UNIVERSIDADE FERNANDO PESSOA

In vitro evaluation of manual and mechanical canal preparation time: natural versus artificial teeth

[Avaliação *in vitro* do tempo de preparação manual e mecânica do canal radicular: dente natural versus dente artificial]

Dissertação de Mestrado

Mestrado Integrado em Medicina Dentária

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Orientador:

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À minha família, pelo seu amor, apoio incondicional e por acreditar em mim a cada passo do caminho. Aos meus pais, que através do seu exemplo e sacrifícios me ensinaram o valor do trabalho árduo e da perseverança. Aos meus irmãos, por sempre serem uma fonte de inspiração e pelo constante incentivo.

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RESUMO

A endodontia é a área da medicina dentária que se ocupa da terapia do endodonto, que é a parte interna do dente ou polpa. O tratamento endodôntico envolve a remoção do tecido pulpar, seguida da limpeza e preparação dos canais radiculares e, por fim, a obturação definitiva com cimento e guta-percha. A técnica manual envolve a utilização de limas K-File. Por outro lado, a técnica mecânica deste estudo utiliza limas ProTaper Gold® associadas a um motor endodôntico. O trabalho com dentes naturais permite testar a anatomia do sistema de canais radiculares e a dureza natural da dentina, embora a sua obtenção seja cada vez mais difícil (sujeita a consentimento informado). Para ultrapassar estas desvantagens, têm sido desenvolvidos dentes artificiais com o objetivo de reproduzir as características anatómicas e físicas dos dentes naturais. Este estudo experimental tem como objetivo avaliar o tempo de trabalho, comparando duas técnicas endodônticas: manual e mecânica, em relação a dentes naturais e artificiais. Os dentes naturais utilizados neste estudo foram recolhidos em várias clínicas dentárias localizadas no Norte de Itália, obtendo-se dois grupos de amostragem de 10 dentes naturais compostos por 4 incisivos, 2 caninos e 4 pré-molares. Os dentes naturais foram padronizados em termos de comprimento de trabalho, de modo a serem comparáveis com os dentes artificiais.Em segundo lugar, assim como para os dentes naturais, os dentes artificiais foram divididos em 2 grupos, cada um composto por 10 dentes artificiais, sendo 4 incisivos centrais, 2 caninos e 4 pré-molares, com o mesmo comprimento de trabalho dos grupos de dentes naturais. A preparação dos dentes naturais e artificiais unirradiculares foi realizada de acordo com o protocolo da técnica manual e ProTaper Gold®, leccionado nas unidades curriculares de Endodontia I, II, III e Medicina Dentária da Conservação do Mestrado Integrado em Medicina Dentária da Faculdade de Ciências da Saúde da Universidade Fernando Pessoa. Para a técnica manual, foram utilizadas limas K-File de secção quadrada (Dentsply-Sirona®) de forma sequencial até se obter um calibre apical igual a ISO 25, enquanto que as limas do sistema ProTaper Gold® (Dentsply-Sirona®) foram utilizadas até à lima F2 com um diâmetro apical de ISO25. A medição do tempo de trabalho foi realizada através da cronometragem dos segundos em que as limas rodam no interior do canal radicular, eliminando o tempo necessário para a troca de limas manuais e/ou mecânicas da peça de mão do micromotor. O sistema ProTaper Gold® mostrou tempos de preparação significativamente mais curtos para dentes naturais e artificiais em comparação com a técnica manual ($p < 0,05$). Tanto na técnica manual quanto na ProTaper Gold®, os dentes naturais exigiram um tempo de preparação maior em comparação com os dentes artificiais. No entanto, essas diferenças não foram estatisticamente significativas ($p > 0,05$). Em resumo, os resultados deste estudo experimental demonstram que a preparação mecânica requer menos tempo para completar a preparação do canal em comparação com a preparação manual, enquanto que a preparação de dentes naturais normalmente exige mais tempo do que a de dentes artificiais.

Palavras-chave: Endodontia; técnicas de preparação endodôntica; tempo de preparação; dentes naturais; dentes artificiais

ABSTRACT

Endodontics is the field of dentistry that deals with the therapy of the endodontium, which is the inner part of the tooth or pulp. Endodontic treatment involves the removal of the pulp tissue, followed by cleaning and shaping of the root canals, and finally, the definitive filling with cement and gutta-percha. The manual technique involves the use of K-File files (ranging from ISO 008 to ISO 080). On the other hand, the mechanical technique in this study uses ProTaper Gold® files associated with an endodontic motor. Working with natural teeth allows testing the anatomy of the root canal system and the natural hardness of dentin, although they are increasingly difficult to obtain (subject to informed consent). To overcome these disadvantages, artificial teeth have been developed with the aim of replicating the anatomical and physical characteristics of natural teeth. This experimental study aims to evaluate working time by comparing two endodontic techniques: manual and mechanical, in relation to natural and artificial teeth. The natural teeth used in this study were collected in various dental clinics located in Northern Italy, obtaining two sample group of 10 natural teeth composed of 4 incisors, 2 canines and 4 premolars. The natural teeth were standardized in terms of working length in order to be comparable with the artificial teeth. Secondly, as for natural teeth, the artificial teeth were divided into 2 groups each composed of 10 artificial teeth, in which there are 4 central incisors; 2 canines; and 4 premolars, with the same working length as the natural teeth groups. The root canal instrumentation of natural and artificial single-root teeth was performed according to the protocol of the manual technique and ProTaper Gold®, taught in the curricular units of Endodontics I, II, III and Conservative Dentistry of the Integrated Master of Dentistry of the Faculty of Health Sciences of Fernando Pessoa. For the manual technique, square-section K-File files (Dentsply-Sirona®) were used in sequence until an apical caliber equal to ISO 25 was obtained, while the ProTaper Gold® system (Dentsply-Sirona®) were used up to the F2 file with an apical diameter of ISO25. The measurement of the working time was carried out by timing the seconds in which the files rotate inside the root canal, eliminating the time necessary for changing manual and/or mechanical files from the micromotor handpiece. The ProTaper Gold® system showed significantly shorter preparation times for both natural and artificial teeth compared to the manual technique ($p < 0.05$). In both the manual and ProTaper Gold® techniques, natural teeth required a longer preparation time compared to artificial teeth. However, these differences were not statistically significant ($p > 0.05$). In summary, the findings from this experimental study demonstrate that mechanical preparation requires less time to complete canal preparation compared to manual preparation, whereas preparation of natural teeth typically demands more time than artificial teeth.

Keywords: Endodontics; Endodontic preparation techniques; preparation time; natural teeth; artificial teeth

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1 Introduction

1.1 Endodontics

Endodontics is the branch of dentistry that deals with the treatment of endo-donto (Comp. of *endo-* and of the gr*odũs -óntos* 'tooth' XX.), i.e the internal part of the tooth or pulp, a soft tissue mainly made up of blood vessels and nerves which guarantees nourishment and sensitivity to the dental element. It has also been defined by the ESE (European Society of Endodontics), an organization with global reach and impact focused on the broad field of Endodontics, as "the branch of dental science which deals with the health, injuries, and diseases of the dental pulp and periradicular region, and their relations to general health and well-being" (Gulabivala et al., 2010). Endodontics represents a developing clinical discipline that encompasses academic activities such as microbiology, oral biology, pathology, epidemiology, radiology, biomaterial science and the prevention and management of periapical and pulp diseases, as well as emerging fields of tissue engineering and molecular genetic investigation (Hülsmann, 2022).

Endodontic therapy is used when an injury to the tooth causes an irreversible alteration of the dental pulp, in other words, when the pulp undergoes an infection, necrosis, or a periapical lesion (Liang et al., 2018).

Endodontic treatment involves the removal of inflamed and infected dental pulp from the roots of the tooth. Once removed, the canals are cleansed and shaped and then permanently filled with canal cement and gutta-percha. A study, lasting approximately 20 years, analyzed the causes of the success and failure of endodontic treatment demonstrating that the cause of more than 60% of endodontic treatment failures is due to the poor quality of the root canal filling, and by overfilling rate which is 4 times higher than underfilling, highlighting that the correct working length is essential to obtain a quality filling, thus ensuring the success of endodontic treatment (Swartz et al., 1983).

A prerequisite to obtain a successful endodontic treatment is an accurate knowledge of the morphological complexity of the root canal system, which is the basis for understanding the problems of shaping and cleaning, also useful to define the apical limits and dimensions of root canal preparations. In addition to be aware of the anatomical morphology of the hard tissues and dental pulp, which in human nature has the possibility of having multiple configurations and shapes, it is necessary to carry out a radiographic

study using different angles to show the root morphology; Finally, it is important to achieve a good access thus allowing a detailed exploration of the inside of the root canals (Vertucci, 2005).

It is not less important the preparation of the canal, being fundamental to obtain a homogeneous canal and without any interference, with the aim of having a obturation strongly adhered to the walls of the canal. The canal preparation techniques are distinguished in biomechanical and chemical-mechanical: The first consists in widening, cleaning, and modeling the space inside the pulp canal, with the aid of manual or rotary instruments and of irrigants. The second is characterized by the use of chemical products used during irrigation of the canal to induce the demineralization of the dentin and the dissolution of the pulp tissue, in order to neutralize possible toxins and bacterial products (Eleazer et al., 2020).

The manual technique is characterized by the use of K-File files (from ISO 008 to ISO 080), stainless steel endodontic instruments with tactile plastic handles, which allow the canal to be widened, making the walls smooth and ready for filling definitive with endodontic cement and gutta percha.

1.1.2 Consideration of use K-File

Files must be organized by caliber and correct movements are key. Each file has a different colored plastic handle, indicating the size of the tip. The files are composed of a smooth part and a spiral part and are used with twisting movements.

Endodontic files are crucial tools in the preparation of root canals, essential for removing necrotic tissue and ensuring effective cleaning. Organized by caliber, the files have different characteristics that make them suitable for specific uses. Each file comes with a colored handle to indicate the tip size, which varies based on the cross-section diameter.

The active part of the file, usually 16 mm long, is the one that does the main work inside the canal. The files consist of a smooth and a spiral part, used with twisting movements to remove material efficiently.

K-files, for example, are particularly used for removal of necrotic material and for initial entry into root canals. The file series are divided into categories: the Special Series, characterized by thinner filings such as pink (0.06 mm), gray (0.08 mm) and purple (0.10 mm); the First Series, which includes files such as white (0.15 mm), yellow (0.20 mm),

red (0.25 mm), and so on up to black (0.40 mm); the Second Series, with increases in caliber that continue up to black (0.80 mm). Also, after 60 gauge, the increments change from 5 in 5 to 10 in 10, and beyond 80, the files range from 90 (white) up to 140 (black).

This sequence ensures meticulous and methodical preparation of the root canals, which is crucial for achieving clinical success in endodontic treatment. It guarantees precise and safe management throughout the entire procedure, emphasizing the importance of systematic steps to optimize treatment outcomes. This approach not only enhances the efficiency of root canal preparation but also prioritizes patient safety and the long-term success of the dental procedure (Rosa et al., 2014). The mechanical technique, however, involves the use of special files driven by an endodontic motor, as is the ProTaper Gold® system: ProTaper Gold® shaping files (SX, S1, S2) and ProTaper Gold® finishing files (F1, F2, F3, e F4), for which direct access is essential, thus ensuring adequate treatment of the root canal. Finally, they must only be used in canal areas with a confirmed and reproducible glide path using manual files, measuring at least ISO 015. It is relevant that the morphology of the root canal changes depending on the preparation and that there is a difference in mutability between the various techniques (Cui et al, 2018).

Preparation sequence according to the mechanized technique:

As described by the manufacturer it is necessary to use the following sequence of files to reach an apical caliber equal to ISO25: Shaping File Extra (SX): Allows the initial opening of the coronal third of the canal thanks to its variable taper, facilitating initial shaping; Shaping File 1 (S1): Allows the shaping of the coronal third of the canal through an increasing taper which allows a controlled progression; Shaping File 2 (S2): Continues shaping the middle third and begins preparing the apical third of the canal; Finishing File 1 (F1): Used for shaping and finishing the apical third, with an apical diameter of ISO20; Finishing File 2 (F2): Continues shaping and finishing the apical third, thus reaching an apical diameter of ISO25.

1.1.3 Description of ProTaper Gold® protocol

SX: Insert and operate the SX file to shape the coronal third of the canal and irrigate the canal with 2 ml of 3% NaOCl after using the SX; S1: Use the S1 file to continue shaping the middle third of the canal and irrigate with 2 ml of 3% NaOCl after using the S1; S2: Insert the S2 tool and complete the shaping of the middle third thus starting to prepare the

apical third and irrigate with 2 ml of 3% NaOCl after the use of S2; F1: Use the F1 tool to shape the apical third to a diameter of ISO20 and irrigate with 2 ml of 3% NaOCl after using the F1; F2: Use the F2 tool to complete the shaping of the apical third thus reaching an apical diameter of ISO25 and irrigate with 2 ml of 3% NaOCl after using F2.

Throughout the entire procedure, it is essential to maintain a rigorous irrigation of the root canal with 2 ml of 3% NaOCl using an irrigation syringe and a 25 mm irrigation needle carrying out "back and forth" movements to ensure correct cleansing and removal of debris (Rosa et al., 2014).

1.2 Laboratory teaching

For years the use of extracted natural teeth has been one of the few forms of teaching for endodontic education, although they present drawbacks for teaching, such as the possibility of cross infection and the lack of standardized procedures and assessments (Tchorz et al., 2015).

The use of natural teeth allows the clinical reality to be reproduced in terms of canal geometry and physical and chemical properties of the hard tissues. On the other hand, they present problems in collecting a sufficient number of suitable teeth, the lack of anatomical standardization, the difficulty in creating groups of comparable size, and finally the complications with ethical considerations, where as a rule, owners must declare their agreement for the academic donation of the biomaterial (Hülsmann, 2022).

Nowadays it is common for laboratory teaching of endodontics to use a combination of extracted human teeth and standardized resin models, commonly called artificial teeth (Sonntag et al., 2008).

The article of Davey et al. (2014) aims to understand the perception of undergraduate dental students in terms of their confidence and competence in performing root canal treatments and their perception of the quality of endodontic education. By distributing an online questionnaire to all 3rd, 4th, and 5th year dental students at Cardiff University through their academic email addresses, the questionnaire utilized both scaled responses and open-ended questions to gather an insight into the students' opinions.

Out of a total of 208 students, 98 responses were obtained (response rate = 47%). The perception of competence and confidence was significantly higher among the more senior year groups ($p < 0.01$). However, 49% (n = 38) of participants did not feel competent in

performing root canal treatments on anterior, single-rooted teeth, while 74% (n = 70) did not feel competent in performing root canal treatments on posterior, multi-rooted teeth. Free comments from participants indicated that this was due to a lack of clinical experience. Approximately 80% of participants rated endodontic education at Cardiff University as ≤5 on a Likert scale (1 = inadequate to 10 = good), indicating that improvement was needed. Improvements suggested by students included the provision of more information in lectures, a broader range of lecturers, an increased number of shorter, more organized practical sessions, additional training equipment, greater supervision, and online reference guides for root canal treatments. In conclusion, improving undergraduate education in endodontics is necessary to enhance students' perception of their confidence and competence in performing root canal treatments.

In recent years, various replicas of natural teeth have been produced, with the aim of becoming increasingly closer to clinical reality. These replicas have the aim of replicating the characteristics of natural teeth; Although the quality of artificial teeth, thanks to the advent of 3D printing, has improved in recent years, they equally present advantages and disadvantages. For example, their use in preclinical education would lead to the elimination of possible cross-infection and would also allow the student to be able to learn standardized procedures and consequently a uniform evaluation, since they are structurally homologous (Nassri et al., 2008).

Tchorz et al. (2015) stated that the use of resin for the construction of artificial teeth has no relevance in the quality of root fillings compared to natural teeth.

A study demonstrated that the use of artificial teeth instead of natural teeth in pre-clinical training did not affect negatively the technical quality of canal fillings subsequently provided in a clinical setting; On the contrary, another study found out that artificial teeth do not accurately reproduce the natural tooth, limiting their suitability for pre-clinical training because students don’t deal with the true anatomical complexity and morphological variations of teeth (Bitter et al., 2016).

In fact, according to research of Al-Sudani et al. (2017) students find more difficult the use of artificial teeth than natural ones, recommending the improvement of some physical abilities, such as the hardness of the resin of artificial teeth to faithfully replicate tissues such as dentin and enamel.

It has also emerged that root canal preparation timing undergoes large variations according to the degree of experience of the operators, underlining that it is the parameter with the greatest inter-individual time variations (Hulsmann et al., 2005). Despite the great evolution in the construction of 3D printed teeth, only extracted teeth have been considered adequate for root canal preparation research, since they are the only realistic option (Hülsmann, 2022).

1.3 Advantages and disadvantages natural teeth and artificial teeth

1.3.1 Advantages Natural Teeth

Extracted natural teeth (with prior informed consent) are, today, the most realistic model in root canal geometry. The uniqueness that belongs to natural teeth is mainly given by their composition, such as the different layers of dentin, and by their structure, such as the presence of dentinal tubules; As demonstrated, the quantity of tubules and the density of dentin are linked to aging (Montoya et al., 2016), these characteristics make it impossible to faithfully replicate natural teeth with inorganic substances (Hülsmann, 2022).

1.3.1.1 Geometry of the Canal System

Natural teeth have several components of the root canal system. The pulp cavity is the internal space of the tooth where the pulp is contained. During the life cycle it is shaped by physiological aging, occlusion, and by pathology with the help of secondary and tertiary stratifications of dentin and cement. The pulp cavity is divided into two portions: the pulp cavity, inside the crown, and the root canal, contained in the roots of the tooth (Vertucci, 2005). It is important to consider the presence of the dental horns and the possible lateral and accessory canals. Most root canals have a vestibulo-lingual curvature, which complicates the instrumentation and cleaning procedure as they are not very evident on a vestibular x-ray. With less chance, double curvatures with an "S" shape may also be present (Cunningham et al., 1992). The accessory canal is defined as any branch extending from the main pulp canal and connecting to the external surface of the root, commonly located between the apical or middle third of the root (American Association of Endodontists, 2003), with 73.5% in the apical third, 11,4% in the middle third and 6.3% in the cervical third (Vertucci, 1984). These accessory canals have embryological origins, due to the imprisonment of some periodontal vessels in the Hertwig's epithelial sheath of the root during the calcification’s period, where irritating substances require passageways between the pulp and the periodontium (Cutright et al., 1969). Knowledge

of the possibility of variability in root canal morphology is an essential requirement for endodontic success. It's important to highlight that the geometric variation of the canal before the shaping and cleaning procedures led to greater changes during the instrumentation procedure (Peters et al., 2001). The student, future professional, is able to treat any tooth with the awareness that the anatomy can manifest complex morphologies, with the possibility of encountering teeth with multiple canals, additional and intracanal connections, loops, "C" canals and accessory canals (Hess et al., 1925). The anatomy of the apical root is based on the presence of three reference anatomical and histological points: The apical constriction, the cemento-dentinal junction and the apical foramen (Vertucci, 2005). The root canal becomes increasingly thinner towards the apical constriction and the latter is normally located at 0.5 –1.5 mm inside the apical foramen (Kuttler, 1955). Finally, the apical constriction is considered the reference point for dentists as the apical conclusion in most endodontic clinical procedures, since it is the part of the root canal with the smallest diameter (Vertucci , 2005)

1.3.1.2 Physical properties

Natural teeth very often get into the hands of students after many years of inadequate storage; Moreover, the tooth tissues undergo mutations, due to the external environment; even aging affects the reduction in diameter of the dentinal tubules. It has been found the difference between normal and sclerotic dentin with the aid of spectroscopy and fluorescence microscopy, demonstrating that within the dentinal tubules of sclerotic dentin was a form of peritubular dentin, a less dense form of apatite; Subsequently, thanks to new techniques to evaluate the structure and chemistry of sclerotic dentin, agreeing with the previous study on the quantity of intertubular dentin inside the lumen ((Balooch et al., 2001), a volumetric reduction of sclerotic dentin crystals was demonstrated rating as insufficient evidence to elicit differences in the mechanical properties of natural dentin compared to artificial resin (Porter et al., 2005).

1.3.2 Disadvantages of Natural Teeth

Natural teeth present important drawbacks. Their use for educational purposes is effective, but requires instructions on how to store them, and on possible cross-infections, following academic regulations. They also present organizational problems of the teaching environment, related to the importance of ensuring a safe environment. Despite their morphology, natural teeth have therefore some disadvantages:

1.3.2.1 Difficult to Collect

They are difficult to find in sufficient numbers and with the requirements necessary for their use. Teeth with very complex root canal morphology and previous root canal treatment are not acceptable (Al-Sudani et al., 2017). Furthermore, extracted human teeth require complete root development, an intact crown and roots, and no anatomical irregularities (Reis et al., 2022).

1.3.2.2 Cross infections

Another obstacle is the risk of cross-infection. This is because natural teeth are severely contaminated: in the pulp and tissues may be found radicular and periradicular pathogens such as hepatitis B virus, human immunodeficiency virus and bacterial pathogens. Furthermore, extracted teeth are difficult to sterilize due to their structure, and could be damaged or altered by sterilization processes (Kumar et al., 2005). In the past, the United States Center for Disease Control and Prevention recommended the preservation of biomaterial, such as extracted teeth, in household bleach in 1:10 solutions. However, thanks to the advancement of technologies it was demonstrated the ineffectiveness of sterilization with the latter solution for extracted teeth. Nevertheless, ethylene oxide has a disinfection effectiveness of approximately 35% on the spores of the B. Subtilis bacterium. In recent years, the effectiveness of a one-week immersion in 10% Formalin or a forty-minute autoclave cycle at 240°F and 20 psi has been demonstrated. These disinfection processes do not affect the physical properties of dentin and tooth enamel (Dominici et al, 2001).

1.3.2.3 Ethical Considerations

Furthermore, there are limiting ethical considerations: the teeth should be released according to the patient's informed consent (Holden, 2017). A worrying phenomenon is the sale of natural teeth without paying attention to ethical considerations. As a result, students facing great pressure in collecting teeth for laboratory practice, lose interest in knowing to whom the teeth belonged to and the reason that led to the extraction of the natural teeth (Dobros et al., 2022)

1.3.2.4 Standardization

Finally, the anatomical variability of root canals makes them inadequate for a standardized evaluation, once the evaluation can only be individual to the chosen tooth (Versiani et al., 2013). To overcome the problem of standardization and to improve the similarity and comparability of experimental groups, it is possible to create “matched pairs” of teeth based on the main anatomical characteristics (tooth type, root length, tooth

length, root anatomy, degree or angle of curvature, root canal diameter) (Hülsmann, 2022). With the use of micro-CT scanning, allow reference to the anatomical parameters of natural teeth. Compared with the randomized method, micro-CT provided more effective control of morphological anatomical variants. The main problem of computerized scanning is the excessive expense for the assigned use and its long procedure (De-Deus, 2012). In conclusion, it is necessary to consider the lack of effectiveness of these methods in standardizing a sample group, due to parameters such as age, ethnicity of the donor and environmental factors. These factors have an impact on the mechanical properties of dentin and consequently on instrumentation (Marending et al., 2015).

1.3.3 Advantages of Artificial Teeth

Thanks to their popularity, artificial teeth have been the most followed decision by endodontic educators in recent years, due to common problems with natural teeth, such as the difficulty in meeting the requirements and especially the low quantity of the latter. On the market, among the various brands such as True-Tooth®, NextDent®, e Replidens® there are valid alternatives among the choice of artificial tooth models (Marending et al., 2015). Artificial teeth are a viable alternative presenting some advantages compared to natural teeth, such as excellent standardization for evaluation, unlimited availability and the possibility of working on complex anatomies (Reymus et al., 2019). In other words, 3D printed teeth, although partially reproducing the morphological characteristics of natural teeth, overcome the limitations that natural teeth present (Reymus et al., 2021). They are considered, therefore, suitable for teaching purposes even in carrying out the access opening, in canal instrumentation and in the radiographic control of working measure and obturation (Reymus et al., 2020).

1.3.3.1 Easy to find

Artificial teeth have no limitations regarding availability, as they can be purchased in physical and online stores. Some studies recommend the creation of a digitized platform with the aim of allowing institutions to share their printable files, which would bring a significant benefit to the entire teaching community (Kröger et al., 2017).

1.3.3.2 Ethical considerations

Since artificial teeth are not human organs but standardized replicas of resin teeth, they don’t present ethical restrictions. Ethical considerations arise only in the case of 3D artificial teeth generated by cone beam computed tomography or Micro-CT of natural teeth, requiring the consent from the donor for the use of their teeth (Holden et al., 2017).

1.3.3.3 Cross infections

The possibility of cross-infection is non-existent, as they are more hygienic and above all they must not be stored in liquids, which makes the clinical teaching environment safer (Kolling et al., 2021)

1.3.3.4 Standardization

Several studies have highlighted that artificial teeth are realistic and standardized, guaranteeing the same degree of difficulty for each individual student, and thus also for a fair evaluation (Pouhaer et al., 2022). These advantages allow students and teachers to concentrate or deepen the clinical procedures without having to deal with possible morphological variability (Decurcio et al, 2019). Furthermore, students can repeat the same procedure several times and even compare different protocols. This would also lead to the decrease of stress during the first clinical endodontic treatment (Yekta-Michael et al., 2021)

1.3.4 Disadvantages of Artificial Teeth

1.3.4.1 Physical properties

The major drawback of artificial teeth is the low physical similarity of tissues such as dentin and enamel, due to the different physical possibilities of the resin. This downside of the replication is an obvious problem, which could have an impact on the first treatment. No manufacturer of these replicas can give its artifacts the physical capacity of hardness comparable to natural dentin, highlighting the difference existing between the products on the market, due to the production processes (Reymus et al., 2020). Another disadvantage is the radiopacity of resin-molded teeth compared to natural teeth (Reis et al., 2022), which could greatly influence the student's radiographic study.

1.3.4.2 Ecology

It’s important to consider the impact of 3D printing techniques on the environment. Since technologies are only at their beginning, they use many materials that are not recyclable and also imply a significant dispersion of chemical substances deriving from these plastics into the environment. The possible effects of releasing these products into the environment are still little known (Walker et al., 2019).

1.3.4.3 Cost

The new technologies proposed are very expensive and even the artifacts are not advantageous. Students may consider that the price of these teeth is excessive in terms of value for money (Gok et al., 2017).

1.4 Objectives

The aim of the present study is to evaluate and compare the preparation time required of a single root natural tooth and artificial teeth used in endodontics I and II curricular units of the Dentistry Integrated Master of the Health Science Faculty of Fernando Pessoa, employing both manual and rotary preparation techniques. To the authors knowledge, no previous study has explored this aspect, highlighting the necessity to provide such information for better scheduling of the curricular units.

2. Development

2.1 Materials and methods

This *in vitro* study was approved on 02/2024 by the Ethics Commission of the Faculty of Health Sciences of the Fernando Pessoa University.

2.1.1 Artificial teeth

The artificial teeth chosen as a sample for this research are from the brand DRSK® which as declared by the manufacturer in the catalog available on the web page https://www.drsk.com, is a reliable endodontic model to simulate the entire procedure of a routine treatment, guaranteeing similar tactile feedback.

2.1.2 Natural teeth

The natural teeth used in this study were collected in various dental clinics located in Northern Italy. After extraction, for reasons unrelated to the present study, these teeth were immersed in distilled water, keeping them in a low temperature environment.

2.1.3 Inclusion and exclusion criteria

To select the teeth for the inclusion and exclusion criteria, a visual and radiographic evaluation was carried out, in the buccal-lingual direction and in the mesio-distal direction.

The initial group of teeth was composed of 78 human teeth of the human permanent dentition, from which 30 upper and lower anterior teeth were selected according to the inclusion criteria: 1) Single-root teeth; 2) absence of signs of caries and internal and external root resorption; 3) Absence of root fractures; 4) Apex completely formed and closed.

After the first selection, the following exclusion criteria were applied: 1) Teeth with endodontic treatment; 2) Teeth with apical caliber greater than 15; 3) Teeth with length less than 22 mm; 4) Teeth with calcified and non-permeable canals; and finally, 5) Dental anomalies.

All procedures were performed by the same operator to reduce the possibility of errors between operators and above all to standardize operator preparation.

Following the radiographic analysis for the exclusion criteria of natural teeth, three teeth that had previous endodontic treatment in which one tooth also had a broken file inside and four teeth that had calcified canals and therefore presented a lack of permeability for study.

Following the radiographic analysis, focusing on the exclusion criteria of natural teeth, 30 natural teeth were selected, in which four teeth were found that had been treated with previous endodontic treatment, in which one tooth also had a broken file inside furthermore, three teeth with calcified root canals and which therefore lacked the apical permeability requirements requested in the study were descarted.

By completing the selection of the 78 natural teeth, 23 natural teeth are obtained, of which 9 are upper central incisors, 4 are upper canines and 9 are upper premolars.

2.2 Standardization of natural teeth

Subsequently, an objective measurement of the length of all remaining teeth was carried out using a digital caliper from the Borletti® brand, more precisely the CDJB15 model, and three teeth with a working length of less than 22 mm were detected, which makes them unsuitable to the exclusion criteria, thus being eliminated; following this selection, 20 natural teeth were obtained.

These 20 natural teeth were cut, to obtain groups with the same working dimensions, with a transversal cut using a separating diamond disc with a glass fiber reinforcement mesh from the Renfert® brand, Dynex Brillant model, with the relevant Pop-on mandrel from Dentaltix® using a high-rotation instrument, a refrigerated AppleDental® contra-angle, until a comparable working length is achieved in the natural tooth groups.

In this way two groups are obtained with a working length equal to 23 mm for 8 Upper Central Incisors, 27 mm for 4 Upper Canines, and 22mm for 8 Lower Premolars, in order

to uniform the working length of the root canals. Thus, obtaining a sample group of 10 natural teeth composed of 4 incisors, 2 canines and 4 premolars.

The creation of the access cavity was carried out using a 001-016M medium grain spherical diamond bur fromDentaltix® and subsequently by an Endo-Z bur from the Maillefer® brand, accompanied by the same refrigerated turbine from the Apple Dental® brand. The aim of this phase is the elimination of the infected carious tissue with the complete removal of the roof of the pulp chamber to thus obtain an access cavity that allows optimal visualization of the root canal.

The effective working length of the examined teeth was obtained inserting a K10 file until its tip was visible through the apex and then subtracting 1 mm from this measurement.

Thus, obtaining groups of natural teeth with standardized working lengths such as the 8 Central Incisors of 22 mm, the 4 canines of 26 mm and the 8 premolars of 21 mm.

The 20 natural teeth were divided into 2 distinct groups, thus creating two groups each composed of 10 natural teeth. Each group had 4 central incisors, 2 canines and 4 premolars, all, clearly, with comparable working lengths.

2.2.1 Standardization of artificial teeth

Unlike the central incisors and the artificial canines which had a length of 23 mm and 27 mm, the artificial premolars had longer lengths therefore, thanks to the use of a Renfert® cutting disc with relative Apple Dental® contra-angle, they were sectioned in to obtain root canals with working lengths of 22 mm comparable to the working lengths of natural teeth.

The working lengths of the artificial teeth were obtained by inserting a K-File -10 files until they protrude from the apex, and subtracting 1 mm from the previously recorded value, thus obtaining groups comparable to those of natural teeth: 8 central incisors of 22 mm; 4 canines of 26 mm; and 8 premolars of 21 mm.

Secondly, as for natural teeth, the 20 artificial teeth were divided into 2 groups each composed of 10 artificial teeth, in which there are 4 central incisors; 2 canines; and 4 premolars.

2.2.2 Conclusion standardization of artificial and natural teeth

At the end of the standardization of Artificial and Natural teeth, a total of 40 samples are obtained, of which 20 Artificial teeth and 20 Natural teeth; as already mentioned previously, they have already been divided into 10 teeth per group, thus resulting in 4 groups of 10 teeth each, two groups of artificial teeth, group A-B, and two groups of natural teeth, group C-D.

2.3 Introduction preparation

In this study, two methods of root canal instrumentation were compared: the manual technique with K-File files and the mechanical ProTaper Gold® system.

The root canal instrumentation of natural and artificial single-root teeth was performed according to the protocol of the manual technique and ProTaper Gold®, taught in the curricular units of Endodontics I, II, III and Conservative Dentistry of the Integrated Master of Dentistry of the Faculty of Health Sciences of Fernando Pessoa.

In particular, for groups A-C, square-section K-File files (Dentsply-Sirona®) were used, as shown in the head of the handle, in sequence until an apical caliber equal to ISO 25 was obtained, while groups B and D were prepared using the ProTaper Gold® system (Dentsply-Sirona®) up to the F2 file with an apical diameter of ISO25.

2.3.1 Manual preparation K-File

According to what is taught in the Curricular unit of Endodontics I, II, III and Conservative Dentistry of the Integrated Master of Dentistry of the Faculty of Health Sciences of Fernando Pessoa, the preparation protocol of the Root Canal System is composed of the following root canal preparation phases:

-Canal exploration or negotiation

-Determination of the working length

-Preparation of the coronal 2/3

-Preparation of the apical 1/3 until fusion with the coronal preparation

-Apical calibration

The first phase of root canal negotiation consists in irrigating and using K ISO 08-10-15 files set with the rubber stop, using them with light rotation movements, in the anti-clockwise direction 1/4 of a turn, which will give useful information on the root canal.

The determination of the working length, as previously mentioned, was obtained by inserting a K10 file until its tip was visible through the apex and then subtracting 1 mm from this measurement.

The Crown-Down aims to give taper to the root canal and is performed through the preparation from the reference point up to 2/3 of the canal. Once the processing has been completed, the instrumentation is stopped since the canal has been widened in the coronal 2/3.

The preparation takes place respecting the following instructions:

-From the largest caliber to the smallest caliber

-Reducing the size of the next file

-1 mm increase in file length

Ex. The Crown Down file sequence:

K70- 11mm

K60- 12mm

K55- 13mm

K50- 14mm

K45- 15mm

The first file of the preparation enters the canal only for 2 mm and must be blocked, i.e. it must not be able to enter beyond this measurement. Furthermore, this file is proportionate with the original anatomy of the root canal, in fact in the finest canals, a file with a smaller caliber will probably be used, such as a K35 or K40 file; On the contrary, in larger canals the choice of the first file could go up to K60 or higher caliber.

It is essential to irrigate between each file because of the creation of debris in the canal widening procedure, and because the following file cannot enter the dry canal.

Furthermore, it is important to check the apical permeability with the K10 file set with a working length + 1 mm thus guaranteeing total permeability. For this phase, file movements of 1/4 turn clockwise and anticlockwise are indicated until the rubber stop draws on the coronal reference.

The permeability verification phase does not have the objective of instrumenting the apex, in fact the apical constriction is an ideal location to help support the filling material and for this purpose it must be kept morphologically intact. Furthermore, this phase facilitates the action of the irrigation solutions and avoids the loss of working length.

The preparation phase of the apical 1/3 up to the fusion with the coronal preparation aims at creating continuous conicity in the most apical region, furthermore it allows to foresee instrumentation errors such as apical transport and finally facilitates the entry of the irrigation into the apical area of the canal system.

The Step Back acts in the opposite direction of the Crown Down, that is from bottom upwards to the apical constriction and presents the following indications:

-Increasing the caliber of the following file

-Decrease of 1 mm in setting the file

Ex. The Step Back file sequence:

K25 -20mm;

K30 -19mm;

K35 -18mm;

K40 -17mm;

K45 -16mm;

K50 -15mm.

The first Step Back file must be of caliber ≥ 25, because the apical constriction has a caliber of 25. Therefore, if the file is not correct it will go beyond the apical constriction. The larger the caliber of the first file is, the greater the microbiological control will be.

Between each file of the Step Back it is recommended to irrigate, summarize using the first file of the Step - Back and check the apical permeability with a K10 file set with a

working length + 1 mm with movements of 1/4 of a turn clockwise and anticlockwise. In this phase the aim is to give apical patency to the canal, specifically the apical constriction is exceeded by 0.5mm in order not to damage the periapical tissues.

However, for the groups, the preparation was standardized to avoid possible interactions with the study, as listed below:

For the Central Incisors in the First file of the Step-Back a rubber stop with a working length of 21 mm was placed using 25 mm K-File files. K-Files of the following sequence were used: K10, K15, K20, K25. Each instrumentation was followed by the irrigation protocol with 2 ml of 3% Sodium Hypochlorite (Canalpro; Dentaltix®).

For Premolars, the rubber stop of the first Step-Back file was set to 21 mm The instrumentation sequence includes K-File K10, K15, K20, K25 files, each with a rubber stop marked at 21 mm. We start with smaller K10 files to check the apical permeability and then proceed with larger files up to K25. After each instrumentation, the irrigation protocol is performed with 2 ml of 3% sodium hypochlorite (Canalpro; Dentaltix®).

For Canines it is A rubber stop was set at a working size of 27 mm on each file of the ISO 10-25 sequence, using 30 mm files, since 25 mm files would not reach the apical constriction. The instrumentation sequence involves the use of K-File K10, K15, K20, K25 files. As in premolars, we start with smaller caliber files to ensure the permeability of the canal and proceed with larger caliber files. This detailed description ensures that each root canal preparation step is well understood and standardized to minimize variations in study results.

2.3.2 Mechanical preparation of Pro Taper Gold®

The preparation of the root canals of group B-D using the Pro Taper Gold® file system was performed by associating it with the X-SMART model endodontic micromotor from the Dentsply® brand, calibrated at a speed of 250 revolutions per minute, with a torque of 2.8 Ncm, and a gear ratio of 16:1.

The mechanical preparation system involves the use of Pro Taper Gold® SX, S1, S2 shaping files and Pro Taper Gold® F1, F2, finishing files, for which direct access is essential, thus guaranteeing an adequate root canal treatment. However, according to the manufacturer's information, achieving an ISO25 apical caliber with Pro Taper Gold®

mechanized files would occur by the use of the file sequence SX; S1; S2 (Finishing files) and F1; F2 (Shaping files).

2.4 Measurement of working time

The measurement of the working time was carried out by timing the seconds in which the files rotate inside the root canal, eliminating the time necessary for changing manual and/or mechanical files from the micromotor handpiece, until the K-File® files and/or or Pro Taper Gold® encountered resistance and were therefore removed and cleaned; thus completing the cycle for each file, both mechanical and manual, until the ISO25 apical caliber is reached. In other words, the Digital Chronometer was stopped when the files did not work inside the canal and reactivated at the same time as the insertion of the next file in the sequence up to the ISO25 diameter.

2.4.1 Statistical analysis

The data collected were processed using the IBM SPSS Statistics vs. 26.0 software. The Shapiro-Wilk test was applied to verify data normality. Accordingly, to non-normal distribution, Mann-Whitney U test was applied. The significance level was 5% for all statistical tests (p <.05).

3. Results

Table 1 illustrates the total time taken for root canal preparation in each group.

The ProTaper Gold® system exhibited the shortest preparation time for both natural and artificial teeth compared to the manual technique, with statistically significant disparities in both groups ($p< 0.05$).

Within each preparation technique, the duration required for natural teeth was longer than for artificial teeth. However, there were no statistically significant differences between them ($p> 0.05$).

TABLE 1 - Total time of root canal preparation for each group

	Total preparation Time (s)	
	Mean ± SD	Median
Natural Teeth Manual Technique	149.28 ± 33.05	147.92
Natural Teeth ProTaper Gold®	103.57 ± 31.23	96.66
Artificial Teeth Manual Technique	131.36 ± 42.00	122.10
Artificial Teeth ProTaper Gold®	86.78 ± 23.08	79.87

4. Discussion

4.1 Introdution Discussion

In the context of this experimental study, we compared the preparation time of two root canal preparation techniques: one manual, using K-Files, and one mechanized with the Pro Taper Gold® system. These techniques were applied on both natural teeth and artificial teeth, in order to examine any differences in the time required for preparation between the two types of teeth.

A key objective of this research was to determine whether there was a significant temporal disparity in manual and mechanical preparation between natural and artificial teeth. This evaluation is crucial to understand the suitability of using artificial teeth in clinical and educational contexts, thus contributing to improving endodontic practices.

From the results obtained for the manual technique, it emerges that natural teeth required a slightly longer average preparation time than artificial teeth, recording 149.28 seconds and 131.36 seconds respectively. However, this difference did not reach statistical significance (p >0.05), suggesting that, although there is variation, the preparation time of the manual technique is not significantly influenced by tooth type.

In contrast, in the mechanical technique with the Pro Taper Gold® system, the natural teeth took an average of 103.57 seconds compared to 86.78 seconds for the artificial teeth. Also in this case, the difference was not statistically significant (p >0.05), indicating that, like the manual technique, the time of preparation of the Pro Taper Gold® system is consistent between natural and artificial teeth.

Data collected from the analysis of root canal preparation times were examined to evaluate differences between both techniques and identify any disparities between natural and artificial teeth. It was found that the Pro Taper Gold® system was significantly quicker to prepare than the manual technique, for both natural and artificial teeth. For example, the manual technique took an average of 149.28 seconds while the Pro Taper Gold® system took 103.57 seconds. This time difference was statistically significant (p <0.05), indicating that the adoption of the Pro Taper Gold® system effectively reduces root canal preparation time in natural teeth.

Similarly, for artificial teeth, the manual technique took an average of 131.36 seconds, while the Pro Taper Gold® system took 86.78 seconds. Again, the time difference was

statistically significant (p <0.05), suggesting that the Pro Taper Gold® system needs less time to total preparation than the manual technique even in artificial teeth.

Comparing the results of the present study with the results obtained with the study shown by Luz et al. (2014), that compared the preparation time with manual technique between natural teeth and artificial teeth, prespared by dental students and by specialists, that reported A preparation time for natural teeth generally longer compared to artificial teeth for both groups of operators., results that are in line with the results of the present study.

In the study by Reis et al. (2023), that compared the preparation time using ProTaper Gold in natural teeth and an artificial tooth (TrueTooth®) found that, although the preparation of natural teeth needed a second more than the preparation of the artificial teeth, no statistically significant differences were found between natural and artificial teeth, these results are in accordance with the results of the present study.

These findingds can be explained by the difference of hardness between human dentin and the resin that constitutes the artificial teeth, as stated before, the major drawback of artificial teeth is the low physical similarity of tissues such as dentin and enamel, due to the different physical possibilities of the resin (Reymus et al., 2020).

Regarding the preparation time with Protaper Gold in natural teeth, as stated before, the results of the present study was 103,57 seconds, in contrast to the values described in the study of Reis et al. (2022) and Arslan et al. (2017) with preparation time respectively of 64,3 seconds and 78 seconds. This difference could be explained with the operator experience since that in the present study the operator was an undagraduated study with no clinical experience with the ProTaper Gold system, contrarily to the other studies in wich the operators were experienced. An experienced operator normally needs less time to total preparation than an unexperienced one as seen in the study of Tchorz et al. (2015) and in the study of Dablanca et al. (2022), that evaluated the preparation times between unexperienced and experienced operators with manual tecnhnique and mechanical preparation respectively.

In a recent review article, the potential of 3D printers in creating tooth models for endodontics was explored, comparing them with natural teeth traditionally used in ex vivo studies and pre-clinical courses. The authors outline how 3D printed teeth represent a beneficial alternative to natural teeth, highlighting manufacturing methods, current issues, and future research directions. The limitations of natural teeth, including difficulty of

sourcing, ethical considerations, risks of cross-infection and complexity of sterilization and storage procedures, are compared with the advantages of 3D printed teeth, which offer ease of sourcing, no risk of infection and no need for liquid storage. However, 3D printed teeth present challenges such as differences in radiopacity and hardness compared to human dentin. The authors conclude that 3D printed teeth could become the new standard in ex vivo studies and endodontic training, offering more accessible, safe and effective models for dental education and research (Reis et al., 2022).

Based on the available evidence, the study demonstrated concordant opinions for the use of artificial teeth in preclinical endodontic training which achieved similar educational results compared to human extracted teeth (Decurcio et al., 2019). Although the experiences reported by practitioners were different, the overall results were comparable, highlighting the effectiveness of artificial teeth as an educational tool (Yekta-Michael et al., 2021).

A study that analyzed the technical quality of root canal treatments performed by dental students during their university training. The research aimed to answer two main questions: What is the frequency of technically acceptable root canal fillings evaluated radiographically by university students? And what are the most common radiographically evaluated errors reported in these treatments? From the data analysis, it emerged that the overall frequency of technically acceptable root canal fillings was 48%. Among these, 52% were related to anterior teeth, 49% to premolars, and 26% to molars. The most common procedural errors included ledge formation, furcal perforations, apical transportation, and apical perforations. The overall quality of evidence was judged to be very low. The study concludes that the technical quality of root canal fillings performed by university students is low, suggesting that endodontic education at the university level has limited success (Ribeiro et al., 2018).

4.1.2 Morphological reproduction quality of artificial tooth

The repertoire of hard tissues in the human dental pulp takes on numerous configurations and shapes. A thorough understanding of tooth morphology, careful interpretation of angled radiographs, proper access preparation, and a detailed exploration of the tooth's interior are essential prerequisites for a successful treatment outcome. This article by Vertucci (2005) describes and illustrates that a deep comprehension of the complexity of

the root canal system is crucial for understanding the principles and challenges associated with shaping and cleaning. Furthermore, it is essential for determining the apical limits and dimensions of root canal preparations and for performing successful microsurgical procedures. To expand further, the intricacies of tooth morphology present a significant challenge in endodontic treatment. Each tooth's unique anatomical features require careful consideration during diagnosis and treatment planning. The use of advanced imaging techniques, such as 3D cone beam computed tomography can provide more detailed insights into the internal structure of teeth, revealing hidden canals and intricate configurations that standard radiographs might miss. In addition, magnification tools like dental operating microscopes allow endodontists to visualize the root canal system with greater precision. Enhanced illumination provided by these microscopes aids in identifying fine details within the canals, leading to more accurate cleaning and shaping. This meticulous approach helps in removing all necrotic tissue and bacteria, which is crucial for preventing future infections and ensuring long-term treatment success. The article also emphasizes the importance of continuous education and training for dental professionals. Mastery of modern endodontic techniques and staying updated with the latest advancements in the field are vital for achieving optimal outcomes. Understanding the variations in root canal anatomy and adapting techniques accordingly can significantly improve the efficacy of endodontic procedures. In conclusion, a comprehensive grasp of the complexities of the root canal system, aided by advanced imaging and magnification technologies, is indispensable for successful endodontic treatment. This understanding not only facilitates effective cleaning and shaping but also ensures precise apical limit determination and enhances the success rates of microsurgical interventions. The insights provided by Vertucci (2005) serve as a valuable resource for endodontists striving for excellence in patient care.

To reiterate the three-dimensional morphological conformity of the root canal of artificial teeth, the research conducted by Razavian et al. (2021) showed favorable opinions regarding the internal and external anatomy of artificial teeth, the coronal pulp chamber, the root canal, manipulation and radiographic imaging. This study found that the content of the pulp space and the hardness of the artificial teeth were considered satisfactory and necessary requirements to enable adequate training in endodontics for students. These results indicate that the artificial teeth presented in this study represent valid alternatives in university teaching, where there is a need for a standardized model both for the

evaluation and for the standardization of the procedures, in order to be able to be used in large classrooms with a high number of students.

4.1.3 Quality of the DRSK® artificial tooth model

As demonstrated in the study by Said Yekta-Michael et al. (2020) the DRSK® artificial tooth model has proven to be a promising candidate as an alternative to extracted teeth or as a supplementary tool to enhance dental education. Students rated both variants of the DRSK® model positively, with particularly high scores in the overall rating. Student ratings of anatomical pulp morphology increased significantly from 5.4 ± 1.1 (mean ± SD) to 5.9 ± 0.9 (mean ± SD; $p < 0.05$) for the modified model. Additionally, students perceived a significant improvement in their ability to flare root canals after applying the modifications, with ratings increasing from 4.8 ± 1.6 (mean ± SD) to 5.6 ± 1.0 (mean ± SD; $p < 0.05$). These findings further support the adoption of artificial teeth in dental education, suggesting that they can offer a realistic and standardized learning experience for dental students.

4.1.4 Manual and mechanical difference

The evolution of root canal instrumentation techniques from the use of hand instruments to mechanical and rotary devices highlights the importance of nickel-titanium alloys and smart technologies in improving clinical efficiency and patient comfort. Through an overview of key historical developments and technological innovations, including digital imaging and navigation systems, the files address the challenges presented by complex root canal anatomy and current instrumentation techniques, as well as the potential of emerging trends such as artificial intelligence and advanced materials (Srivastava, 2024).

In conclusion, the experimental study proposed in this text highlighted how the mechanized Pro Taper Gold® system is significantly faster than the manual technique with K-File in root canal preparation, both on natural and artificial teeth. The collected data clearly indicate that the preparation time is substantially reduced with the use of the Pro Taper Gold® system, with statistically significant time differences ($p < 0.05$) for both types of teeth. This result suggests that adopting mechanized techniques can improve efficiency and reduce the time required for endodontic procedures, potentially increasing clinical productivity. Furthermore, the study aims to emphasize that the use of artificial teeth as study models is a valid and promising alternative to natural teeth. These artificial

models offer numerous advantages, including greater availability, safety, and standardization of dental education and training. The use of artificial teeth can overcome the difficulties related to the procurement and anatomical variability of natural teeth, ensuring a more controlled and reproducible learning environment. Additionally, artificial teeth can be used without the ethical and logistical complications associated with the use of human teeth, thus facilitating continuous education and the updating of dental skills. Therefore, the study highlights not only the effectiveness of the Pro Taper Gold® system in reducing root canal preparation times but also the importance and benefits of integrating artificial teeth into dental training programs. These models can help improve the quality of education, allowing students and professionals to acquire practical skills in a safe and controlled context. Ultimately, the adoption of mechanized techniques and the use of artificial models represent significant advancements in the modernization and optimization of endodontic practice and professional training in dentistry.

4.2 Limitations and Recommendations for Future Research

Despite the statistically significant results obtained, the study presents some limitations that must be considered for a correct interpretation of the data.

One of the main limitations is the relatively small number of samples used, with 20 natural teeth and 20 artificial teeth. A larger sample could provide more robust and generalizable results, allowing greater confidence in the conclusions drawn. A larger sample size could also improve the statistical validity of the study by reducing variability and increasing the precision of estimates.

Furthermore, the study focused exclusively on single-rooted teeth, thus limiting the applicability of the results to all tooth types. It would undoubtedly be of common interest to extend the research to multi-root teeth to verify whether the differences observed in preparation techniques are also consistent in situations in which the root canal system is more complex. Multi-root teeth have a much more complicated root canal morphology, with potential anatomical variations that could significantly influence the effectiveness of different preparation techniques.

Another limitation concerns the type of artificial teeth used. Although DRSK® brand artificial teeth are declared by the manufacturer as reliable endodontic models, their characteristics may not perfectly replicate those of natural teeth. In particular, there may be significant differences in tactile response and shear resistance, which could influence

operators' perception and, consequently, treatment outcomes. The mechanical and physical properties of artificial teeth may not exactly match those of natural teeth, thus affecting the accuracy of the simulation and the generalizability of the results.

Considering the limitations mentioned, future research should aim to expand the number of samples and include multi-rooted teeth to fully understand the effectiveness of root canal preparation techniques. A more varied sample that includes different types of teeth and a greater number of specimens would allow us to obtain a more complete and detailed view of the differences between preparation techniques and their applicability in different clinical situations.

It would also be helpful to compare different types of artificial teeth to determine which models are most representative of natural teeth. Comparing different materials and designs of artificial teeth could lead to a better understanding of which model provides the most realistic simulation, thus improving the quality of preclinical training.

5. Conclusion

Within the limitations of the present study, the following conclusions can be drawn:

1 - Mechanical preparation requires less time to complete total root canal preparation compared to the manual technique, regardless of the type of teeth used.

2 - Preparing natural teeth takes more time than preparing artificial teeth, irrespective of the preparation technique employed.

Future research should aim to include multi-rooted teeth to fully understand the effectiveness of root canal preparation techniques; also should aim to compare different types of artificial teeth to identify which models most accurately represent natural teeth. By evaluating various materials and designs of artificial teeth, researchers could gain a better understanding of which model offers the most realistic simulation, thereby enhancing the quality of preclinical training.

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Appendix

UNIVERSIDADE FERNANDO PESSOA

Exma. Senhora
Prof. Doutora Sandra Gavinha
Diretora da FCS

Nº	Data
FCS/MMED – 497/23-2	01 de fevereiro de 2024

Exma. Senhora Professor Doutora,

A Comissão de Ética apreciou a resubmissão do projeto de investigação apresentado por Stefano Caputo, intitulado "In vitro evaluation of manual and mechanical canal preparation time: natural versus artificial teeth", a realizar no âmbito do Mestrado Integrado em Medicina Dentária.

Foram realizadas todas as alterações solicitadas.

Deste modo, a Comissão de Ética considera nada haver a opor quanto à realização deste projeto.

Com os melhores cumprimentos,

A Presidente da
Comissão de Ética da UFP
Inês Lopes Cardoso

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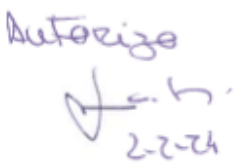
* (chamada para a rede fixa nacional)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