significant differences between the sexes were found in all points located 4 and 12 mm posterior to the IF, as well as in two points located 8 mm posterior to the IF. It is noteworthy that the points situated 16 and 20 mm posterior to the IF did not reveal any significant differences in thickness between females and males.

Furthermore, upon analyzing distinct age groups we can also observe that the highest average palatal bone thickness is located in the anterior palatal region, 4–8 mm posterior to IF. Both age groups demonstrated the highest value at the S4/C9 point, with a mean thickness of 13.30 ± 2.38 mm for *adolescents and young adults* and 12.27 ± 2.03 mm for *adults*. Additionally, elevated high values were observed at the following points: S4/C3, S4/C6, S8/C3, S8/C6, and S8/C9 (Table 12). The group of adolescents and young adults exhibited a greater average palatal bone thickness compared to adults. Statistically significant differences were observed at 8, 12 and 16mm posterior to the IF.

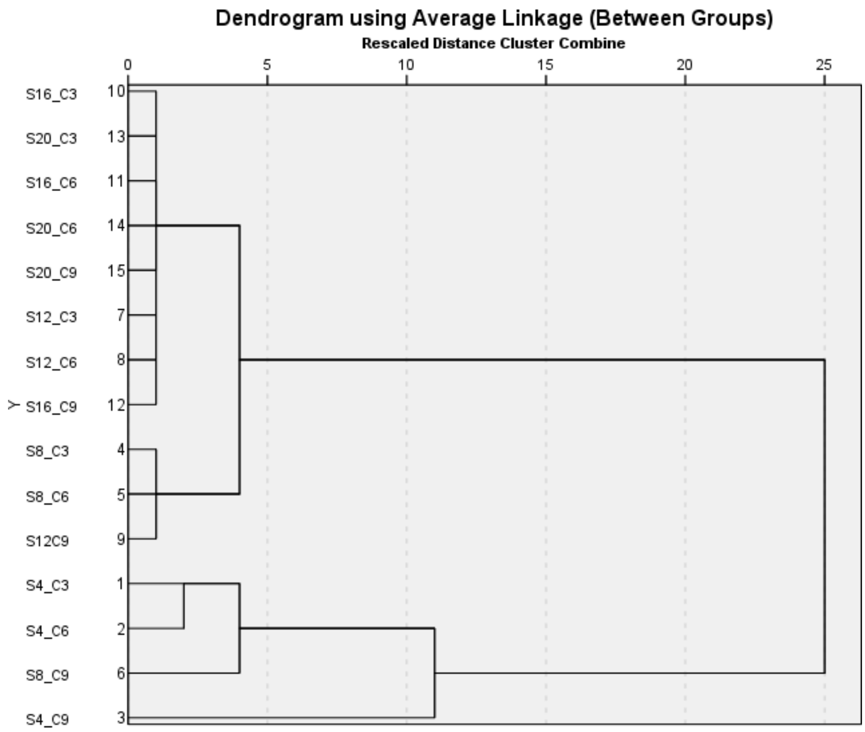
Table 12. Mean and Standard Deviation of the palatal bone thickness by age (distance in millimeters).

Points*	Mean (SD)		*t-test*
	Adolescents/ young adults *(12-25 y.o)*	**Adults *(27-51 y.o)***	
S4/C3	9.08 (1.69)	8.9 (1.97)	-
S4/C6	10.32 (2.10)	9.51 (2.24)	-
S4/C9	13.30 (2.38)	12.27 (2.03)	-
S8/C3	5.57 (1.37)	5.64 (1.63)	-
S8/C6	6.38 (1.57)	5.38 (1.52)	$p < 0.05$
S8/C9	8.75 (1.92)	6.88 (1.74)	$p < 0.05$
S12/C3	4.27 (.97)	3.87 (1.12)	-
S12/C6	4.05 (1.17)	3.25 (1.15)	$p < 0.05$
S12/C9	5.57 (1.36)	4.21 (1.49)	$p < 0.05$
S16/C3	3.63 (.97)	3.25 (.98)	-
S16/C6	3.49 (.83)	2.58 (.81)	$p < 0.05$
S16/C9	4.40 (.10)	3.38 (1.47)	$p < 0.05$
S20/C3	3.24 (.92)	2.81 (.94)	-
S20/C6	2.76 (.89)	2.43 (.68)	-
S20/C9	3.41 (1.13)	2.93 (1.26)	-

*Red colour: anterior region, 4-8 mm posterior to the IF, 3-9mm lateral to the MPS (S4/C3- S8/C9); blue colour: posterior region, 12-20mm posterior to the IF, 3-9mm lateral to the MPS (S12/C3 – S20/C9).

The results of the cluster analysis indicate a high degree of homogeneity. Table 13 shows that the points S16/C3, S20/C3, S16/C6, S20/C9, S12/C3, S12/C6, and S16/C9 form the first homogeneous group, representing the measurements from the posterior region of the hard palate (12-20mm posterior from the IF). The second homogeneous group is constituted by the S8/C3, S8/C6, and S12/C9 points, which are predominantly located in the anterior part of the palate.

Table 13. Points that form homogeneous groups.



2. Discussion

2.1 Research Methodology

The present study was a retrospective, radiographic observational investigation performed on a cohort of patients attending the Egas Moniz Dental Clinic. This investigation employed 3D assessment tools to evaluate the applicability of emerging anchorage techniques that have recently gained popularity in orthodontics. Furthermore, it was the first study in Portugal with a calculated sample size and adherence to the STROBE guidelines. The suboptimal adherence to STROBE guidelines, as highlighted by Bruggesser et al. (2023), underscores the critical need for rigorous reporting in observational studies. Clear and transparent reporting, facilitated by guidelines like

STROBE, is essential for ensuring the validity and reproducibility of research findings. In recognition of this importance, the present study has meticulously adhered to the STROBE guidelines, ensuring comprehensive and transparent reporting of our methodology and results. In this study, care was taken to include only Portuguese individuals. This was performed by reading each participant’s record. However, due to the similarity of Portuguese names with Brazilian names, errors in the patients’ origin might have been introduced.

Similar to dental implants, the success of MIs is heavily influenced by the quantity and quality of the surrounding bone, particularly cortical bone density and thickness. These factors are vital for establishing primary stability, which is a pivotal element for ensuring long-term success. The present study aimed to identify the optimal insertion site for orthodontic MIs, defined as the region with the greatest palatal bone height, in a sample of patients stratified by age and sex and investigate potential differences in thicknesses values.

In our investigation, the sample size consisted of patients ranging in age from 12 to 51 years old. This age range was determined due to several practical considerations, including the limited availability of CBCT scans and the necessity of fulfilling the inclusion criteria, such as full upper arch permanent dentition. This criterion is inherently age-dependent, as the prevalence of a complete dental arch tends to decrease with advancing age. Notably, this age range aligns with some previous undertakenstudies likely due to the necessity of meeting similar inclusion criteria (Chang et al., 2021; Suteerapongpun et al., 2018; Vidalón et al., 2021).

The acquired CBCT images were oriented within axial and sagittal reconstructions. This standardization was focused at proximity to the region of interest (hard palate), a crucial step in ensuring uniformity across CBCT scans. A comparable standardized positioning was also employed by Santiago et al. (2020) and Vidalón et al. (2021) to enhance inter-study comparability and facilitate accurate measurements. This meticulous approach is essential for minimizing measurement variability and ensuring the reliability of subsequent analyses.

In order to evaluate the human hard palate, different types of studies have already been conducted. Among them are: the radiological evaluation of the soft tissue thicknesses of the palate (Yu et al., 2021), investigation of palatal cortical bone thickness (C. J. Chang et al., 2021), (Mallick et al., 2021) , (Hourfar et al., 2015) and investigation of total bone thickness (Santiago et al., 2020) , (Bonangi et al., 2018) , (Suteerapongpun et al., 2018) , (Santiago et al., 2020) , (Vidalón et al., 2021) etc.

The majority of the analyzed studies investigated the total palatal bone thickness with the main aim of guiding the insertion of palatal MIs and decreasing the failure rate in clinical practice. The samples were mostly divided by age and sex with subsequent analysis of differences. Our study further categorized the subjects into age and sex groups to similarly investigate the effect of age and sex on palatal bone thickness. According to the results of their assessment of the total palatal bone thickness Chang et al. (2021) and Gracco et al. (2007) concluded that there was no significant difference observed between males and females in their investigated groups. On the other hand, the results of the study conducted by Bonangi et al. (2018) reported greater palatal bone thickness in males than in females, which is consistent with the findings of the present study.

Several studies have explored the potential influence of craniofacial characteristics and malocclusion on palatal bone thickness. For instance, Vidalón et al. (2021) investigated the relationship between palatal bone thickness and facial patterns using CBCT scans. Their sample was divided into three groups (normodivergent, hypodivergent, and hyperdivergent) based on facial morphology. Results revealed a significant association between facial pattern and palatal bone dimensions, with the hypodivergent group demonstrating the greatest palatal bone height and cortical thickness compared to the other two groups. Suteerapongpun et al. (2018) conducted a study comparing palatal bone thickness in patients with Class I malocclusion, examining the impact of vertical skeletal configuration (normal vs. open bite). Their results revealed a consistent trend of reduced palatal bone thickness at most measurement sites in individuals with an open bite configuration compared to those with a normal bite. These investigations offer valuable findings, and our study could lay the groundwork for future population-specific investigations into the impact of craniofacial morphology and malocclusion on palatal bone thickness.

2.2 Discussion of Results

The results of the present study revealed a decrease in palatal bone thickness from the anterior to posterior regions. This indicates a significant difference in palatal bone thickness across different regions of the palate. These findings are in agreement with those of most previous studies (Vidalón et al., 2021, Santiago et al., 2020, C. J. Chang etal., 2021, Bonangi et al., 2018; Hourfar et al., 2015; Ludwig et al., 2011).
Therefore, the null hypothesis of the first research question is rejected.

This investigation identified the highest mean vertical palatal bone in the anterior region of the hard palate, specifically at the point S4C9, located 4 mm posterior to IF and 9 mm laterally to MPS in all investigated groups. This finding aligns with results reported by Vidalón et al., 2021 who observed the maximum palatal bone thickness at ananalogous point in a CBCT study that evaluated the palatal bone in different facial patterns. The findings of Chang et al. (2021) study also revealed that the zone located 3 mm posterior to the IF and 4 to 8 mm lateral to the midsagittal line exhibited the thickestpalatal bone. Additionally, Suteerapongpun et al. 2018 concluded that the highest mean value of palatal bone thickness was located within 4mm posteriorly from the IF. According to the findings of the present study, the smallest mean vertical palatal bone height is located in the distal region of the hard palate, 20 mm posterior from the IF and 6 mm lateral to the MPS. This result was in line with those of some other studies where the thinnest palatal bone was observed within 20-24 mm posterior to the IF (Suteerapongpun et al., 2018; Vidalón et al., 2021).

Our investigation revealed significant differences in palatal bone thickness between the observed sex groups at various measurement points. Specifically, the male group exhibited significantly greater palatal bone thickness than the female group, leading to the rejection of the null hypothesis for the second research question. Similar to the present study findings, Bonangi et al. (2018) reported more palatal bone thickness in males than in females. The same sex specific pattern has been reported for other areas of the jaws like the alveolar bone, where females seem to have thinner bone compared to males (Cassetta et al., 2013). However, the opposite conclusion was made by Chang et al. (2021)

where no significant difference was observed between males and females in terms of total palatal bone thickness.

Regarding age differences, the present study reveals that adolescents and young adults exhibited greater average palatal bone thickness compared to adults, thus rejecting the null hypothesis of our third research question.

The same results were obtained by Chhatwani et al. (2019) in their retrospective cross-sectional CBCT study of 180 males and females healthy orthodontic patients aged 8–40 years. On the contrary, Farnsworth et al. (2011) investigated the cortical bone thickness of the palate in the 3-mm paramedian and 3-9-mm anteroposterior area. They found no age difference in these areas. The findings of Santiago et al. (2020) also revealed that the palatal bone thickness has a significant weak correlation with the age of individuals.

Palatal bone thickness measurements are instrumental in selecting optimal MI placement sites and determining appropriate implant length. This information is critical for achieving sufficient implant stability and preventing iatrogenic injury to vital anatomical structures. It was suggested that a minimum of 5 mm of bony support is crucial for resisting rotational forces and dynamic loads, thereby contributing to MI stability, and preventing iatrogenic injury to vital anatomical structures (Winsauer et al., 2014). Ludwig et al. (2011) in the *Anatomical Guideline for Miniscrew Insertion* reported that the ideal area for MI insertion is 3-9 mm anteroposterior and within 6 mm mediolaterally including the MPS. According to the results of our study, which are in agreement with the findings above, suitable insertion sites for MI are located 4-8mm posterior to the IF and within 9mm mediolaterally for both *males* and *females* groups (Table 7). Regarding the age, the preferable insertion site is located 4-8 mm posterior to the IF and 3-9 mm lateral to the MPS for *adults* and 4-12 mm posterior to the IF and 3-9 mm lateral to the MPS for *adolescents and young adults.* Results of the present study also confirm previous findings that the T-zone, the area just posterior to the third palatal rugae in the anterior region of the palate, is one of the most favorable sites in the hard palate for MI insertion (Hourfar et al., 2015; Wilmes et al., 2016).

Nakahara et al. (2012) prior investigation on 20 skulls of Japanese subjects observed a similar trend of decreasing palatal bone thickness from the anterior to posterior regions in spite of their different examined sample from our study. Moreover, Jayakumar et al. (2012) in their investigation of 60 Indian patients (30 males and 30 females) reported significant variations in palatal bone thickness in across two age groups (group A: 15–24 years; group B: 25–35 years). They also found that the anterior region, 4 mm behind the incisive papilla, showed the maximum thickness and reported the anteroposterior trend of decreasing palatal bone thickness.

Our study demonstrates that palatal bone thickness exhibits significant variation across both sexes and age groups. This finding has a high clinical relevance for determining the acceptable insertion length of MIs. In contrast to the present investigation, some studies revealed that females have an equal or greater bone supply in the posterior region of the palate than men (Gracco et al., 2007; Sumer et al., 2016), whereas other investigations confirmed our results (Bonangi et al., 2018; Chhatwani et al., 2019). A possible reason for these differences is the variations in measurement methods and protocols or differences in the study populations, including potential specific ethnic variations.

Despite the various studies' findings, careful diagnostic evaluation remains essential for each patient. Assessment of palatal bone thickness is crucial in orthodontic practice due to its implications for MI placement. Thicker bone regions offer enhanced MI stability, while thinner areas increase the risk of MIs failure and iatrogenic injury. Individual variations in bone thickness, influenced by sex and age, necessitate personalized treatment plans. Accurate assessment guides optimal MI placement site and length maximizing success rates and minimizing complications. This clinical relevance underscores the need for thorough bone thickness evaluation prior to MI insertion and further research in this area to refine treatment protocols and improve patient outcomes.

The findings of the current study enhance our knowledge regarding palatalbone and provide clinical guidelines. These updated clinical guidelines could reduce the necessity for radiographic imaging before the insertion of orthodontic MIs. Further research in specific populations would improve their reliability.

The ongoing advancements in artificial intelligence (AI) and the emerging field of computer graphics are poised to revolutionize landmark evaluation. The integration of these technologies is expected to facilitate self-automated assessment processes that are both efficient and reliable, eliminating the time-consuming nature of traditional methods. By integrating AI algorithms with advanced computer graphics, researchers and clinicians can develop automated systems capable of analyzing 3D imaging data, such as CBCT scans. These AI-powered systems can accurately identify and segment the palatal bone, enabling precise measurements of its thickness at various locations. This automated approach not only streamlines the assessment process but also enhances its accuracy and reliability, ultimately leading to better-informed treatment decisions and improved patient outcomes.

Recent research demonstrates the potential of AI in analyzing bone structure and development. For instance, Radwan et al. (2023) in their study aimed to develop an AI algorithm capable of automatically determining Cervical Vertebra Maturation (CVM) stages. This is particularly relevant because CVM is a key indicator of skeletal growth and can inform orthodontic treatment planning. This successful application of AI in CVM assessment provides a compelling model for future research into bone thickness measurement. Similar methodologies could be employed to train AI algorithms on datasets of bone scans or other imaging modalities. By analyzing patterns in bone density and structure, AI could potentially provide rapid, accurate, and objective assessments of bone thickness.

2.3. Limitations of the Study

1. The limitations embedded in the retrospective design of this investigation did not allow controlling the imaging procedure and characteristics, which might have influenced the obtained results.
2. Although the used power calculation concluded that the examined sample size is adequate to detect significant differences when existed, a larger sample size could not be selected due to the limited number of the available CBCTs that fulfilled the study inclusion criteria.

3. The obtained results represent only the patients attending Egas Moniz Dental Clinic.
4. While this study targeted the Portuguese population, there remains a margin for potential bias due to the diverse origins of individuals residing in Portugal.
5. Given that the current investigation employed a single researcher, the reliability of measurements was evaluated only through intraobserver repeatability.

2.4. Suggestions for Future Studies

In the present study, the achieved power of the sample size (N=50) was notably high. While this suggests a robust statistical foundation for the findings, it is acknowledged that a larger sample size would further enhance the reliability and generalizability of the results. Therefore, this study should be considered a foundational step for future research, providing a basis for prospective multicenter studies that expand beyond Egas Moniz Dental Clinic and encompass data from various dental clinics and medical centers across Portugal.

Furthermore, while this study focused on the Portuguese population, the diverse origins of individuals residing in Portugal present a potential source of bias. To address this, it is recommended to include the patient's country of origin in their clinical records, enabling a more nuanced selection of data for analysis and interpretation.

Future research should explore potential interactions between facial skeletal growth pattern and cortical bone thickness in different populations, given the observed influence of skeletal morphology on bone structure (Vidalón et al., 2021). Consequently, our study may serve as the groundwork for future research exploring the impact of craniofacial morphology and malocclusion on palatal bone thickness within specific populations.

Additionally, a more comprehensive study encompassing a larger sample size would be enhanced by the inclusion of interobserver agreement (reproducibility) analysis, thereby augmenting the generalizability and validity of the research findings.

This study would also benefit from prospectively designed investigation allowing for a more robust analysis of the impact of aging on cortical bone width in various parasagittal locations. This study could serve as a foundation for future population-specific investigations.

V. CONCLUSIONS

This study investigated the suitability of the palatal bone for MI placement by analyzing variations in the palatal bone thickness based on anatomical location, age, and sex. Our findings reveal the following key points:

Decreasing anteroposterior thickness: Palatal bone thickness decreases from anterior to posterior direction.

Favourable insertion sites: Anterior region of the palate is a highly favorable location for orthodontic MI placement due to its sufficient bone thickness, contributing to optimal primary stability.

Sex differences: Females generally have a thinner palatal bone compared to males.

Age-related differences: Palatal bone thickness tends to be greater in the adolescents and young adults age group (12-25 years old), than in adults (27-51years old).

These findings offer valuable insights for clinicians when selecting appropriate MI placement sites during orthodontic treatment, taking into consideration factors such as patient age and sex. A thorough understanding of craniofacial variations across diverse populations is crucial for establishing population-specific anatomical guidelines for MI insertion. By tailoring orthodontic interventions to the unique anatomical features of each population, clinicians can optimize treatment outcomes, minimize the risk of complications, and ultimately enhance the quality of care provided to patients worldwide. This approach represents a significant advancement in the field of orthodontics, promising a future of more personalized and effective treatments.

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VII. ANNEXES

EGAS MONIZ SCHOOL of HEALTH & SCIENCE

Comissão de Ética EGAS MONIZ

Proc. Interno nº 1300
PT-201/23

Ex.ma Senhora
Anastasiia Ananieva

Monte de Caparica, 30 de novembro de 2023.

Ex.ma Senhora,

Em resposta ao Pedido de Parecer que submeteu à apreciação da Comissão de Ética da Egas Moniz, com o tema denominado: "**Avaliação da espessura do osso palatino para a inserção dos dispositivos de ancoragem temporária numa população portuguesa: estudo retrospectivo**", foi aprovado.

A secretária da Comissão de Ética da Egas Moniz

Profª Doutora Ângela Pereira

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