UNIVERSIDADE FERNANDO PESSOA

INFLUENCE OF OPERATOR EXPERIENCE ON CANAL PREPARATION TIME WITH THREE ENDODONTIC SYSTEMS – AN IN VITRO STUDY

[Influência da experiência do operador no tempo de preparação do canal com três sistemas endodônticos – um estudo in vitro]

Dissertação de Mestrado

Medicina Dentária

Fadi Al Kafri

Orientador:

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This thesis is dedicated to my beloved mother, Suzan. who always dreamed of seeing me become a dentist. Her unwavering support, love, and belief in me have been the foundation of my success. She was my biggest cheerleader, always encouraging me to pursue my dreams and never give up, even in the face of challenges.

Mom, your strength, wisdom, and compassion have shaped me into the person I am today. Though you are no longer with us, I feel your presence in every step I take. Your dreams and aspirations for me have been my guiding light, and it is with immense gratitude and love that I dedicate this work to you.

Thank you for your endless sacrifices, for believing in me when I doubted myself, and for teaching me the value of hard work and perseverance. I hope this achievement makes you as proud as you always made me feel.

This thesis is for you, Mom. Your legacy lives on in every success I achieve. The God bless you.

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RESUMO

Introdução: O sucesso do tratamento endodôntico depende muito da preparação eficiente e completa do sistema de canais radiculares. Avanços na instrumentação de níquel-titânio (NiTi) melhoraram significativamente a facilidade e a eficácia desse processo. No entanto, a influência da experiência do operador no desempenho de diferentes sistemas NiTi continua sendo uma consideração importante. Compreender quais sistemas proporcionam os tempos de preparação mais eficientes e têm as curvas de aprendizagem mais curtas pode beneficiar grandemente a prática clínica. Objetivo: O objetivo deste estudo é avaliar a influência da experiência do operador no tempo de preparação endodôntica de dentes unirradiculares utilizando três sistemas de instrumentação NiTi: ProTaper Gold®, WaveOne Gold® e Endogal®. O estudo visa avaliar o tempo total necessário para a preparação, determinar se há diferenças entre dois operadores com diferentes níveis de experiência e identificar qual sistema tem a curva de aprendizagem mais curta. Materiais e Métodos: Este estudo foi conduzido em 60 dentes naturais unirradiculares, divididos em seis grupos de dez dentes cada. Três grupos foram preparados por um operador inexperiente usando os três sistemas de instrumentação, e os outros três grupos foram preparados por um operador experiente. O tempo total de preparação foi registado até que um tamanho apical de 25 fosse alcançado, com o cronômetro registando apenas o tempo de preparação ativa, iniciando quando o instrumento entrava no canal e parando quando era removido, excluindo pausas. Um nível de significância de 5% ($p<0,05$) foi estabelecido para todos os testes estatísticos. Resultados: Os resultados deste estudo mostraram que o sistema WaveOne Gold® exigiu o menor tempo para a preparação do canal radicular em comparação com os sistemas ProTaper Gold® e Endogal®. O sistema Endogal® demonstrou desempenho intermediário, exigindo mais tempo que o WaveOne Gold®, mas menos que o ProTaper Gold®. Este desempenho intermediário é atribuído ao uso de um arquivo a menos do que o sistema ProTaper Gold®, o que simplifica o processo de preparação. O operador inexperiente precisou de significativamente mais tempo para as preparações do canal radicular em comparação com o operador experiente, destacando a importância da experiência clínica. O sistema ProTaper Gold® mostrou uma diferença substancial nos tempos de preparação entre os operadores, indicando uma curva de aprendizagem mais acentuada, enquanto o sistema Endogal® apresentou diferenças menos pronunciadas. O desempenho consistente do sistema WaveOne Gold® entre operadores inexperientes e experientes sugere que é o sistema mais acessível para profissionais de diferentes níveis de experiência. O tempo reduzido de preparação e a variação mínima de desempenho destacam sua eficiência e facilidade de uso. Conclusão: O sistema WaveOne Gold® demonstrou tempos de preparação significativamente mais curtos em comparação com os sistemas ProTaper Gold® e EndoGal®. A experiência do operador foi um fator crucial nos tempos de preparação, com clínicos experientes que realizaram constantemente procedimentos mais rápidos do que os menos experientes em todos os sistemas. O sistema WaveOne Gold® mostrou variação mínima de desempenho entre operadores experientes e inexperientes, sugerindo uma curva de aprendizagem mais curta.

Palavras-chave: Preparação endodôntica, ProTaper Gold®, WaveOne Gold®, Endogal®, experiência do operador, tempo de preparação.

ABSTRACT

Introduction: Endodontic treatment success relies heavily on the efficient and thorough preparation of the root canal system. Advances in nickel-titanium (NiTi) instrumentation have significantly improved the ease and effectiveness of this process. However, the influence of operator experience on the performance of different NiTi systems remains an important consideration. Understanding which systems provide the most efficient preparation times and have the shortest learning curves can greatly benefit clinical practice. Aim: The objective of this study is to evaluate the influence of operator experience on the endodontic preparation time of single-rooted teeth using three NiTi instrumentation systems: ProTaper Gold®, WaveOne Gold®, and Endogal®. The study aims to assess the total time required for preparation, determine if there are differences between two operators with different levels of experience, and identify which system has the shortest learning curve. Materials and Methods: This study was conducted on 60 natural single-rooted teeth, divided into six groups of ten teeth each. Three groups were prepared by an inexperienced operator using the three instrumentation systems, and the other three groups were prepared by an experienced operator. The total preparation time was recorded until an apical size of 25 was achieved, with the timer tracking only active preparation time by starting when the instrument entered the canal and stopping when removed, excluding pauses. A significance level of 5% ($p<.05$) was set for all statistical tests. Results: The results of this study showed that the WaveOne Gold® system required the least amount of time for root canal preparation when compared to the ProTaper Gold® and Endogal® systems. The Endogal® system demonstrated intermediate performance. It required more time than WaveOne Gold® but less than ProTaper Gold®. This intermediate performance is attributed to the use of one fewer file than the ProTaper Gold® system, which streamlines the preparation process. The inexperienced operator needed significantly more time for root canal preparations compared to the experienced operator, highlighting the importance of clinical experience. The ProTaper Gold® system showed a substantial difference in preparation times between operators, indicating a steeper learning curve, while the Endogal® system exhibited less pronounced differences. The consistent performance of the WaveOne Gold® system across both inexperienced and experienced operators suggests that it is the most accessible system for practitioners of different experience levels. The reduced preparation time and minimal performance variation highlight its efficiency and ease of use. Conclusion: The WaveOne Gold® system demonstrated significantly shorter preparation times compared to the Protaper Gold® and EndoGal® systems. Operator experience was a crucial factor in preparation times, with experienced clinicians consistently performing faster than less experienced one across all systems. The WaveOne Gold® system showed minimal performance variation between experienced and unexperienced operators, suggesting a shorter learning curve.

Keywords: Endodontic preparation, ProTaper Gold®, WaveOne Gold®, Endogal®, operator experience, preparation time.

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LIST OF ABBREVIATIONS AND ACRONYMS

®	Registered Brand
°C	Celsius Degree
A	Austenite
ANOVA	Analysis of Variance
DSC	Differential Scanning Calorimetry
FCS-UFP	Faculdade de Ciencias da Saude, Universidade Fernando Pessoa
IBM	International Business Machines Corporation
M	Martensite
mm	Millimeter
N/cm	Newton per Centimeter
Ni´	Nickel
nm	Nanometer
OK	Oklahoma
R	R Phase
rpm	Rotations per Minute
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
Ti	Titanium
USA	United States of America
WL	Working Length

I. INTRODUCTION

1. Definition of Endodontics

The term "Endodontics" originates from the Greek words "endo," meaning inside, and "odons," meaning tooth. Combined, they refer to the study of the inner part of the tooth, specifically the dental pulp. Endodontics is a branch of dentistry focused on the morphology, physiology, and pathology of the human dental pulp and periapical tissues, as well as the prevention and treatment of diseases and injuries affecting these tissues (European Society of Endodontology, 2006).

In essence, endodontics includes all necessary operations for maintaining healthy teeth as well as the treatments needed to restore diseased teeth to their original state of health (Karamifar et al., 2020).

Human teeth that have erupted have crowns covered in symbiotic microbial communities, which are primarily made up of Gram-positive saprophytic bacteria that are generally unharmful to the tooth. These communities attach themselves as biofilms to the highly mineralized enamel, which forms an impenetrable barrier to safeguard the loose connective tissue and underlying mineralized dentin located in the tooth's center, known as the dental pulp. However, certain bacterial populations from these communities emit acids that gradually demineralize enamel when they are introduced in an environment rich in sugar (Hamilton, 2000). As a result, a carious lesion appears, which is defined by the formation of a cavity that is home to "cariogenic" bacteria that multiply and produce more acids, deepening the lesion over time (Farges et al, 2009).

Gram-positive bacteria that predominate the dentin caries microflora, such as streptococci, lactobacilli, and actinomyces, break down dentin when the enamel barrier is compromised (Love & Jenkinson 2002). These germs proliferate and undergo metabolic processes that release bacterial components into dentinal tubules, where they diffuse towards the peripheral pulp. Bioactive molecules may potentially be released from the dentin matrix as a result of dentin demineralization (Cooper et al., 2011). The pulp might respond in a way that allows it to tolerate the discomfort and continue to operate. However, if the caries has spread to the pulp's surrounding area, the tissue may die and experience excruciating agony pulp necrosis, which can be partial or total (Heyeraas & Berggreen, 1999).

1.1. Pulpitis (Reversible/Irreversible/Necrosis)

1.1.1 Reversible pulpitis

clinical aspects include a decrease of the stimulation threshold for A-delta nerve fibers, a localized rise in the intra-pulpal pressure threshold, and hypersensitivity to thermal (hot, cold, or sweet) stimuli that quickly goes away when the stimulus is withdrawn. The etiology of reversible pulpitis is as follows: bacterial, chemical, or physical irritation (Iaculli et al., 2022). Histologically, it is distinguished by the rupture of the odontoblastic layer by inflammatory cells and the presence of dilated blood vessels (Stashenko et al., 1998).

1.1.2. Irreversible pulpitis

is characterized by hypersensitivity to thermal stimulus (hot or cold), which causes discomfort that lasts for a few seconds after the stimulus is removed. It typically develops from reversible pulpitis, and is a severe inflammation of the pulp. The pain is intense, continuous, poorly localized, and might extend to the neck, ear, or eye (Iaculli et al., 2022). Histologically, it is distinguished by inflammatory cells infiltrating the limited area of necrosis and dilated blood vessels (Stashenko et al., 1998).

1.1.3. Pulpal necrosis

also known as nonvital pulp, results in the absence of pulpal blood supply and dysfunction of pulpal nerves. It is the only clinical classification that makes an explicit attempt to characterize the pulp's histologic state. This illness comes after irreversible pulpitis, which may be symptomatic or asymptomatic. Until symptoms arise due to the disease process spreading to the peri radicular tissues, a tooth that has reached total necrosis will usually remain asymptomatic. A tooth that has pulp necrosis will not react to cold stimulation or electric pulp tests (Patel & Chong, 2010).

1.2 Principles of Endodontics

Endodontic therapy aims to remove the bacterial biofilm and its byproducts (Jhajharia et al., 2015), together with any irreversibly inflamed or necrotic pulp tissue, from the root canal and the dentinal tubules that line the root canal system. After endodontic treatment, the root canal is sealed (obturated) with a biologically suitable filling material to maintain and promote the tooth's periapical health. When the root canal is obturated, the definitive restoration is placed in place to achieve many goals: it supports the patient's occlusion, seals the obturated root canal to avoid oral contamination and reinfection, and restores the tooth's functionality. This all-inclusive method guarantees the tooth's long-term health and performance after endodontic therapy (Spielman et al., 2012).

Recent decades have witnessed a tremendous evolution in the field of endodontics, characterized by improvements in a number of areas. These include a better understanding of the pathophysiology and microbial etiology of endodontic diseases, innovations in chemical and mechanical instrumentation, the development of dental tissue regeneration and repair techniques targeted at improving clinical outcomes (Blum 2020).

These developments have given practitioners more confidence to handle challenging clinical situations, which has improved results in teeth healing (Amza et al., 2020).

It is important to realize that endodontic therapy's effectiveness is dependent on more than just technology. In fact, infection is the primary cause of endodontic therapy. This implies that the main goal of therapy is to eliminate the root canal infection so that the tooth is protected throughout time and doesn't get inflamed or negatively impact the body's general health. This is undoubtedly the long-held belief in the endodontic field (Bergenholtz, 2016).

There are three main rules to follow during this treatment: identify and prepare all main canals using endodontic instruments, find and respect working lengths, and assess the initial apical canal diameter to achieve optimum shaping width (Simon et al., 2009). One of the most crucial phases of endodontic treatment is root canal preparation, which is closely linked to both concurrent and following disinfection. Its goals are to remove germs, pulp tissue, and other byproducts and to preserve the original anatomy while providing a form that is appropriate for root canal obturation (Peters, 2004). The necessity of reducing therapeutic failures in endodontics (periapical infections) and their consequences in terms of public health (fate of the treated tooth, prosthetic replacement on the arch or impact on general pathologies such as cardiovascular disease or diabetes) implies the need to promote the quality of this care (Astolfi et al., 2013; Segura-Egea et al., 2012; Simão et al., 2013).

1.3 The Nickel-Titanium revolution

Before the development of Nickel-Titanium, more equipment was needed to achieve the perfect root canal form, and numerous methods, procedures, and techniques were created over time (Grande et al., 2023). For example, stainless steel tools are not recommended for substantial apical expansion in thin, curved canals because of their rigidity (Montalvão et al., 2014).

The introduction of Nickel-Titanium alloy equipment has been a significant development in dentistry. Since the 1990s, the design of Nickel-Titanium instruments has significantly evolved, with notable advancements in the manufacturing and processing of the alloy (Haapasalo & Shen, 2013) The properties of these instruments can be modified depending on the type of alloy, the degree of taper, and the cross-sectional design. From the first files manufactured, improvements have been made leading to the files we use today, utilizing various technologies according to their function and design characteristics. These technologies include electropolishing, M-Wire, R-Phase, CM-Wire, Blue/Gold treatment, electrical discharge machining, and Max-Wire (Liang et al., 2022).

1.3.1 Presentation — Nickel-Titanium alloys

The majority of Nickel-Titanium alloys used in root canal therapy are made up of roughly 55% nickel (Ni) and 45% titanium (Ti) by weight. The ideal balance of strength and flexibility needed for root canal instrumentation is provided by these particular ratios of titanium to nickel (Montalvão et al, 2014)

In 2010, Zinelis et al. studied the composition of 10 Nickel-Titanium files on the market. 9 files showed a nickel content of 54.2-56.2% by weight, and 1 file was the exception with a low nickel content (52.1% by weight) (Zinelis et al., 2010).

The superelastic behavior of Nickel-Titanium files is a major determinant of their flexibility (Taschieri et al., 2005). This behavior is impacted by various elements such as the alloy's crystallographic phases and the mechanical, chemical, and thermal treatments that have been done to it (Montalvão et al., 2014).

1.3.2 Crystal Structures

1.3.2.1 Phase of Austenitic

The basic phase is Austenite B'2, which has a cubic structure. A very regular latticework is formed by the interlocking of the crystals. it is a stable phase at high temperatures.

It is recognized that the alloy's hardness is derived from this crystalline structure (Shen et al., 2013).

1.3.2.2 Phase of Martensitic

phase B'19 martensite, with its monoclinic structure, is, unlike austenite, stable at low temperatures. The crystals (called martensite variants) can be oriented in two different ways, giving self-accommodated martensite (obtained by cooling) or oriented martensite (obtained following the application of stress) (Jordan & Rocher, 2009). In the first case, the crystals are twinned and arranged in a twinned pattern, with little or no macroscopic impact on shape. In the 2nd case, following the application of stress, the crystals are detwinned in this case, macroscopic deformation becomes visible. This structure gives the alloy its ductility (Thompson, 2000).

So a Nickel-Titanium material in the martensitic phase will be much more flexible than in the austenitic phase and will deform easily, also will reach irreversible deformation under stress more quickly (Otsuka & Ren, 2005).

1.3.2.3 The R phase

The R phase is in between austenite and martensite and has a trigonal or rhombohedral structure. The Nickel-Titanium alloy in the R phase is even more flexible than in martensite because of its lower Young's modulus compared to austenite and martensite (Kuhn & Jordan, 2002). Under specific circumstances, the R phase develops during cooling (Duerig & Bhattacharya, 2015), before the martensitic phase, and during heating, before to the austenitic phase: austenite (A) <> R phase (R) <> martensite (M) (Urbina, 2010).

1.4 Technology in Nickel-Titanium

1.4.1 CM-wire

In contrast to traditional Nickel-Titanium alloys, the CM-wire alloy undergoes two phases of transformation when heated and cooled: the martensitic phase, the R-phase, and the austenitic phase, which also happens during the reverse transformation. According to (Zhou et al., 2013), the only direct change that occurs in ordinary Nickel-Titanium alloys during cooling is from austenitic to martensitic.

The advent of CM-wire files marks a significant development in endodontic instruments, diverging from the conventional shape memory characteristics observed in traditional Nickel-Titanium files (Shim et al., 2017). This innovation in file design has been exemplified by the introduction of the ProDesign R and ProDesign Logic series. The ProDesign R (25/.06) operates in a reciprocating motion, whereas the ProDesign Logic (40/.05) utilizes a rotary motion, showcasing a hybrid design and CM heat treatment as per the manufacturer's specifications. These advancements aim to enhance the performance and safety of endodontic procedures by offering greater flexibility and resistance to cyclic fatigue (Rodrigues et al., 2016).

1.4.2 MaxWire

FKG Dentaire has introduced a groundbreaking thermomechanically treated alloy known as Max Wire, marking a significant advancement in endodontic technology. This alloy is the first of its kind to combine the properties of shape memory effect and superelasticity, features that greatly enhance clinical practice. Instruments made from Max Wire, such as the XP-endo Shaper® and the XP-endo Finisher®, exhibit remarkable capabilities due to these properties (Zupanc et al., 2018).

At room temperature, these Max Wire instruments maintain a relatively linear shape in their martensitic phase. However, when exposed to intracanal temperatures, they transform into the austenitic phase and adopt a curved shape. This transformation demonstrates the shape memory effect, enabling the instruments to adapt perfectly to the root canal's morphology. Consequently, these instruments provide superior preparation of the root canal, especially in navigating complex anatomical structures (Zupanc et al., 2018).

1.4.3 M-Wire

A new Nickel-Titanium wire named M-Wire, has been developed through a proprietary thermomechanical processing procedure (Ye & Gao, 2012). It undergoes a specialized stretching process under intricate temperature conditions, raising the crystal phase transition temperature from 16 - 31 °C to 47 °C. As a result, the alloy contains a considerable amount of stable martensite at room temperature, leading to reduced stiffness and enhanced elasticity (Liang & Yue, 2022). M-Wire showed significantly improved cyclic fatigue resistance on endodontic rotary instrument products in comparison with those made of conventional superelastic Nickel-Titanium alloys M-Wire contains all 3 crystalline phases, including deformed and microtwinned martensite, R-phase, and austenite (Ye & Gao, 2012; Pereira et al., 2013).

1.4.4 Thermally Treated Alloys

A new Nickel-Titanium alloy with thermal treatment application were introduced and the instrument's surface develops a layer of titanium oxide as a result of repetitive heating and cooling. For instruments made of blue alloy, this oxide layer has a thickness of 60 – 80 nm, while for instruments made of gold alloy, it is 100 – 140 nm (Alcalde et al., 2018).

1.4.5 Gold Alloys

Dentsply (Tulsa, OK, USA) introduced gold heat-treated equipment with a unique gold color (Chan et al., 2022). After being produced, the instruments underwent multiple heat treatments followed by a gradual cooling process, giving them a unique surface color that matched the thickness of the titanium oxide coating. The new heat treatment, according to the company, makes the files more flexible. Dentsply manufactures the Wave One Gold and Protaper Gold heat-treated Nickel-Titanium shaping devices, which have distinct geometric designs and kinematics (Shi et al., 2022). Differential Scanning Calorimetry (DSC) analysis of Protaper Gold showed an austenite finish temperature of approximately 50°C, suggesting that these instruments primarily consist of martensite or R-phase under clinical conditions (Hieawy et al., 2015).

1.5 Design of Nickel-Titanium files

The key design elements of Nickel-Titanium files include the flute-like cutting edge, the depth of the flute, the tip, cross-sectional shape, rake angles, and radial lands (Lian & Yue, 2022).

1.5.1 Helical Flute Angle and Pitch

The helical flute angle is created by the intersection of the cutting edge with a cross-section perpendicular to the file's long axis (Dablanca-Blanco et al., 2022). In contrast, the pitch is the distance between two adjacent cutting edges when viewed laterally. (Atmeh, 2016). Typically, a Nickel-Titanium file features 5–15 flutes, and the design of these flutes plays a crucial role in the file's performance (Liang & Yue, 2022). For example, instruments with a constant helical flute angle and pitch are more likely to retain cutting debris within their grooves, especially in the coronal groove, increasing the risk of the instrument becoming lodged in the dentin wall (Versluis, 2012). Altering the pitch and the number of flutes can greatly affect the file's functionality. A smaller pitch combined with more flutes can extend the length of the working cutting edge, improving cutting efficiency, enhancing bending stiffness, and reducing stress (Baek, 2011). Conversely, files with a larger pitch excel in debris removal and flexibility but are more prone to torsional failure due to the uneven distribution of high stress (Yum, 2011; Liang & Yue, 2022).

1.5.2 Flute Depth and Cutting Edge

The depth of the flute, defined as the distance from the tip of the cutting edge to the bottom of the debris removal flute, is vital to the file's performance (Liang & Yue, 2022). During the cutting process of the root canal wall, stress builds up progressively from the cutting edge to the flute. Enlarging the flute space can aid in the efficient discharge of dentin debris during preparation, but it may also concentrate stress near the deep flute, increasing the risk of defects or instrument separation (Xu, 2006).

1.5.3 Rake Angle

The rake angle of engine-driven Nickel-Titanium files, which can be either positive or negative, is determined by the slope and position of the cutting edge. It is represented by two lines: one connecting the cutting tip to the geometric center, and another tangent to the cutting face at the tip (Liang & Yue, 2022). A positive rake angle, where the first line is ahead of the tangent line, allows for high cutting efficiency but leads to rapid wear. Instruments with a neutral or negative rake angle primarily grind the root canal wall, thus reducing dentin cutting efficiency (Guppy et al., 2000).

1.5.4 Taper

Taper refers to the rate at which the diameter of the file increases per millimeter from the tip toward the handle (Berman & Hargreaves, 2015). For example, a file with a taper of 0.2 means that the diameter increases by 0.2 mm for every millimeter from the tip (Dablanca-Blanco et al., 2022).

1.5.5 Diameter

The diameter of the file changes along its length due to its taper. Knowing the diameter at various points is crucial for understanding the stress exerted on the file during use (Dablanca-Blanco et al., 2022).

1.5.6 Radial Land

The features a smooth cutting surface (Haapasalo & Shen, 2013) that reduces the file's tendency to screw into the canal and limits the depth of cut, ensuring more controlled cutting action (Dablanca-Blanco et al., 2022).

1.6 Continuous vs. Reciprocating Motion in Nickel-Titanium Systems

Continuous rotation in Nickel-Titanium instruments refers to the uninterrupted rotary motion of the Nickel-Titanium files during endodontic instrumentation procedures (Matta et al., 2021). In the majority of Nickel-Titanium systems, electric motors and reduction contra-angle handpieces power the file, enabling it to continuously cut the root canal wall by rotating fully, incorporating both centric and eccentric rotary motions within the root canal (Gavini et al., 2018). This rotational movement is advantageous in root canal treatments as it allows for efficient debris removal and shaping of the root canal walls (Dagna, 2016). Nickel-Titanium instruments are renowned for their flexibility and resistance to cyclic fatigue, making them suitable for continuous rotation without compromising their structural integrity (Zanza et al., 2021). This method not only streamlines the procedure by enhancing cutting efficiency but also contributes to better clinical outcomes by maintaining consistent contact with the canal walls, ensuring thorough cleaning and shaping throughout the treatment process (Chan, 2022).

Reciprocal rotation began when (Yared, 2008) presented a new method with a single reciprocating Nickel-Titanium device. This method was an extension of the balanced forces method developed by (Roane et al., 1985; De-Deus et al., 2010). examined the cycle fatigue resistance of Protaper Universal F2 instruments in reciprocating motion and continuous rotation at 250 and 400 rpm, building on Yared's principle. They came to the conclusion that reciprocating motion extends the life of the instrument and emphasized the importance of usage speed in fracture time.

Many writers then investigated this kind of rotation. Reciproc and Wave One were the first two reciprocal rotation systems to hit the market. The distinguishing feature of these instruments lies in their counterclockwise cutting direction, actively cutting if counterclockwise rotation exceeds clockwise rotation due to their cross-sectional design.

However, except for these systems, nevertheless, the majority of instruments are made for cutting in a clockwise direction. Consequently, as long as clockwise rotation predominates, devices designed for continuous clockwise rotation can likewise operate with reciprocating movement (Dablanca-Blanco et al., 2022).

1.6.1 Principal distinctions between reciprocating and continuous rotation

Using the same file system, alternative mechanics were tested, revealing that reciprocating movement exhibits significantly higher resistance to cyclical fatigue (Matta et al., 2021). Opinions vary regarding transportation via canal preparation (Kim et al., 2021). According to (Ahn et al., 2016), reciprocating instruments rely on a single file for canal preparation, whereas continuous rotation instruments may offer better centring capacity due to gradual file sequence utilization. The literature presents conflicting views on apical extrusion of debris; some studies suggest continuous rotation results in more debris extrusion due to multiple instrument use, while others indicate reciprocating rotation leads to increased extrusion (De-Deus et al., 2010). Conversely, rotary instruments generally excel in minimizing debris extrusion and preserving root canal curvature, critical for preventing post-treatment complications like flare-ups (Laurindo et al., 2016). Studies on dentin defects or cracks diverge; while some suggest fewer defects with alternating motion, others find the opposite or no significant differences. Recent research by (De-Deus et al., 2010) suggests pre-existing dentin defects may influence outcomes, questioning previous microcrack studies (Dablanca-Blanco et al., 2022). Both systems demonstrate similar effectiveness in reducing microbial load, including Enterococcus faecalis. However, differences in operational mechanics reciprocating's alternating motion versus rotary's continuous rotation result in varying clinical outcomes such as instrument fatigue and debris management. Therefore, the choice between reciprocating and rotary systems hinges on specific clinical scenarios, dentist experience, and patient needs (Laurindo et al., 2016).

1.6.2 Principle of instrumental shaping

Whether instrumental shaping is performed using an instrument in continuous rotation or reciprocal movement, the practitioner must adhere to a strict protocol. There are five mechanical objectives: achieving a continuous conical preparation, respecting the original root canal path, maintaining the apical foramen in its initial position and limiting its diameter, to facilitate successful root canal obturation and ensure the durability of the treatment (Schilder, 1974). After taking a pre-operative radiograph, the practitioner creates an endodontic access cavity under absolute isolation (Jacob et al., 2021). The primary objective is to prevent contamination of the operative field, this initial phase of the root canal treatment is consistent across all root canal shaping systems. Subsequently, a passive root canal exploration is performed using a K 08 or K 10 file (Alovisi et al., 2018). Irrigation with sodium hypochlorite is essential after each passage of an endodontic instrument, whether manual or mechanized, from the creation of the endodontic access cavity through to the completion of ductal shaping (Abuhaimed & Abou Neel, 2017; Bergmans et al., 2001). Non-compliance with these protocols can lead to instrument fractures, root perforations, or the creation of ledges. For this reason, reduced instrument sequences have been developed to simplify and minimize these potential errors (Ajina et al., 2022).

1.6.3 Protaper gold®

1.6.3.1 Presentation

The ProTaper system is unique in that each instrument has increasingly varying tapers that prepare the canal in both vertical and horizontal directions (Ruddle, 2001).

Pro-Taper gold files have a progressive taper presenting a convex triangular cross-section. The manufacturer says that while Pro-Taper gold instruments are made with a specific thermal treatment, they have the same design as Pro-Taper Universal but are more flexible and resistant to cycle fatigue (Hieawy et al., 2015). Using this system ideally involves setting the motor speed between 250 to 300 rpm and adjusting the torque between 2.6 and 3.0 N/cm. ProTaper files are designed to minimize the risk of instrument fracture caused by binding, utilizing a helical angle and a large pitch distance between spirals. These features, coupled with their triangular cutting section, enhance the system's cutting efficacy significantly (Fayyad & Elgendy, 2011).

1.6.3.2 Files

Shaping Files: The handle of the auxiliary shaping file, known as Shaper X, makes it simple to identify because it without an identification ring. With an overall length of 19 mm, Shaper X, also known as SX, offers great access in restricted areas. The SX file features a D 14 diameter that is getting close to 1.20 mm, a redesigned guiding tip, and a D 0 diameter of 0.19 mm. Compared to the other two shaping files, Shaper X taper from D 0 to D 9 at a substantially faster rate. For instance, the cross-sectional diameters of the instruments at D 6, D 7, D 8, and D 9 are roughly equal to 0.50, 0.70, 0.90, and 1.10 mm (Gagliardi et al., 2015) Shaping File No. 1 and No. 2, often known as S 1 and S 2, are easily identified by their handles' purple and white identification rings, respectively. The S 1 and S 2 files have modified guiding tips with D diameters of 0.17 mm and 0.20 mm, respectively, and their D 14 maximal flute diameters are close to 1.20 mm (Gagliardi et al., 2015).

Finishing Files: The handles of three Finishing files, designated F 1, F 2, and F 3, contain identification rings that are yellow, red, and blue, respectively. These rings correspond to D 0 diameters of 0.20, 0.25, and 0.30 mm. The F 1, F 2, and F 3 feature set tapers of 7%, 8%, and 9% between D 0 and D 3 (Gagliardi et al., 2015; Ruddle, 2001).

1.6.3.3 Protocol

The standard protocol for using the ProTaper gold protocol involves taking a pre-operative radiograph to assess the canal morphology, followed by creating an access cavity and irrigating to clean and disinfect the area (Abuhaimed & Abou Neel, 2017). The canal entrance is located and permeability is checked using a manual file, usually size # 10 or # 15. The coronal curvature is eliminated with the shaping file SX, The working length is measured using a manual file # 10 or # 15 with an apex locator or a radiograph with the file in place. The S 1 file is then used to the exact working length, followed by the S 2 file to the working length to shape the middle third and increase the volume of the apical region. Shaping and Finishing files F 1 (yellow ring), F 2 (red ring), and F 3 (blue ring) are used successively to complete the canal shaping, depending on the size of the foramen. If the size is larger than 20/100, F 2 and possibly F 3 finishing files are employed (Ruddle, 2005).

1.6.4 Endogal®

1.6.4.1 Presentation

The endogal ® system, a new system with a parallelogram cross section and instruments with continuous 4% and 6% taper, was utilized throughout the working length of the sequence, with the exception of the X file, which was solely utilized for the removal of coronal interference (Reis et al., 2024; Faus-Matoses et al., 2022).

1.6.4.2 Files

File glide path A: Endogal rotary instrument 15, taper 3%, length 21 mm

File X: Endogal rotary instrument 25, taper 9%, length 19 mm

File B: Endogal rotary instrument 20, taper 4%, length 25 mm

File C: Endogal rotary instrument 25, taper 4%, length 25 mm

File D: Endogal rotary instrument 25, taper 6%, length 25 mm (Reis et al., 2024).

1.6.4.3 Protocol

The root canal procedure involves using instruments sequentially, starting with A until reaching the working length. Each instrument, including X, B, C, and D, is used progressively, with X primarily for coronal interference removal, C, C, and files are used successively to complete the canal shaping, depending on the size of the foramen (Reis et al., 2024).

1.6.5 Wave One Gold®

1.6.5.1 Presentation

Wave One ® Gold represents the newest iteration of the Wave One file series. These files feature a parallelogram cross-section with an 85º degree active cutting edge, designed to alternate between single-and double-point contact. They undergo a specialized gold heat treatment process, which involves heating and then gradually cooling the files post-production. This treatment enhances their flexibility and resistance to cyclic fatigue (Ríos-Osorio et al., 2024).

It incorporates a reverse helix structure, a semiactive guiding tip, and a maximum flute diameter of 1.2 mm. The system maintains a fixed taper from D0–D3 and transitions to a decreasing taper from D4–D16, enhancing both effectiveness and flexibility compared to the Wave One system (Ribeiro et al., 2023; Caviedes-Bucheli et al., 2021).

1.6.5.2 Files

Wave One ® Gold Glider 0.25 mm Dentsply Sirona Endodontics

Wave One ® Gold Small A 0.20 mm or 7%.

Wave One ® Gold Primary A 0.25 mm or 7%. This is the most commonly used option in various cases.

Wave One ® Gold Medium A 0.35 mm or 6%.

Wave One ® Gold Large A 0.45 mm or 5% (Dentsply Sirona) and (Dablanca-Blanco et al., 2022).

1.6.5.3 Protocol

The glide paths is established with Wave One gold Gliderat to the working length (WL) using a reciprocating motion set to the 'Wave One Gold' mode on the X-Smart Plus endodontic motor (Dentsply Maillefer, Ballaigues, Switzerland) (Çiftçioğlu et al., 2023). Select the Wave One Gold® instrument: small (yellow), primary (red), or large (black). Use the selected Wave One Gold® in a reciprocating motion to prepare the canal segment, progression is made with short back-and-forth movements (< 3 mm) under light pressure; the instrument is withdrawn every two or three movements or if it binds; the instrument is then cleaned and the canal thoroughly irrigated. This process is repeated until the length previously reached by the file is achieved (Zunzarren, 2019, p. 172) The recommended rotation speed for this instrument is 350 rpm (Yılmaz & Özyürek, 2017).

II. OBJECTIVES

The objective of this study is to evaluate the influence of the operator's experience on the endodontic preparation time of single root teeth using three Nickel-Titanium instrumentation systems: Protaper Gold ®, Wave One Gold ®, and Endogal ®. Protaper Gold ® is known for its flexibility and cutting efficiency, Wave One Gold ® is recognized for its reciprocating motion which aims to simplify the procedure, and Endogal ® is a newer system designed to optimize endodontic outcomes. This study will focus on the time required to complete the preparation of single root teeth, by two operators with different levels of experience. By comparing the preparation times, the study aims to determine whether the experience level of the operator significantly influences the efficiency of the procedure. Additionally, the study will identify which of the three instrumentation systems offers the shortest learning curve, providing insights into their practicality and ease of adoption for less experienced practitioners.

III. MATERIALS AND METHODS

Ethical Approval:

The study protocol was reviewed and approved by the Ethics Committee of the Faculty of Health Sciences, University of Fernando Pessoa (FCS-UFP) Approval No. FCS/MMED-451/23.

Sample Selection:

From a pool of 87 teeth sixty single-rooted teeth were selected for this study. The criteria for selection included teeth that were free from caries, cracks, or previous endodontic treatments, ensuring uniformity in the sample. These teeth, which were extracted for reasons unrelated to this study, were stored in distilled water solution at room temperature to maintain hydration.

Access Opening:

Using a high-speed dental handpiece equipped with a Dental Bur Diamond Round, an initial access cavity was created on the anterior teeth on the palatal surface.

Shape and Size:

The access cavity was widened with an Endo Z bur to ensure adequate access to the root canal system.

Determining Working Length:

A K-file 10 was inserted into the root canal of the tooth until the tip became visible at the apex. Once the tip of the file was visible at the apex, the file was removed and the measured length was reduced by 1 mm.

Standardization:

Each tooth was adjusted to have a standardized working length of 19 mm, and the coronal portion of the tooth was trimmed to achieve this length.

Grouping:

The 60 teeth were evenly divided into six groups of 10: 4 incisors, 4 canines, and 2 premolars. Three groups were prepared by an inexperienced operator, an undergraduate dentistry student with no clinical experience with the three systems, and the other three groups were prepared by an experienced clinician with 23 years of clinical experience and with clinical experience with the three systems. Each operator used the three Nickel-Titanium instrumentation systems - Protaper Gold ®, Wave One Gold ®, or Endogal ®.

Instrumentation Procedure:

The canal preparation steps varied depending on the system used. Before using the systems, each canal was prepared manually to an apical size of 15 mm.

Protaper Gold ®: Continuous rotation was employed, following the manufacturer's recommended sequence and torque settings.

Final file: The F 2 file was the last file in the sequence, designed to give the final shape to the root canal.

Wave One Gold ®: A reciprocating motion was used following the manufacturer's guidelines for file insertion and movement.

Final file: The Gold Primary file was the last file, used as the main working file for the root canals.

Endogal®: Continuous rotation was utilized with the Endogal® files, adhering to the manufacturer's protocol for sequential file use.

Final file: The D file was used as the final file in the instrumentation process, completing the canal preparation according to the effectiveness parameters set by the manufacturer.

Time Measurement:

A digital stopwatch was used to record the overall amount of time spent preparing each tooth. The timing began as soon as the instrument was first inserted into the canal and stopped whenever the files were taken out. When the files were put back in, the timer started up again, making sure that just the active preparation time was recorded. To guarantee accuracy, any pauses or interruptions were not included in the time that was recorded.

IV. RESULTS

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 normal distribution, Independent-Sample t-test and One-Way ANOVA test were applied. The significance level was 5% for all statistical tests ($p<.05$).

RESULTS

The total time for root canal preparation by each preparation system is shown in Table 1. The Wave One Gold ® system required the least amount of time to prepare the root canals, with statistically significant differences to Protaper Gold ® and EndoGal ® systems ($p<.05$). The Protaper Gold ® system required the most amount of time to prepare the root canals, with statistically significant differences to Wave One Gold ® and EndoGal ® systems ($p<.05$).

Table 1.

Total time of root canal preparation by each preparation system

Data	Total preparation Time (s)	
Protaper Gold ®	Mean ± SD	64,40 ± 23,80
	Median	59,00
Wave One Gold ®	Mean ± SD	19,80 ± 6,57
	Median	20,00
EndoGal ®	Mean ± SD	36,85 ± 12,86
	Median	37,50

Graph 1.

Total time of root canal preparation by each preparation system

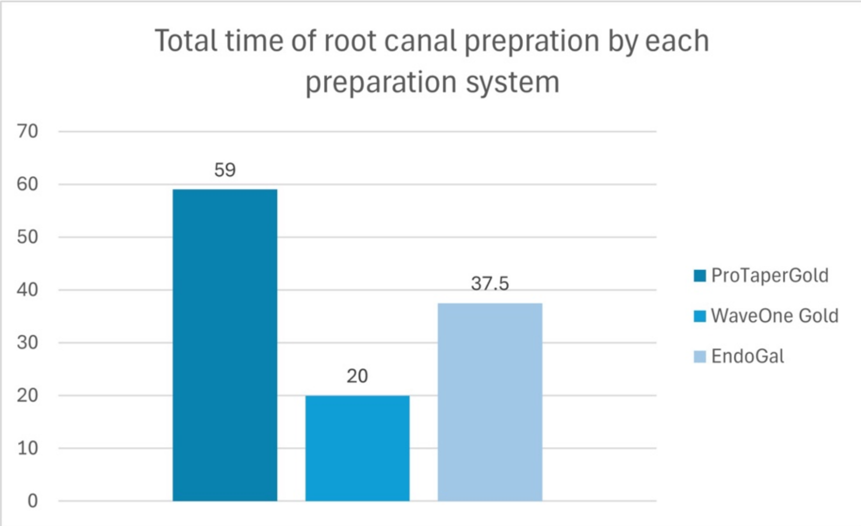


Table 2.

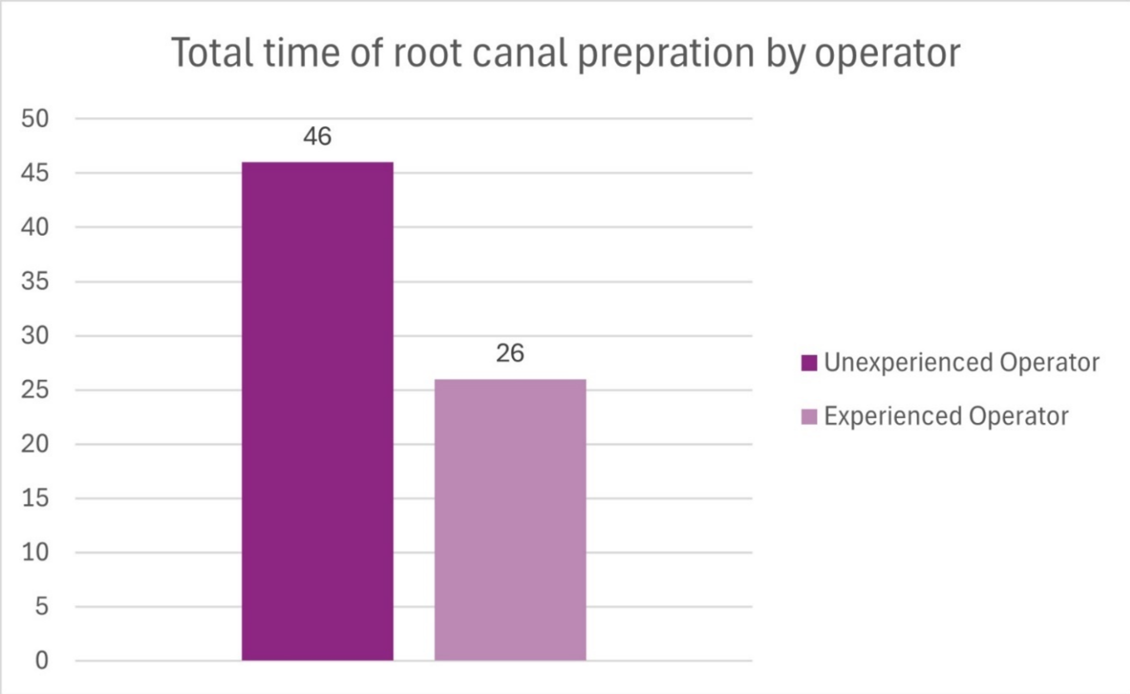
Total time of root canal preparation by operator

Data	**Total preparation Time (s)**	
Unexperienced Operator	Mean ± SD	48,53 ± 26,25
	Median	46,00
Experienced Operator	Mean ± SD	32,17 ± 19,46
	Median	26,00

The total time for root canal preparation by operator is shown in Table 2. There was statistically significant difference between operators ($p<.05$), with unexperienced operator requiring the most amount of time to prepare root canals.

Graph 2.

Total time of root canal preparation by operator



The total time for root canal preparation by operator and by preparation system is shown in Table 3. When comparing the three preparation systems for each operator, there were statistically significant differences between them, being the Wave One Gold ® the systems that required the least amount of time to prepare root canals and Protaper Gold ® the system that required the most amount of time to prepare the root canals within unexperienced operator ($p<.05$). When comparing the operator for each preparation systems, there were statistically significant differences between Protaper Gold ® and EndoGal ® systems ($p<.05$) with the unexperienced operator requiring the most amount of time for preparing root canal, however there was no statistically significant difference regarding the Wave One Gold ® system between operators ($p>.05$).

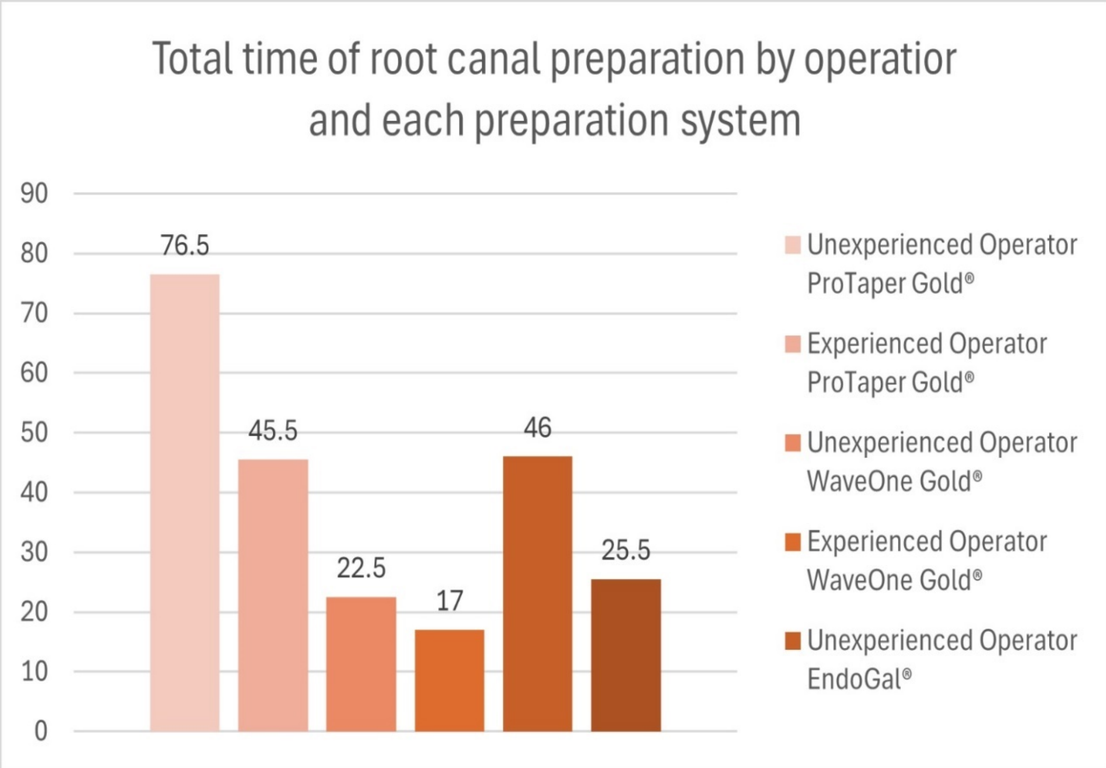
Table 3.

Total time of root canal preparation by operator and each preparation system

Data		Total preparation Time (s)
Unexperienced Operator Protaper Gold ®	Mean ± SD	76,00 ± 22,70
	Median	76,50
Experienced Operator Protaper Gold ®	Mean ± SD	52,80 ± 19,54
	Median	45,50
Unexperienced Operator Wave One Gold ®	Mean ± SD	22,20 ± 6,05
	Median	22,50
Experienced Operator Wave One Gold ®	Mean ± SD	17,40 ± 6,45
	Median	17,00
Unexperienced Operator EndoGal ®	Mean ± SD	47,40 ± 7,65
	Median	46,00
Experienced Operator EndoGal ®	Mean ± SD	26,30 ± 6,58
	Median	25,50

Graph 3.

Total time of root canal preparation by operator and each preparation system



V. DISCUSSION

The findings of this study provide insights into the variations in preparation times based on the system used and the operator's experience level. The Wave One Gold ® system demonstrated the shortest preparation times compared to the Protaper Gold ® and EndoGal ® systems.

These results align with existing literature that emphasizes the reduced preparation time of reciprocating systems like Wave One Gold ®. Previous studies have noted that reciprocating motion reduces the engagement time of the file with the dentin walls, thereby increasing cutting efficiency and reducing overall preparation time (Yared, 2008; Schäfer & Bürklein, 2012). The Wave One Gold ® system's design, featuring a unique reciprocating motion and gold wire technology, likely contributes to its reduced preparation time, which allows for quicker navigation through the root canal (Çiftçioğlu et al., 2023).

In contrast, the Protaper Gold ® system required the longest preparation times. This finding is consistent with the literature that suggests rotary systems, while effective, can be more time-consuming due to their continuous rotation and the need for sequential use of multiple files (Gambarini, 2001). The complexity of the ProTaper system, which requires the use of several files in a specific sequence, may explain the longer preparation times observed.

The EndoGal ® system exhibited intermediate performance and required less time than Protaper Gold ® due to using one fewer file than the ProTaper system (Faus-Matoses et al., 2022) but more than Wave One Gold ®.

<u>Operator Influence</u>

Operator experience had a significant impact on preparation times across all systems. Experienced operators consistently prepared root canals faster than their less experienced counterparts, which underscores the importance of skill and familiarity with the instruments. This aligns with previous research that highlights the role of experience in endodontic procedures, where experienced clinicians can navigate anatomical complexities more efficiently and with greater precision (Gluskin et al., 2014).

For the Protaper Gold ® and EndoGal ® systems, the disparity in preparation times between experienced and unexperienced operators was particularly pronounced.

Experienced operators using the Protaper Gold ® system had a mean preparation time of 52,80 ± 19,54 seconds, compared to 76,00 ± 22,70 seconds for unexperienced operators. Similarly, the EndoGal ® system required 26,30 ± 6,58 seconds for experienced operators versus 47,40 ± 7,65 seconds for unexperienced ones. These differences suggest that these systems are more technique-sensitive, requiring a higher level of skill and familiarity to use efficiently.

The Wave One Gold ® system, however, exhibited the smallest difference in preparation times between experienced and unexperienced operators, with mean times of 17,40 ± 6,45 seconds and 22,20 ± 6,05 seconds, respectively. This suggests that the Wave One Gold ® system has a shorter learning curve compared to the other systems. Its design likely facilitates easier and more intuitive use, which can be particularly advantageous for novice practitioners

Implications

The clinical implications of these findings are substantial for both endodontic practice and education. The Wave One Gold ® system and its relatively short learning curve suggest that it can significantly enhance clinical workflows, particularly in practices with varying levels of operator experience. For new graduates and less experienced clinicians, adopting a system like Wave One Gold ® can reduce preparation times. This can lead to greater confidence among novice practitioners (Generali et al., 2014).

The time saved in each procedure can be redirected towards other aspects of patient care and endodontic procedures. The consistent performance across different experience levels also suggests that practices can maintain high standards of care regardless of the operator’s experience, which is particularly valuable in multi-practitioner clinics (Yang et al., 2016).

In educational settings, the findings highlight the potential benefits of incorporating systems like Wave One Gold ® into training programs. The shorter learning curve can facilitate quicker mastery of endodontic techniques, allowing students to progress to more complex procedures with greater confidence and competence. Training programs can leverage this efficiency to provide students with more hands-on experience within the same timeframe, thereby enhancing their practical skills and readiness for clinical practice (Yang et al., 2016). Moreover, the study underscores the importance of continuing education and skill development for practicing clinicians. While the Wave One Gold ® system may mitigate some challenges associated with less experience, proficiency in endodontics still relies on comprehensive training and continuous skill enhancement. Clinics and educational institutions should emphasize the importance of ongoing professional development to ensure that practitioners remain adept with the latest technologies and techniques (Muñoz et al., 2014).

Given its superior time efficiency and less pronounced dependency on operator experience, Wave One Gold ® stands out as a potentially preferred system, especially in settings with varying levels of operator experience. Its design and operational simplicity appear to mitigate the learning curve often associated with endodontic procedures (Arede et al., 2023)

Limitations and Future research

Root Canal Anatomy Complexity:

The present study did not account for the variations in root canal anatomy, such as the degree and complexity of canal curvature. Root canals with severe curvatures (Duque et al., 2020) or S - shaped configurations can significantly influence preparation times, potentially increasing the difficulty and time required to navigate and prepare the canals effectively (Mamat & Ghani, 2023).

Future studies should include a variety of canal curvatures to assess how these anatomical differences impact preparation times across different Nickel-Titanium systems.

Tooth Type and Radicular Anatomy:

This study primarily focused on single-rooted teeth, which may not reflect the challenges associated with multi-radicular teeth (teeth with multiple roots). Multi-radicular teeth, such as molars, present additional complexities and may require longer preparation times.

Including multi-radicular teeth in future research would provide a more comprehensive understanding of how different Nickel-Titanium systems perform under varied anatomical conditions (Migliau et al., 2014).

Operator Variability:

Although the study took into account the operators' experience level, it did not take into consideration the individual differences in competence and technique among operators in the same experience level group. Differences in personal technique, hand skills, and familiarity with specific systems could influence preparation times (Özyürek et al., 2023). Future studies should include a larger and more diverse pool of operators to better understand how individual variability affects preparation times.

VI. CONCLUSION

The Wave One Gold ® system demonstrated significantly shorter preparation times compared to the Protaper Gold ® and EndoGal ® systems.

Operator experience was a crucial factor in preparation times, with experienced clinicians consistently performing faster than less experienced one across all systems.

The Wave One Gold ® system showed minimal performance variation between experienced and unexperienced operators, suggesting a shorter learning curve.

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VIII. APPENDICES

Appendice A. Authorization of UFP ethics comission

UNIVERSIDADE FERNANDO PESSOA

Exma. Senhora
Prof. Doutora Sandra Gavinha
Diretora da FCS

Nº	Data
FCS/MMED – 451/23	22 de Novembro de 2023

Exma. Senhora Professora Doutora,

A Comissão de Ética apreciou o projeto de investigação apresentado por Fadi Al Kafri, intitulado "Influence of operator experience on canal preparation time with three endodontic systems – an in-vitro study", a realizar no âmbito do Mestrado Integrado em Medicina Dentária.

O projeto tem como finalidade avaliar a influência da experiência do operador no tempo de preparação endodôntica de dentes monoradiculares com três sistemas de instrumentação de NiTi (ProTaper Gold®, WaveOne Gold® e Endogal®).

A Comissão de Ética considera o estudo pertinente e nada tem a opor quanto à sua realização.

A Comissão de Ética lembra que os projetos que tenham parte a ser realizada nas CPMD necessitam um parecer positivo da Direção Clínica da CPMD-FCS da UFP para a realização do estudo.

Com os melhores cumprimentos,

A Presidente da
Comissão de Ética da UFP
Inês Lopes Cardoso
Inês Lopes Cardoso

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