COMPARISON OF APICAL SEALING CAPACITY OF TWO OBTURATION TECHNIQUES : OBTURATION TECHNIQUE OF SINGLE CONE VS OBTURATION WITH GUTTACORE®

[Comparação da capacidade de selamento apical de duas técnicas de obturação : Técnica de obturação Cone único vs obturação com Guttacore®]

Dissertação de Mestrado

Mestrado Integrado em Medicina Dentária

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Orientador :

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To the 90 teeth who sacrificed their canals for science, may your apical seals be tight and your Gutta-Percha cones well-adapted…

Acknowledgments

First and foremost, I extend my deepest gratitude to my orientador, Professor Duarte Guimarães, whose unwavering guidance, patience, and expertise transformed this research from a concept into reality. Your relentless pursuit of excellence and willingness to challenge my thinking have shaped not only this thesis but also my growth as a clinician and scientist.

To my mother, who taught me that reinvention is not failure but courage, thank you for pushing me to chase this dream when I doubted myself. Your strength became mine.

To my brother: Now that I’m (almost) a dentist, I know you’re already planning your "Hollywood smile" makeover. Brace yourself, I’ve got a drill with your name on it.

To Athénaïs: Among all the wonderful surprises my career change brought, meeting you was the most unexpected and beautiful gift. Thank you for making every challenge worthwhile.

A special acknowledgment to Mr. Laurent Lévy, President of Optical Center, whose support during my career transition was pivotal. Your encouragement to pursue dentistry, a "crazy dream" at the time, reminds me that visionary leaders don’t just manage teams; they nurture potential. Thank you for believing in me long before I did.

Abstract

Objective: This in vitro study aimed to evaluate and compare the apical sealing ability of two endodontic obturation techniques: Single Cone (SC) and GuttaCore® (GC), using two different apical preparation sizes (F2 and F3). The assessment was based on dye penetration using a neutral pH 0.5% methylene blue solution. **Materials and Methods:** Ninety extracted human single-rooted teeth were selected. Eighty were randomly assigned to four experimental groups (n = 20): SC-F2, SC-F3, GC-F2, and GC-F3. Ten additional teeth were divided into two control groups (positive and negative, n = 5 each). Root canal instrumentation was standardized using the ProTaper Ultimate™ system. Working length was determined by visualizing a #15 K-file at the apical foramen and subtracting 0.5 mm. Irrigation during instrumentation was performed with 2.5% sodium hypochlorite (NaOCl). Final irrigation included 10% citric acid, followed by NaOCl and 96% ethanol. Obturation was carried out according to each group's assigned technique: either a single gutta-percha cone (SC) or a GuttaCore® carrier-based system (GC), both used with a resin-based sealer (AH Plus Jet). After obturation, all roots were coated with two layers of nail varnish, leaving the apical 2 mm uncoated. Samples were immersed in 0.5% methylene blue solution (pH 7) for 24 hours, then sectioned longitudinally in the bucco-lingual direction using a diamond disc under continuous water irrigation. Dye infiltration was measured in millimeters from the anatomical apex to the most coronal point of penetration along the main canal. When both halves were clearly measurable, their average was used; otherwise, the value from one readable half was recorded. **Results:** The GC-F2 group showed the lowest mean dye penetration, while the GC-F3 group showed the highest. Data distribution was non-normal according to the Shapiro-Wilk test, justifying the use of the non-parametric Kruskal-Wallis test. A statistically significant difference was found between the F2 and F3 groups ($p < 0.05$). However, no significant difference was observed between the SC and GC techniques. Pairwise comparisons confirmed that apical preparation size influenced leakage, but obturation technique did not. **Discussion:** Smaller apical preparations (F2) may enhance sealing by improving material adaptation and reducing sealer volume. While GC allows central compaction and is user-friendly, its benefits may be less effective with larger apical diameters. The use of methylene blue and the measurement from the anatomical apex may slightly overestimate leakage but does not invalidate the comparative analysis. **Conclusion:** Among the tested groups, GC with F2 preparation demonstrated the best apical sealing. Apical diameter significantly influenced microleakage, whereas the obturation technique itself did not. Further studies are recommended to evaluate long-term clinical outcomes, especially in teeth with large apical configurations.

Keywords :

"Apical sealing"; "obturation techniques"; "dye penetration"; "GuttaCore"; "Single Cone"

Resumo

Objetivo: Este estudo in vitro teve como objetivo avaliar e comparar a capacidade de selamento apical de duas técnicas de obturação endodôntica: Cone Único (SC) e GuttaCore® (GC), utilizando dois diâmetros diferentes de preparo apical (F2 e F3). A avaliação foi baseada na penetração de corante azul de metileno a 0,5% com pH neutro. **Materiais e Métodos:** Foram selecionados noventa dentes humanos unirradiculares extraídos. Oitenta foram distribuídos aleatoriamente em quatro grupos experimentais (n = 20): SC-F2, SC-F3, GC-F2 e GC-F3. Dez dentes adicionais foram incluídos em dois grupos controlo (positivo e negativo, n = 5 cada). A instrumentação dos canais foi padronizada com o sistema ProTaper Ultimate™. O comprimento de trabalho foi determinado visualizando uma lima K nº 15 no forame apical e subtraindo 0,5 mm. A irrigação durante a instrumentação foi realizada com hipoclorito de sódio a 2,5%. A irrigação final incluiu ácido cítrico a 10%, seguido por NaOCl e etanol a 96%. A obturação foi realizada conforme a técnica atribuída a cada grupo: Cone Único ou GuttaCore®, ambos associados ao cimento resinoso AH Plus Jet. Após a obturação, todas as raízes foram cobertas com duas camadas de verniz, deixando os 2 mm apicais descobertos. As amostras foram imersas em solução de azul de metileno a 0,5% (pH 7) por 24 horas, depois seccionadas longitudinalmente no sentido vestíbulo-lingual com disco de diamante sob irrigação contínua. A infiltração do corante foi medida (em mm) do ápice anatómico até o ponto mais coronal de penetração no canal principal. Quando possível, utilizou-se a média das duas metades; caso contrário, foi considerado o valor de uma única metade legível. **Resultados:** O grupo GC-F2 apresentou os menores valores médios de infiltração, enquanto o grupo GC-F3 apresentou os maiores. Os dados apresentaram distribuição não normal (teste de Shapiro-Wilk), o que justificou o uso do teste não paramétrico Kruskal-Wallis. Houve diferença estatisticamente significativa entre os grupos F2 e F3 ($p < 0,05$). No entanto, não foi observada diferença significativa entre as técnicas de obturação (SC vs GC). Comparações pareadas confirmaram que o diâmetro de preparo apical influenciou a infiltração, mas a técnica de obturação não. **Discussão:** Preparos apicais menores (F2) podem favorecer melhor selamento ao melhorar a adaptação do material e reduzir o volume de cimento. Embora o GC permita compactação central e seja de fácil aplicação, sua eficácia pode ser reduzida em diâmetros apicais maiores. O uso de azul de metileno e a medição a partir do ápice anatómico podem ter superestimado levemente a infiltração, sem comprometer a comparação entre os grupos. **Conclusão:** Entre os grupos testados, a técnica GuttaCore® com preparo F2 demonstrou o melhor selamento apical. O diâmetro apical influenciou significativamente a microinfiltração, enquanto a técnica de obturação não. Novos estudos são recomendados para avaliar os resultados clínicos a longo prazo, especialmente em casos com configurações apicais amplas.

<u>Palavras-chave :</u>

"Selamento apical"; "técnicas de obturação"; "infiltração de corante"; "GuttaCore"; "Cone Único"

Table of contents

List of Figures

List of Tables

List of Abbreviations

CariesAC : Caries-Driven Access Cavity

CBCT : Cone Bean Computed Tomography

CHX : Chlorexidine

CLC : Cold Lateral Compactation

ConsAC : Conservative Access Cavity

EAL : Electronic Apex Locator

EDTA : Ethylenediaminetetraacetic acid

ET : Endodontic Treatment

GC : Guttacore®

GP : Gutta-Percha

MEACs : Minimal Endodontic Access Cavities

PTU : ProTaper Ultimate

PUI : Passive Ultrasonic Irrigation

RCP : Root Canal Preparation

RC : Root Canal

RCS : Root Canal System

RCT : Root Canal Treatment

RestoAC : Restorative-Driven Access Cavity

SC : Single Cone

TradAC : Tradicional Acess Cavity

TrussAC : Truss Access Cavity

UltraAC : Ultra-Conservative Access Cavity

WL : Working Length

WVC : Warm Vertical Compactation

® : Registrated

1. INTRODUCTION

Root canal treatment (RCT) is the most prevalent method for the treatment of pulp and periapical diseases. RCT's success is based, as discussed by Yang et al. (2024), on three key pillars of well-executed canal preparation (i.e., cleaning and shaping), efficacious irrigation (disinfection), and complete filling with appropriate filling materials (Liu, Hao, and Shen, 2024, Zongova-Adem et al., 2024, Schilder, 2006).

Despite ongoing technological progress, endodontic failures remain frequent. These are often linked to the persistent or reintroduced presence of microorganisms in the root canal system (RCS), typically due to inadequate canal preparation, ineffective irrigation, missed or partially treated canals, incomplete obturation, and microleakage at either the apical or coronal level (Singh et al., 2024).

Endodontic sealing success is closely associated with obtaining hermetic three-dimensional sealing of the RCS space (Schilder, 2006). So far, several obturation procedures have been developed. For example, lateral cold condensation is the "Gold Standard," but there are too many disadvantages, such as excessive sealer use and questionable homogeneity of filling. Sealing helps provide anaerobic content of the canal within the obturation. However, sealers shrink or dissolve over time and become susceptible to bacterial invasion in these areas. Thermoplastic filling methods, such as vertical warm condensation and carrier-based tests, involve limited use of a sealer. The argument is that these procedures give improved adhesion of gutta-percha to the canal walls with a reduced void filling compared to lateral cold condensation (Zongova-Adem et al., 2024, Girelli et al., 2023).

The ProTaper Ultimate® (PTU) rotary system will be used in the shaping and preparation of RCS. These are thermally treated nickel-titanium (NiTi) instruments. Among the most notable advantages, it includes superior flexibility, resistance to torsional stress, and overall improvement in performance due to its increased longevity before fracturing (Martins et al., 2024).

Moreover, there should be performed continuous irrigation with sodium hypochlorite, a disinfectant most commonly used in RCT (Amhmed et al., 2024), to remove microorganisms and debris during instrumentation.

Obturation of the RCS, including accessory canals and dead spaces, has become the center of attention when it comes to achieving full prevention of reinfection and perirradicular diseases. Thus, there has been improving interest in the development of easier ways to use obturation materials and techniques that enable the filling of irregular canals and reduce space voids created during the obturation phases to prevent residual biofilm growth (Didato et al., 2013). Proper coronal and apical sealing with well-condensed obturation determines successful endodontics therapy (Moinuddin et al., 2024).

Apical sealing is the most critical determinant in the success of root canal (RC) therapy because it prevents microleakage and reflux. The SC technique and GC, which is a carrier-based technique, are both used widely for simple and effective obturations; however, their capacity to provide a hermetic apical seal continues to be evaluated. The SC technique relies on the adaptation of sealer to fill voids between GP and canal walls, and GC is designed to thermoplasticize filling that is more homogenous using a cross-linked GP carrier.

The question remains: Which of these methods performs better on the apices, while minimizing permeability and possible reinfection?

In order to answer this question, the present study will compare both techniques at different apical preparation sizes to determine which provides the best sealing and less leakage (PTU F2 vs. PTU F3). The method will involve the immersion of the obturated specimens into methylene blue dye to quantify apical leakage, providing a more objective assessment of sealing ability. The outcomes of this study will also permit an understanding of whether the carrier-based system like GC is significantly better compared to SC obturation in terms of sealing efficacy.

2. FOUNDATIONS OF ENDODONTIC TREATMENT

2.1 ACCESS CAVITY

RCT begins at the level of the crown with access cavity preparation. The goals of access preparation are : to eliminate any decay, expose the pulp chamber, identify all canal orifices, and achieve straight-line access to the canals—all while reserving as much tooth structure as possible (Shabbir et al., 2021, Adams & Tomson, 2014, Silva et al., 2020, Silva et al., 2022).

The first step in access cavity preparation is to create an entry point into the tooth without removing excessive amounts of healthy tissue. Penetration through the enamel and dentine is achieved using round diamond burs or tungsten carbide burs. In restored teeth, additional instruments will be discussed (Silva et al., 2020).

Once the entry point is established, then the next thing is to remove completely the pulp chamber roof to give wide and open access for the RCS. Non-end cutting burs, such as the Endo-Z bur (Dentsply, Sirona, Switzerland), or safe-ended diamond burs, are most often used for this and for refining and smoothing the cavity walls. Such instruments enable precise shaping without perforating the pulp floor.

As the access cavity is enlarged, it is essential that special attention be given to anatomical landmarks. One indication that often points to the locality of the RC orifices is that the pulp floor appears darker than the surrounding dentine. Gradual and controlled removal of dentine will grant an access cavity of appropriate reason toward further instrumentation.

Once the clinician makes that adequate access to the pulp chamber, the next important step is to find the RC openings. The instrument of choice is the DG16 endodontic explorer, which can be used to feel for openings in the pulp floor, allowing the clinician to locate it by touch (Adams & Tomson, 2014).

Where canals are not visible at this stage of access, there are other procedures that may well assist in finding the canals. The sodium hypochlorite bubble test involves applying NaOCl to the cavity and looking for its bubbling, indicating that there would exist hidden canal orifices. Methylene blue staining highlights the pulp floor and makes the orifices more apparent. Finally, in terms of complexity, for teeth with complex anatomy, CBCT imaging is invaluable, providing three-dimensional visualization of root structures for detection of additional or sclerosed canals (Adams & Tomson, 2014, Chan, Brown, & Parashos, 2023).

Once the canals are located, the access cavity must be finished to make it into the best configuration for smooth instrumentation. At this moment, the main goal is to make straight-line access to the apical third of the RC while conserving as much healthy tooth structure as possible. To achieve this, Endo-Z burs and tapered diamond burs are used to smoothen axial walls and to flare the access opening.

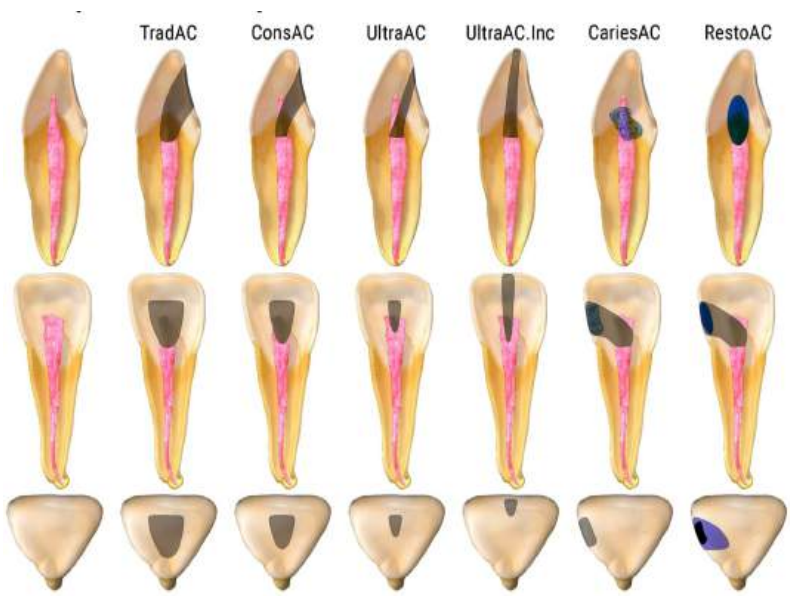
A good access cavity allows sufficient movement of instruments through the RC for instrumentation up to the full working length. However, it should be noted that the excessive removal of dentin may lead to compromise of the structural integrity of the tooth. An ideal access cavity would have sufficient visibility and control of the tools while preserving structural strength of the tooth for the rest of its life during restorations (Adams & Tomson, 2014).

For over a decade now, endodontics has progressively shifted toward minimal endodontic access cavities (MEACs) as part of the trend within the overall field of minimally invasive dentistry. More dentine is theoretically preserved with the idea that the teeth end up being stronger and/or endure longer, given that there is reduced risk of fractures. However, even if MEACs are in line with concepts of tissue conservation, they certainly raise the question of whether such restrictions would compromise effective canal cleaning, disinfection, and obturation, possibly resulting in treatment failures. Technological advances such as ultra-flexible instruments, high magnification, and 3D imaging have made MEACs more feasible, yet debate continues fueled by conflicting research findings. Most intriguing, however, is the fact that no conclusive proof demonstrates that MEACs provide long-term advantages over conventional access cavities ; further clinical studies are needed to judge their true impact on endodontic outcomes (Shabbir et al., 2021, Silva et al., 2020).

To differentiate at least between these designs of minimal access cavity during classification, one such classification suggests the Traditional Access Cavity (TradAC), which follows essentially the same conventional principles in unroofing the pulp chamber fully, while the Conservative Access Cavity (ConsAC) is the one that minimizes most of the dentine removal while allowing the chamber visibility. Thus, the Ultra-Conservative Access Cavity (UltraAC), otherwise called the access "ninja," is designed to conserve as much of the pulp chamber roof as possible. The Truss Access Cavity (TrussAC) retains some dentinal bridges between multiple small access points, while Caries-Driven Access Cavity (CariesAC) and Restorative-Driven Access Cavity (RestoAC) are based on preexisting structural conditions of the tooth. The classification provides a more regimented way of evaluating at different levels concerning dentine conservation in endodontic access cavity designs (Silva et al., 2020, Silva et al., 2022).

Figure 1

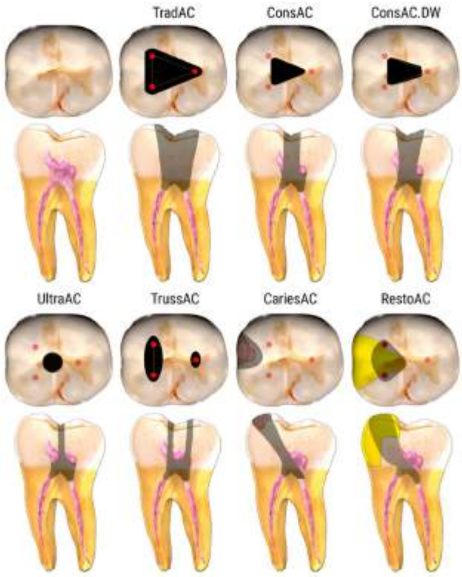
Classification of the access cavity designs in anterior teeth.



Note. Traditional access cavity (TradAC); conservative access cavity (ConsAC); ultra-conservative access cavity (UltraAC); ultra-conservative access cavity performed in the incisal edge (UltraAC. Inc); caries-driven access cavity (CariesAC); and restorative-driven access cavity (RestoAC). Reproduced from Current status on minimal access cavity preparations: A critical analysis and a proposal for a universal nomenclature, by Silva, E. J. N. L., De-Deus, G., Souza, E. M., et al., 2020, International Endodontic Journal, 53(11), 1618–1635. © 2020 Wiley.

Figure 2

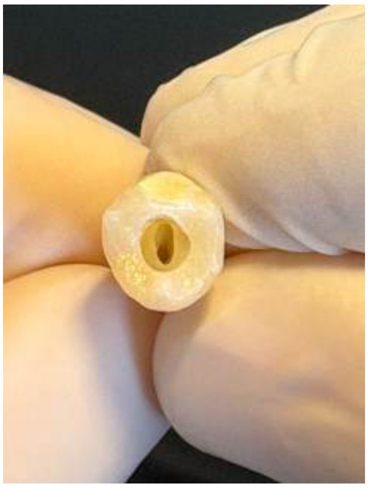
Classification of the access cavity designs in posterior teeth.



Note. Traditional access cavity (TradAC); conservative access cavity (ConsAC); conservative access cavity with divergent walls (ConsAC.DW); ultra-conservative access cavity (UltraAC); truss access cavity (TrussAC); caries-driven access cavity (CariesAC); and restorative-driven access cavity (RestoAC). Reproduced from Current status on minimal access cavity preparations: A critical analysis and a proposal for a universal nomenclature, by Silva, E. J. N. L., De-Deus, G., Souza, E. M., et al., 2020, International Endodontic Journal, 53(11), 1618–1635. © 2020 Wiley

Figure 3

Traditional access cavity preparation performed on a mandibular 1st premolar.



Note. Personal photo

2.2 ROOT CANAL PREPARATION - PTU SYSTEM

Root canal preparation (RCP) may be carried out with either hand or rotary files. This procedure has multiple objectives (Wang et al., 2022; Srivastava, 2024; Ribeiro et al., 2023a; Hülsmann, Peters & Dummer, 2005):

- Removal of Infected or Necrotic Tissues: The primary goal is to remove infected or dead tissue from both the main and lateral extensions of the root canal system, to eliminate bacteria and prevent further infection.
- Creation of Adequate Space: Adequate space has to be created so that cleaning, disinfection, and placement of medications, such as intra-canal medicaments or antibiotics, could be done in a more effective way, whenever necessary.
- Preservation of Original Anatomy and Minimization of Dentin Removal: The treatment should aim at preserving the tooth's natural anatomy and preserving as much healthy dentin. This means that all unnecessary removal of tooth structure should be avoided, as this helps maintain tooth strength and functionality.
- Respecting Periapical Tissues: Care should be exercised not to damage the periapical tissues surrounding the root. This will permit healing of the tooth after treatment.
- Shape for Effective Obturation: The RC must be shaped in a way to allow effective filling (obturation). The filling should seal the canal completely and inhibit any further bacterial invasion, leading to reinfection.

Determination of working length (WL) is the first step in RCP. This is a critical factor for the success of the RC treatment. An accurate WL determination will ensure that the preparation remains confined within the RCS and will avoid possible complications of debris or sealer extrusions to the apical area which could lead to inflammation or infection of surrounding tissues. The apical constriction is considerate the preferred point where canal instrumentation should stop. The apical constriction of the canal is generally found between 0.3 and 0.9 mm coronal to the apical foramen depending on tooth type and patient-related anatomical variability (Piasecki et al., 2018; Teixeira et al., 2021). This landmark is considered the ideal physiological endpoint for canal instrumentation and obturation, as it coincides with the transition from pulpal to periapical tissues. It could be measured or estimated with the help of several techniques: Periapical radiography, Electronic Apex Locator (EAL), or Cone Beam CT (Pham, 2021).

One of the major clinical concerns attached to the procedure is the possibility of unexpected fracture of instruments, especially NiTi files, which happen for two reasons- torsional and cyclic fatigue (Weissheimer, 2023). To avoid these complications, glide-path preparation and coronal pre-flaring should be performed to modify the original RC anatomy:

- The glide path is defined as a smooth passage extending from the RC orifice to the radiographic terminus. Establishing the glide path allows clinicians to know the original canal anatomy and keep the canal patent. A dedicated glide path file could also be used to pre-shape a narrow RC before employing the more tapered shaping files. Once the glide path is established, apical extrusion of debris is reduced and the operational life of the rotary instruments increased because of diminished torsional stress (Kwak et al., 2022).
- Coronal pre-flaring involves the removal of cervical tortuosities from the RC orifice and therefore establishes straight-line access for endodontic instruments to the apical portion of the canal. By applying a greater, tapered instrument prior to the shaping procedure, the apical region will be better prepared by the subsequent files, thus lowering the incidence of taper lock and friction. Consequently, coronal pre-flaring minimizes the risk of file fracture, decreases apical extrusion of debris, and helps achieve the accurate determination of WL (Kwak et al., 2022).

ProTaper Ultimate System :

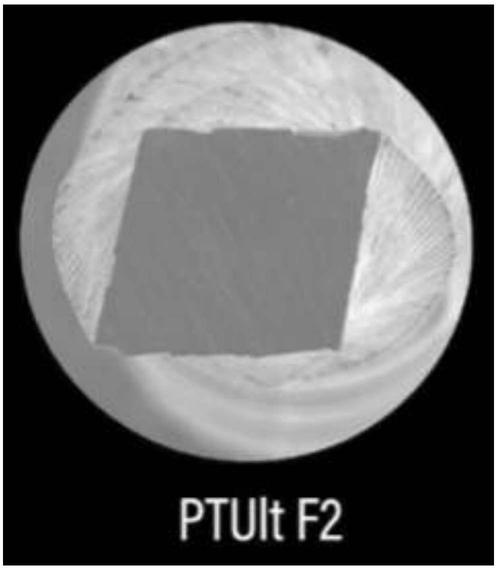
PTU is an advanced design of a nickel-titanium (NiTi) rotary file system tailored for optimal RC shaping, dentine preservation, and mechanical performance. In its latest evolution in the ProTaper family, the PTU employs three types of heat treatment and a special design of the file for enhanced flexibility, cyclic fatigue resistance, and cutting efficiency. Such improvements provide flexibility in its use and immense efficacy for various endodontic cases, especially in curved or complex canals (Ribeiro et al., 2023b).

Several advanced design features are included in the PTU system (Martins et al., 2023):

- Three heat-treated metal alloys: Each instrument is made from a different NiTi alloy to optimize its specific function.
- Parallelogram cross-section: Enhances cutting efficiency while reducing engagement with the canal walls.
- Optimized flexibility and strength: Heat treatments improve the ability to resist torsional stress while maintaining resilience.
- Efficient debris removal: The increased taper of apical files ensures better cleaning of the apical third.

Figure 4

ProTaper Ultimate files with a parallelogram-shaped cross-section.



Note. Reproduced from Characterization of the file-specific heat-treated ProTaper Ultimate rotary system, by Martins, J. N. R., Marques, D., Fernandes, F. M. B., Silva, E. J. N. L., Ajuz, N., Pereira, M. R., Versiani, M. A., & da Costa, R. P., 2023, International Endodontic Journal, 56(4), 530–542. © 2023 Wiley.

The PTU system consists of eight instruments, each designed with specific metallurgical properties and mechanical functions. These files have different heat treatments to optimize flexibility, cyclic fatigue resistance, and cutting efficiency, ensuring safe and predictable RC shaping.

- M-Wire : Slider (16/.02v)

The Slider file is used for glide path preparation, ensuring a smooth and controlled initial pathway for shaping files. It is manufactured from M-Wire, a heat-treated nickel-titanium alloy known for its high flexibility and fatigue resistance. The parallelogram cross-section of the file enhances cutting efficiency while minimizing engagement with dentine, allowing it to follow the natural canal curvature without excessive transportation.

- Gold-Wire : SX (20/.03v), Shaper (20/.04v), F1 (20/.07v), F2 (25/.08v), F3 (30/.09v)

The SX, Shaper, and Finishing (F1-F3) files are constructed from Gold-Wire, a heat-treated NiTi alloy that offers a balanced mix of strength and flexibility. These files undergo a phase transformation that results in a golden appearance, characteristic of controlled-memory NiTi instruments.

- SX (20/.03v) : A short auxiliary shaping file used primarily to optimize coronal and mid-root preparation before deeper instrumentation.
- Shaper (20/.04v) : Designed to enlarge and shape the coronal and middle thirds of the canal, reducing stress on the subsequent finishing files.
- F1 (20/.07v), F2 (25/.08v), F3 (30/.09v) : These are progressively tapered finishing files that enhance apical enlargement, allowing for effective debridement while maintaining dentine conservation.

- Blue-Wire : FX (35/.12v) and FXL (50/.10v)

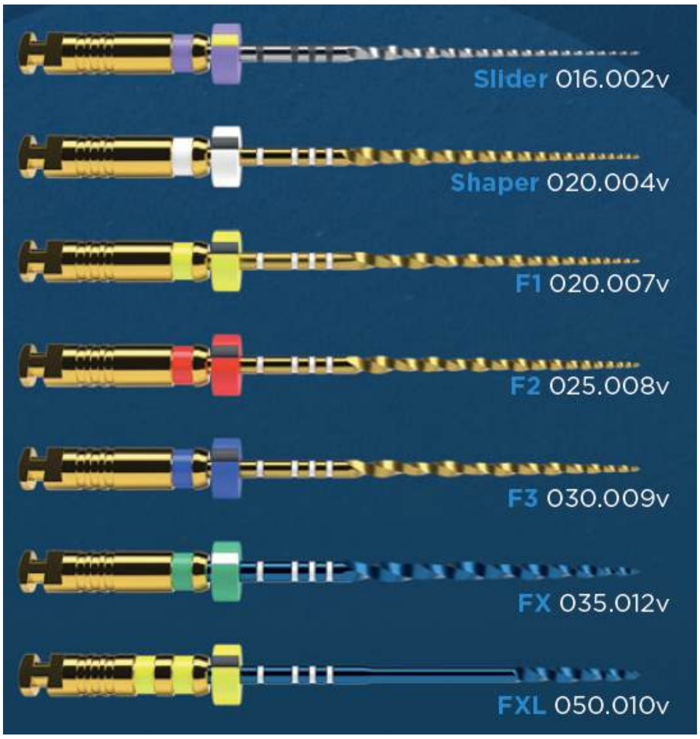
The FX and FXL files are auxiliary finishing instruments designed for use in larger, straighter canals or cases requiring wider apical preparation. Unlike the Gold-Wire files, these are manufactured using Blue-Wire technology, which provides superior flexibility and torsional resistance.

- FX (35/.12v) : Used for enlarging the apical third in moderately wide canals, improving irrigation penetration and debris removal.
- FXL (50/.10v) : Designed for extra-large canals, allowing controlled enlargement with minimal stress on the remaining dentine.

To conclude, ProTaper Ultimate (PTU) is designed to balance efficiency, flexibility, and dentin preservation, making it an advanced choice for RC shaping. It offers superior flexibility, enhanced shaping dynamics, and better dentine conservation compared to previous ProTaper systems. While smear layer removal remains a challenge, PTU's design ensures effective apical cleaning and predictable instrumentation.

Figure 5

Representation of the ProTaper Ultimate file system.



Note. Reproduced from ProTaper Ultimate – Product Brochure, Dentsply Sirona, © 2023.

2.3 IRRIGATION

Irrigation constitutes a very important component of RCT procedure by using liquid solutions to clean as well as disinfect whilst removing debris from the RCS. Mechanical instrumentation alone cannot access some areas within the canal (such as isthmuses, lateral canals, and fins); thus, irrigation takes a position as one of the major means of eliminating global bacteria, biofilms, and necrotic tissues (Mozo, Llena, & Forner, 2012).

One of its prime roles is debridement; flushing out dentinal debris and necrotic pulp tissue occurring along with instrumentation, which cannot solely be removed by mechanical instrumentation. The areas not accessible by the files are cleaned more broadly by irrigation, ensuring thorough cleanup of those areas besides organic and inorganic remnants unreached by mechanical preparation. Thus, irrigation is significant during debridement (Gomes, Aveiro, & Kishen, 2023, Gomes et al., 2013).

Another critical feature of irrigation is disinfection, in doing this by eliminating bacteria and disrupting biofilms found within the RC. Microorganisms embedded in biofilms are particularly resistant to antimicrobial agents, making the action of irrigants indispensable in reducing bacterial load and preventing reinfection. Of such commonly used irrigants, sodium hypochlorite is the most effective for it has got strong antibacterial properties and dissolving organic tissue (Gomes, Aveiro, & Kishen, 2023).

Beyond its antimicrobial role, irrigation removes smear layer which is composed of dentine particles, pulp remnants, and bacteria with the instrumentation on canal walls. Such smear layer impairs the penetration of disinfects, and chelating solutions such as EDTA would dissolve that inorganic portion of smear layer, exposing dentinal tubules for better adhesion of RC sealers (Mozo, Llena, & Forner, 2012).

Other than cleaning and rubbing, irrigation also affects lubrication; this means that less friction is observed between the instrument and dentine while preparing. This lubricating effect reduces stress on the instruments where it lowers the chances of file separation while making shaping smooth along the canal walls (Mozo, Llena, & Forner, 2012).

Irrigation acts like a cooling agent; hence it does not allow immoderate heating of both the tooth and the rotary instruments and preserves integrity dentinal walls (Li et al., 2014). Therefore, the combination of the above functions fulfills irrigation to an extant succeeding treatment of RC. It removes infected tissue, facilitates bacterial elimination, improves adaptation of obturation materials that collectively lead to long-term treatment success (Gomes, Aveiro, & Kishen, 2023, Li et al., 2014).

2.3.1 Main Irrigants Used in Endodontics

Endodontics employs numerous endodontic irrigants that will contribute to better cleaning, disinfection, and smear layer removal, each with characteristic properties and limitations. The ideal result is that the irrigant should kill microorganisms and be able to solubilize organic and inorganic debris but is safe to surrounding periapical tissues. No one solution meets all these criteria. However, when combined with different invigorants, their overall efficacy is increased, leading to better treatment outcomes (Mozo, Llena, & Forner, 2012).

- Sodium hypochlorite (NaOCl) is regarded as the gold standard because of its effectiveness in dissolving organic tissue, including remnants of pulps and biofilms, while exhibiting strong antimicrobial effects against bacteria and fungi. Such efficacies allow the efficacious biodegradation of biofilms. However, NaOCl is highly cytotoxic if extruded beyond the apex and does not completely remove the smear layer. Hence it needs to be combined with a chelating agent like EDTA, (Haapasalo et al., 2014).
- Ethylenediaminetetraacetic acid (EDTA) is primarily used to remove the smear layer produced during instrumentation by dissolving inorganic components like hydroxyapatite. This allows better penetration of disinfecting agents and improved obturation due to better visibility of the dentinal tubules. Although favorable, EDTA shows weak antimicrobial effect and is also unable to dissolve organic tissue, which gives justification of combining it with NaOCl (Haapasalo et al., 2014).
- Chlorhexidine (CHX) is the antimicrobial alternative value of NaOCl because of its capacity to kill bacteria as well as fungi. The substantivity feature of CHX binds it to

the dentine and keeps up in providing antimicrobial activity through time. Nevertheless, CHX would not be able to dissolve organic or inorganic tissue; that is why it cannot be used as a primary irrigant because, at times, poisonous precipitate could form when mixed with NaOCl, making it less compatible with irrigation protocols (Gomes et al., 2013, Haapasalo et al., 2014).

- Citric acid is another of those alternative chelating agents used to remove the smear layer, as EDTA works. However, citric acid may be harsher in some concentrations in demineralization, exposing more dentinal tubules.

2.3.2 Irrigation Techniques and Activation Methods

Irrigation is performed by employing several techniques to improve penetration, debris removal, and antimicrobial effectiveness within the RCS (Haapasalo et al., 2014; Boutsioukis & Arias-Moliz, 2022; Tonini et al., 2022; Susila & Minu, 2019). Syringe and needle irrigation is the most common technique; it allows the direct delivery of irrigants but has limited penetration into the complex canal anatomy (Haapasalo et al., 2014). Passive ultrasonic irrigation utilizes ultrasonic energy to create a movement of fluid, improving the flow and distribution of irrigants, thereby enhancing cleaning efficiency (Boutsioukis & Arias-Moliz, 2022). Negatively pressurized irrigation (EndoVac® - SybronEndo, KerrDental) aims to prevent the risk of extruding irrigant past the apex, thus being safer, especially in cases of open apices (Boutsioukis & Arias-Moliz, 2022; Tonini et al., 2022). Furthermore, sonic activation (EndoActivator Smartlite Pro® - MAILLEFER, Dentsply Sirona) creates a hydraulic effect in the irrigant, aiding biofilm disruption and thereby enhancing disinfecting efficacy (Susila & Minu, 2019).

To summarize, irrigation is a major constituent in RC treatment, enabling proper cleansing, bacterial elimination, and preparation for obturation. Sodium hypochlorite remains the main irrigant; however, it should be applied along with EDTA or citric acid in order to remove the smear layer, and possibly CHX for an added antimicrobial effect. Advanced activation techniques even more enhance the penetration of the irrigant, thus improving the success of treatment and long-term prognosis

2.4 ROOT CANAL OBTURATION

In obturation, the RCS is sealed after thorough cleaning and shaping to create a fluid-tight barrier that prevents microbial invasion and reinfection. Given the presence of lateral canals and irregularities in the RCS, it is difficult, if not impossible, to carry out cleansing to completely eliminate microorganisms. Hence, obturation plays a vital role in containing any remaining bacteria and preventing their propagation (Tomson, Polycarpou, & Tomson, 2014, Peng et al., 2007).

The main objectives of obturation are (Tomson, Polycarpou, & Tomson, 2014, Peng et al., 2007) :

- To Prevent Coronal Leakage – Preventing entry of microorganisms and nutrients into the canal system from the oral cavity.
- To Prevent Apical and Periodontal Fluid Penetration – Preventing contamination from periapical tissues in a manner that could support bacterial survival.
- To Seal Off Any Remaining Microorganisms – Ensuring that any bacteria that survived cleaning and disinfection are isolated from nutrients and thus depriving them of pathogenic potential.

A well-obturated RCS increases the long-term success of endodontic treatment (ET) and promotes periapical healing by maintaining a sterile and sealed environment.

2.4.1 Materials Used for Obturation

Different materials are there for obturation, each having specific characteristics (Tomson, Polycarpou, & Tomson, 2014, Li et al., 2014, Peng et al., 2007) :

- Gutta-Percha (GP)

It is the principal core material. Contains zinc oxide, resins, and metal sulfates, and is available in various techniques such as SC, lateral and vertical compaction, and thermoplastic methods (Li et al., 2014).

- Sealers
  - Sealing agents combined with core materials improve the seal of RCS. Different types include (Tomson, Polycarpou, & Tomson, 2014) :
  - Zinc Oxide Eugenol Based Sealers : Antimicrobial, slightly soluble, and slow-setting.
  - Calcium Hydroxide Based Sealers : Antibacterial, but their efficacy is doubtful as they get dissolved over the time.
  - Glass Ionomer Based Sealers : Bonds to dentin but with lesser antimicrobial property.
  - Resin-Based Sealers (e.g., AH Plus) : Bonds strongly to dentin but tissue irritation if extruded.
  - Silicone-Based Sealers : Biocompatible and easy to use but need further studies for effectiveness.
  - Calcium Silicate Based Sealers : For use in regenerative endodontics and bioactive.
- Advanced Materials

The latest innovations are the so-called bioactive and hydrophilic materials such as SmartSeal and RealSeal, which boast superior adaptation and sealing on expansion (Tomson, Polycarpou, & Tomson, 2014).

2.4.2 Techniques of obturation

There are multiple techniques of obturation, and their acceptance will depend on factors such as RC anatomy and the clinical preference (Tomson, Polycarpou, & Tomson, 2014, Li et al., 2014, Peng et al., 2007).:

- Cold Lateral Compaction (CLC)
  - The most commonly used and regarded as the gold standard.
  - Gives good control and adaptation but might leave voids behind.

- Warm Vertical Compaction (WVC) - Continuous Wave Compactation
    - Uses heat to soften GP to enhance its adaptation and reduce voids.
    - Gives a denser fill; however, requires high competence and equipment.
- Thermoplastic Injection
    - Injection from softened GP into the canal for a three-dimensional fill.
    - This is effective but may lead to overfilling.
- Single Cone (SC) Technique
- GP carriers

2.4.3 Single Cone (SC) Technique

The SC technique is an RC sealing method where a single GP cone is placed according to the taper and size of the prepared RC. This method is often associated with hydraulic condensation because the spaces between the GP and the walls of the canal are filled by means of the sealer rather than by mechanical compaction (Moinuddin et al., 2024).

In applying such technique, a master GP cone is chosen in such a way as to fit the ultimate preparation of the canal. The cone is then coated with sealer and inserted into the RC for sealing. One prominent feature of SC is that it does not require the additional placement of accessory cones or lateral/vertical compaction; thus reducing operator dependency and simplifying the procedure (Nouroloyouni et al., 2023). A very important element of the SC technique is the sealer selection. Bioceramic sealers are mostly recommended because of their chemical bonding ability to dentin, providing hermetic sealing through hydroxyapatite formation (Boutsioukis & Arias-Moliz, 2022). Studies have proven that when the SC technique is used with bioceramic sealers, the bonding to dentin becomes stronger in comparison to resin-based sealers like AH-Plus (Nouroloyouni et al., 2023).

The SC technique offers several advantages. It is an easy and fast technique that takes fewer steps and less instrumentation than CLC or WVC, making it popular among general practitioners (Jaha, 2024). There is a reduction in the risk of vertical root fractures from SC, as it is commonly associated with lateral condensation, since no compaction forces are applied during the procedure (Jaha, 2024). The best adaptation to irregular canal walls, thus improving sealing ability and microleakage prevention, is offered when the technique is combined with bioceramic sealers (Boutsioukis & Arias-Moliz, 2022). Less extrusion of sealer beyond the apex is also an advantage of SC, leading to a reduction of post-operative pain and inflammation (Jaha, 2024).

Yet even with these advantages, SC has limitations. The long-term seal would be jeopardized if the sealer degrades or dissolves over time. SC obturations were reported to have more voids than warm vertical compaction, particularly when resin-based sealers such as AH-Plus were in use (Boutsioukis & Arias-Moliz, 2022). The technique is effective in straight, round canals; however, it may not work so well when confronting the adaptations by warm GP techniques in irregularly shaped and tapered canals (Jaha, 2024).

Figure 6

Gutta-percha cones (F2 and F3) and AH Plus Jet sealer used for single cone obturation with the ProTaper Ultimate system - Dentqply Sirona.

Note. Personal photo.

2.4.4 Carrier-Based Systems - Guttacore®

It is important to note that the GP carrier-based obturation technique is a method for which a central carrier is completely coated with thermoplasticized GP to fill the RCS. This leaves the GP more adaptable to the canal wall, especially in those most difficult apical thirds, which are often not sealed properly. Compared to lateral compaction or any other warm techniques, carrier-based obturation gives rise to a more homogeneous as well as dense fill while lessening the operator dependency (Fracchia et al., 2020).

The term GC denotes an improvement in carrier based systems for their obturation. Unlike typical plastic carriers such as Thermafil, GC contains a cross-linked GP carrier so that a separate core material is not required. It thus improves the three-dimensional sealing ability but maintains the flexibility of GP to be able to flow and adapt much better into the anatomy of the canal. An additional advantage of GC is that it offers a much tighter seal toward the apical third, because GP carrier rigidity guarantees placement to the correct working length (Fracchia et al., 2020).

According to studies, GC achieves the apical third filling of the canal with a minimum percentage of voids and thus encloses a high-quality seal. Its very low viscosity and high thixotropy allow the material to flow into the canal space, forming a dense and uniform obturation, whereas adaptation in the middle and coronal thirds might be affected by natural variations of morphology of the canal, probably in wider or in oval-shaped canals (Migliau et al., 2022).

Overall, GP carries advantages over conventional carrier-based obturation techniques due to doing away with a separate plastic core while enhancing flowability and adaptation. It also provides good strength in an apical seal, an important option in cases where the RC is required to be filled densely and consistently (Migliau et al., 2022).

Lesson learned here is that proper cleaning, sealing, and choice of materials accomplishes the success of RC obturation. Though most newer materials would claim to improve sealing ability, GP being a classic and time-tested material in clinical outcome has not only given patients success for years but still serves the criteria for making GP and traditional sealers the gold standard.

Figure 7

Thermaprep 2 oven, GuttaCore obturator and AH Plus Jet sealer used for the carrier-based obturation technique.

Note. Personal photo.

2.5 APICAL PERCOLATION

Apical percolation refers to the infiltration of fluids, bacteria, and their metabolites through the interface formed by the root-canal filling material with the adjacent dentin walls; such leakage compromises the success of ET by generating a reentry of bacteria in RCS (Muliyar et al., 2014, Giovarruscio et al., 2020).

An ideal root canal filling should seal three-dimensionally to bar the movement of periapical fluids into the canal or prevent microbial ingress from coronal leakage for a successful ET. Unfortunately, due to anatomical complexities such as lateral canals, apical deltas, and isthmuses, perfect sealing remains unattainable and microleakage occurs despite using modern obturation techniques (Giovarruscio et al., 2020).

2.5.1 Factors Contributing to Apical Percolation

- Quality of RC Obturation
  - Voids or gaps in the obturation material create pathways for bacterial infiltration.
  - Over or under-extension of gutta-percha or sealer can leave unsealed areas.
  - Poor determination of apical gauging
- Type of Sealer and Obturation Technique (Muliyar et al., 2014)
  - Different sealers have varying levels of adhesion to dentin and gutta-percha. Resin-based sealers tend to provide a better seal than zinc oxide eugenol-based sealers.
  - Some obturation techniques, like lateral compaction, may leave voids that increase leakage risk.
- Presence or Absence of Smear Layer (Muliyar et al., 2014)

The smear layer (a thin layer of debris from instrumentation) can prevent the sealer from bonding properly to dentin, increasing microleakage.

- Bacterial Contamination (Giovarruscio et al., 2020)

If bacteria remain in the canal after cleaning and shaping, they can migrate through gaps in the filling, leading to reinfection.

- Coronal Leakage (Muliyar et al., 2014)

Defective restorations or exposed gutta-percha at the coronal end of the canal can allow bacterial ingress, compromising the apical seal.

2.5.2 Testing Methods for Apical Percolation

Several experimental techniques have been developed to evaluate apical leakage and measure the effectiveness of different obturation techniques.

- Bacterial Percolation Test (Giovarruscio et al., 2020)
    - The RCS is exposed to bacterial cultures, such as “Enterococcus faecalis”.
    - After incubation, bacterial infiltration is assessed by culturing the samples or using molecular detection techniques.
    - Advantages : Closely simulates clinical conditions.
    - Disadvantages : Requires microbiological expertise and takes time.

- Fluid Filtration Method (Muliyar et al., 2014)
    - A non-destructive method that measures the movement of fluids under pressure through the filled canal.
    - A capillary tube containing an air bubble is connected to the root apex; any movement of the air bubble indicates leakage.
    - Advantages : Real-time, repeatable measurements without destroying the sample.
    - Disadvantages : Requires precise calibration and specialized equipment.

- Radioisotope Penetration Test (Muliyar et al., 2014)
  - Uses radioactive tracers (e.g., Iodine-125) to measure microleakage. The penetration of the isotope is detected using radiation counters.
  - Advantages : Provides precise quantitative data.
  - Disadvantages : Requires handling of radioactive materials and specialized equipment.
- Electrochemical Method (Muliyar et al., 2014)
  - Electrodes are placed at the coronal and apical ends of the tooth, and ionic movement is measured to detect leakage.
  - Advantages : Provides real-time, highly sensitive data.
  - Disadvantages : Requires specialized equipment and setup.
- Neutron Activation and Metal Tracer Tests (Muliyar et al., 2014)
  - Uses metal solutions (e.g., silver nitrate) or neutron-activated elements to track microleakage.
  - Highly sensitive in detecting percolation at a microscopic level.
  - Advantages : High accuracy in detecting small-scale leakage.
  - Disadvantages : Requires advanced laboratory facilities.
- Dye Penetration Test (Muliyar et al., 2014)
  - One of the most commonly used methods to assess microleakage.
  - The tooth is immersed in a dye solution (e.g., methylene blue, India ink) for a specific period.
  - Afterward, the sample is sectioned longitudinally, and the depth of dye penetration is measured.
  - Advantages : Simple, cost-effective, and easy to perform.
  - Disadvantages : Does not accurately replicate in vivo conditions; dyes may penetrate areas where bacteria cannot.

2.5.3 Blue methylene dye

Methylene blue dye is widely used in endodontic research to assess the integrity of RC fillings by detecting apical microleakage. Its applicability in dye penetration studies allows visual evaluation of the seal with different obturation techniques. The process involves immersing the apical part of the tooth in a 0,5% methylene blue solution for a prescribed amount of time. The dye would ascend either by capillarity or diffusion, thus staining the non-sealed areas. The specimen then may be sectioned longitudinally or transversely, and the extent of dye penetration is assessed under a microscope (Camps & Pashley, 2003).

Figure 8

Bottle of 0,5% methylene blue solution (pH 7) used for apical permeability evaluation.

Note. Personal photo.

One of the principal advantages of methylene blue is that it is inexpensive and easy. Unlike other sophisticated and pricey methods for microleakage evaluation, such as radioisotope penetration or electrochemical techniques, this dye penetration method requires less equipment and technical expertise. Small molecular size allows methylene blue to penetrate even the tiniest of gaps; therefore, it is an appropriate indicator of microleakage. It is non-toxic; therefore, all these factors add to its popularity in dental research (Muliyar et al., 2014, Camps & Pashley, 2003).

Despite all these advantages there are some limitations of using methylene blue for microleakage assessment. Majorly, the variability of dye penetration results from sectioning artifacts. Since the tooth is cut randomly along its longitudinal axis, there is no guarantee that the deepest point of dye penetration would be captured, leading to possible underestimation of leakage (Camps & Pashley, 2003).

Because methylene blue is acidic, consideration should be given to the phenomenon of dentin demineralization, as this may overestimate the extent of percolation. Furthermore, some bacteria responsible for peri-apical reinfection are larger than the dye particles, leading to possible overestimation of measurements (Tamse, Katz, & Kablan, 1998).

Bacterial infiltration may not always correlate with methylene blue penetration, as the dye may reach areas where bacteria cannot thrive. This discrepancy raises a question of biological relevance to their intended clinical application (Camps & Pashley, 2003).

3. EXPERIMENTAL PROTOCOL

3.1 OBJECTIVES

This in vitro study aims to compare the apical sealing ability between two obturation techniques, Single Cone (SC) vs. GuttaCore (GC), using two different apical preparations (F2 and F3) at 1mm, 3mm, and 5mm from the apex. Apical microleakage will be evaluated using methylene blue dye penetration.

3.2 MATERIALS AND METHODS

3.2.1 Literature review

The literature survey was rather in-depth from June 2024 to May 2025 and was carried out prior to designing the experimental protocol. The intention was to create a firm theoretical basis on the main aspects brought out in this dissertation: namely on the anatomy of the root canal system, preparation protocol, irrigation protocols, endodontic obturation materials and techniques as well as methods in evaluating apical permeability.

The review included Portuguese and English books, scientific articles, and master's dissertations published in the well-known international Endodontics journals. Article search engines were used without applying any time limits for direct article access through online databases using preference for recent scientific evidence.

Search engines used were : PubMed, ScienceDirect, and SciELO. Most highly regarded journals within the field of Endodontics, such as the Journal of Endodontics, the International Endodontic Journal, and the Australian Endodontic Journal, received special attention.

The keywords used were: "irrigation", "chemical preparation", "root canal disinfection", "sodium hypochlorite", "irrigant solutions", "endodontic treatment", "root canal obturation", "single cone technique", "GuttaCore", "bioceramic sealers", "resin-based sealers", "apical sealing", "microleakage", "carrier-based obturation", “ProTaper Ultimate”, “Access Cavity”, “Apical Percolation”.

They ended up with 51 articles, of which 42 were considered important according to their methodology and scientific grounding.

The information derived from this literature review has been necessary in defining the variables, materials selection, and building the methodology used in the experimental protocol. That was the underlying rationale behind developing a detailed protocol then submitted to the Ethics Committee of the FCS-UFP where a favorable opinion was granted (Appendix A).

3.2.2 Materials

- Teeth samples : 90 extracted single-rooted human teeth, all teeth used in this study were obtained from a private dental clinic in France. In this clinic, patients routinely sign a general informed consent upon their first visit, authorizing the use of extracted teeth for academic and scientific research purposes. No personal or clinical data were collected or accessed, ensuring complete anonymity of the samples (Appendix B, Appendix C). The present research protocol was reviewed and approved by the Ethics Committee of FCS-UFP, under a favorable opinion (Appendix A).
- Rotary system : ProTaper Ultimate™ System (Dentsply Sirona)
  - Slider (16/.02v)
  - Shaper (20/.04v)
  - F1 (20/.07v)
  - F2 (25/.08v)
  - F3 (30/.09v)
- Irrigation solutions :
  - 5.25% sodium hypochlorite (NaOCl)
  - 10% citric acid
  - 96% ethanol
- Obturation materials :
  - GuttaCore® obturators (sizes 0.20, 0.25, and 0.30, Dentsply Sirona)
  - ProTaper Ultimate™ Conform Fit® Gutta-Percha Points (F2 and F3, Dentsply Sirona)
  - AH Plus® Resin Sealer (Dentsply Sirona)

- Glass Ionomer Cement (for negative control sealing)

- Drying materials :
  - ProTaper Ultimate™ Absorbent Points (F2 and F3, Dentsply Sirona)
- Imaging system :
  - Radiovisiography (RVG) system for radiographic evaluation
- Equipment:
  - Endodontic motor (XSmart Pro+ Dentsply Sirona)
  - ThermaPrep® Obturator Oven
  - Stereomicroscope (10-40× magnification)
  - Water bath Incubator (37°C, 100% humidity)
  - Diamond disc for sectioning samples (Okadent)
  - Eppendorf tubes
  - 0,5% methylene blue dye
  - Nail varnish (Nocibé, Paris)

3.2.3 Sample Selection and Preparation

- 90 extracted human teeth (will be cleaned, sterilized in autoclave, stored in 0.5% chloramine for 7 days, and rinsed with distilled water 24 hours before experimentation.

Figure 9

Extracted human tooth individually packaged in a sterilization pouch prior to use in the experimental protocol.

Note. Personal photo.

Figure 10

Powder container of chloramine-T trihydrate used to prepare a 0.5% chloramine solution for specimen disinfection.

Note. Personal photo.

- Inclusion criteria :
    - Single canal, confirmed radiographically using an RVG system
    - No previous RC treatment, root fractures, or resorption
    - Closed apex
- Preoperative radiograph to assess the canal anatomy and determine an estimated working length (WL)

Figure 11

Preoperative buco-lingual periodical radiograph of a mandibulary premolar obtained using a digital RVG sensor.

Note. Personal photo.

3.2.4 Root Canal Preparation

- Access cavity preparation using Diamond round and Endo-Z burs.
- Working length determination: 10 K-file inserted until visible at the apex, subtracting 0,5mm, confirmed with RVG radiography using a 15 K-file for odontometric radiograph.

Figure 12.

Buco-lingual odontometric radiograph of a mandibulary premolar with a size 15 K-file and a determined working length of 23 mm using a digital RVG sensor.

Note. Personal photo.

- Instrumentation : according to the manufacturer's protocol
    - Group F2 : ProTaper Ultimate™ up to F2 (#25/.08)/XSmart Dentsply: 250rpm ; 2,8 N.cm
    - Group F3 : ProTaper Ultimate™ up to F3 (#30/.09)/XSmart Dentsply: 250rpm ; 2,8 N.cm
    - Negative control group : Prepared with the same protocol as experimental groups (F2 or F3).

Figure 13

Clinical setup for rotary canal instrumentation of a maxillary canine using the ProTaper Ultimate (PTU) system with the X-Smart motor (Dentsply Sirona).

Note. The image shows the rotary files, the extracted tooth, and the motor display indicating speed, torque, and gear settings. Personal photo.

Figure 14

Post-instrumentation buco-lingual radiograph of a mandibulary premolar showing root canal preparation completed up to file F2 with the ProTaper Ultimate (PTU) system.

Note. The image confirms full working length instrumentation. Personal image.

- Irrigation sequence :
    - 5.25% NaOCl used throughout canal preparation.
    - Final irrigation :
        - 10 mL 10% citric acid
        - 10 mL 5.25% NaOCl
        - 2-3 mL 96% ethanol
- Drying of the canal : ProTaper Ultimate™ Absorbent Points (F2 or F3) will be used to completely dry the root canal before obturation.

3.2.5 Experimental Groups and Obturation

The 90 teeth will be divided into six groups, with positive and negative control groups (n = 10 total for control).

Table 1

Description of the experimental and control groups according to obturation technique, final file, sealer, cone size, and additional sealing protocol.

Group	Final File	Obturation Technique	Sealer Used	Principal Cone Size	Additional Sealing
1 : SC-F2	F2 (#25/.08v)	Single Cone (SC)	AH Plus® Resin Sealer	F2	None
2 : SC-F3	F3 (#30/.09v)	Single Cone (SC)	AH Plus® Resin Sealer	F3	None
3 : GC-F2	F2 (#25/.08v)	GuttaCore (GC)	AH Plus® Resin Sealer	0,25	None
4 : GC-F3	F3 (#30/.09v)	GuttaCore (GC)	AH Plus® Resin Sealer	0,30	None
Control (+)	No prep	No obturation	No sealer	None	None
Control (-)	F2 (#25/.08v) ou F3 (#30/.09v)	Single Cone (SC)	AH Plus® Resin Sealer	F2/F3	Glass Ionomer Cement

- Positive Control group (n = 5) : These teeth will not be obturated. The canals will remain empty to allow maximum dye penetration, ensuring that apical permeability is measurable.

- Negative Control group (n = 5) : These teeth will be instrumented with F2 or F3, obturated with ProTaper Ultimate™ Conform Fit® Gutta-Percha and AH Plus® Resin Sealer, and then completely sealed externally (including the apical foramen) with glass ionomer cement, ensuring that apical permeability isn't measurable.

- **Single Cone (SC) Obturation Protocol**

For Single Cone obturation, the following steps will be followed:

(i) Selection and Fitting of Master Cone

- A ProTaper Ultimate™ Conform Fit® Gutta-Percha Point (size F2 or F3) will be selected.
- The cone will be checked for tug-back at the working length (WL).
- Radiographic verification will be done using the RVG system to ensure proper fit.

Figure 15

Cone-fit buco-lingual radiograph of a mandibulary premolar showing the F2 ProTaper Ultimate™ Conform Fit™ gutta-percha cone positioned at working length prior to obturation.

Note. Personal photo.

(ii) Application of Sealer

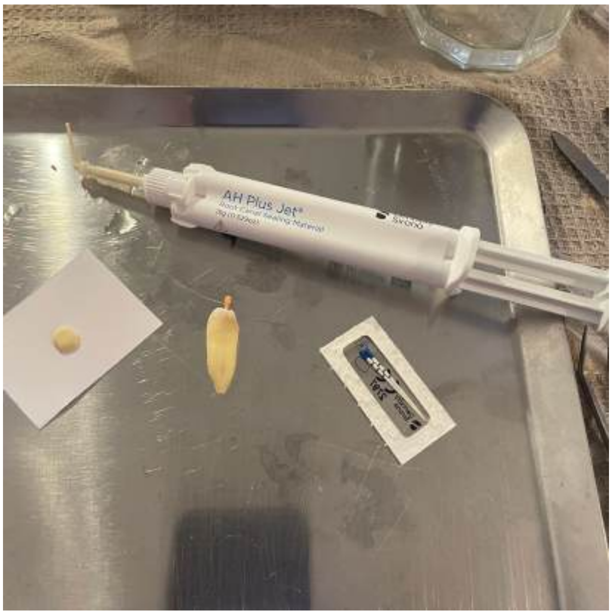
- AH Plus® Resin Sealer will be mixed according to the manufacturer's instructions.
- Gutta-percha cone will be lightly coated with sealer before insertion.

(iii)Insertion of Gutta-Percha Cone

- The master cone will be slowly inserted to full working length.
- A gentle up-and-down motion will be used to allow for optimal adaptation of the cone.
- Any excess sealer will be removed with a sterile cotton pellet.

Figure 16

Single cone obturation procedure showing a F3 gutta-percha cone positioned in a maxillary tooth, with AH Plus Jet sealer (Dentsply Sirona) extruded onto a mixing pad prior to insertion.



Note. Personal photo.

(iv)Cutting and Compacting the Gutta-Percha

- The coronal part of the gutta-percha will be cut at the orifice level using a heated plugger.

- Vertical compaction with a hand plugger will be applied to ensure adaptation at the orifice level.

(v) Final Radiographic Verification

- A final RVG radiograph will confirm proper obturation and adaptation.

Figure 17

Final bucolingual RVG radiograph of a mandibulary premolar confirming proper obturation and gutta-percha cone adaptation following the single cone technique.

Note. Personal photo.

- **GuttaCore® (GC) Obturation Protocol**

For carrier-based obturation (GuttaCore), the following steps will be followed:

(i) Selection of GuttaCore Obturator**

- A GuttaCore® obturator (size 0.25 for F2, size 0.30 for F3) will be selected.

(ii) Application of Sealer

- AH Plus® Resin Sealer will be mixed according to the manufacturer's instructions.

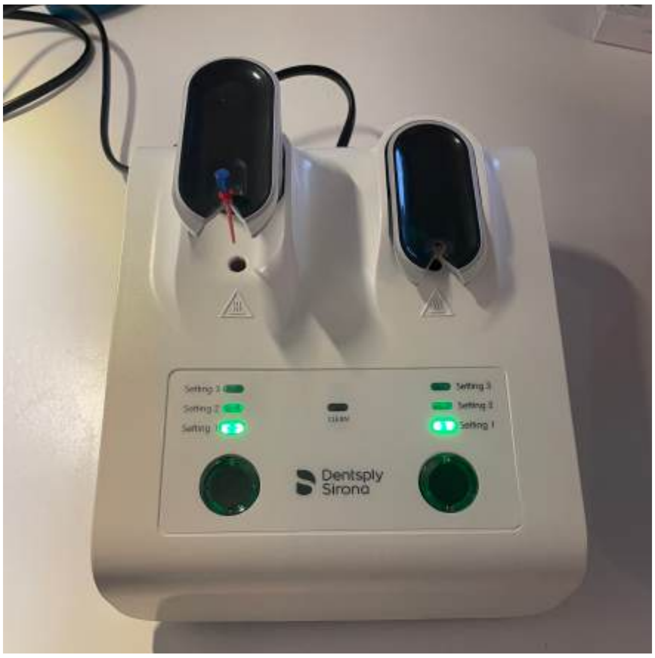
- The sealer will be applied by lightly coating the canal walls with a gutta-percha cone before insertion.

(iii)Heating the GuttaCore® Obturator

- The GuttaCore® obturator will be placed into a ThermaPrep® Obturator Oven and heated according to the manufacturer's settings.
- The heating time is about 30 seconds according to the apical caliber of the GuttaCore

Figure 18.

Thermaprep 2 oven (Dentsply Sirona) heating a GuttaCore obturator prior to insertion.



Note. The unit displays active heating settings on both sides for the carrier-based obturation technique. Personal photo.

(iv)Insertion of the Heated Obturator

- The heated GuttaCore obturator will be slowly and immediately inserted into the canal until resistance is felt at working length.
- A single, firm motion will be used for placement without excessive force.

(v) Cutting and Compacting

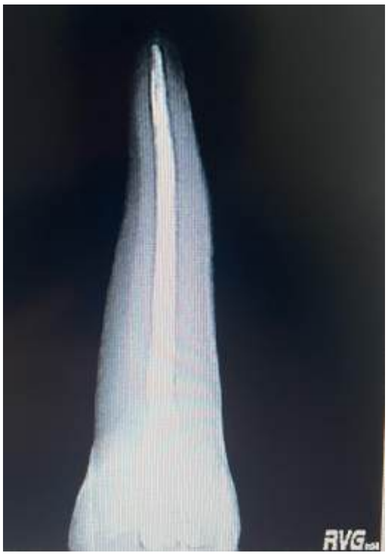
- The plastic carrier handle will be cut at the orifice level using a heated instrument.
- A plugger will be used for light vertical compaction at the coronal level.

(vi) Final Radiographic Verification

- A final RVG radiograph will confirm proper obturation and adaptation.

Figure 19

Final bucolingual RVG radiograph of a maxillary canine confirming proper obturation and carrier adaptation using the GuttaCore system (Dentsply Sirona).



Note. Personal image

3.2.6 Apical Permeability Evaluation

- Preparation of Teeth :
  - ◉ The external root surfaces of each tooth will be coated with two layers of nail varnish (Nocibé®, Paris), leaving the apical 2 mm exposed to ensure proper dye penetration at the apex.

Figure 20

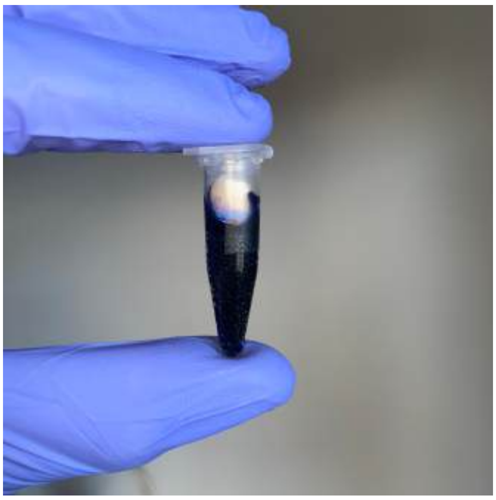
Maxillary canine coated with two layers of varnish on the root surface, leaving a 2 mm apical window exposed to allow dye penetration for permeability assessment.

Note. Personal photo.

- Immersion in Methylene Blue Dye :
  - Each tooth will be placed in an Eppendorf tube and immersed in 0,5% methylene blue dye The immersion will cover the tooth up to the cemento-enamel junction (CEJ), allowing for accurate dye penetration.

Figure 21.

Each tooth was placed in an Eppendorf tube and immersed in a 0.5% methylene blue solution.



Note. The dye level was adjusted to reach the cemento-enamel junction (CEJ), allowing for accurate evaluation of apical dye penetration. Personal photo

- The Eppendorf tubes containing the specimens were placed in a perforated support within a water bath incubator at 37 °C for 24 hours, ensuring that the tubes remained suspended above the water surface to avoid direct contact, while maintaining 100% humidity.

Figure 22

Eppendorf tubes containing the specimens placed in a perforated support within a water bath incubator at 37 °C for 24 hours.

Note. The tubes were suspended above the water surface to avoid direct contact, while maintaining 100% humidity. Personal photo.

- Control Groups :
  - Positive control teeth will remain unsealed to confirm maximum permeability.
  - Negative control teeth will be fully sealed, including the apical foramen, with glass ionomer cement to assess zero permeability.
- Control of Variables :
  - All samples will be stored at 100% humidity at 37°C, simulating intraoral conditions during the experiment.
  - The sealer materials will be allowed to fully set before the teeth are immersed in the dye to ensure results are not influenced by incomplete polymerization.

Figure 23

Low-speed straight handpiece with mounted diamond disc (Okadent®) used for the longitudinal sectioning of the teeth in the bucco-lingual direction under water irrigation.

Note. Personal photo.

- Sectioning and analysis:

    - After dye immersion, the teeth will be sectioned transversely at 1 mm, 3 mm, and 5 mm from the apex or longitudinally using a diamond disc (Okadent). After dye exposure, each tooth was sectioned longitudinally in the bucco-lingual direction using a diamond disc mounted on a low-speed handpiece under constant water irrigation to prevent heat generation and preserve specimen integrity. The sectioned halves were then placed on millimetric paper to facilitate the measurement of apical dye penetration. The extent of dye penetration was evaluated by measuring the length of internal methylene blue infiltration within the canal lumen, excluding any external or lateral surface diffusion. For each tooth, both halves were analyzed independently. When dye was clearly visible in both canal sections, the two values were averaged to obtain a final penetration score for that specimen. In cases where only one half of the tooth showed an exposed and measurable canal lumen, the single measurable value was used. This approach ensured consistency while minimizing the impact of sectioning limitations on data reliability.

Figure 24

Longitudinally sectioned maxillary canine from the GC-F2 group, showing internal dye penetration around the GuttaCore® obturator (Dentsply Sirona) after canal obturation and immersion in 0.5% methylene blue.

Note. The penetration was measured from the apex to the most coronal stained point along the canal walls. Personal photo.

- Quantitative results of dye penetration

  - The following table summarizes the individual apical dye penetration values recorded for all specimens, grouped according to the obturation technique and apical preparation size. These raw measurements form the basis for the subsequent statistical analysis and comparison of sealing performance between experimental groups.

Table 2

Individual apical dye penetration measurements (in mm) for all specimens in experimental and control groups.

ID Tooth	Technique	Caliber	Infiltration - mm
T1	SC	F2	3
T2	SC	F2	12
T3	SC	F2	2
T4	SC	F2	3,5
T5	SC	F2	4

T6	SC	F2	3,75
T7	SC	F2	3
T8	SC	F2	2
T9	SC	F2	3
T10	SC	F2	3,25
T11	SC	F2	4
T12	SC	F2	3
T13	SC	F2	2,5
T14	SC	F2	3,5
T15	SC	F2	4
T16	SC	F2	3
T17	SC	F2	5
T18	SC	F2	2,5
T19	SC	F2	4,5
T20	SC	F2	8
T21	SC	F3	6,5
T22	SC	F3	3,5
T23	SC	F3	11,5
T24	SC	F3	11
T25	SC	F3	4
T26	SC	F3	12
T27	SC	F3	2,5
T28	SC	F3	3,5
T29	SC	F3	10
T30	SC	F3	5
T31	SC	F3	2,75
T32	SC	F3	2,5
T33	SC	F3	4
T34	SC	F3	4,5
T35	SC	F3	4
T36	SC	F3	6
T37	SC	F3	3,5
T38	SC	F3	5
T39	SC	F3	2,5

T40	SC	F3	3,5
T41	GC	F2	2,5
T42	GC	F2	3
T43	GC	F2	5
T44	GC	F2	4
T45	GC	F2	3
T46	GC	F2	2
T47	GC	F2	3
T48	GC	F2	3
T49	GC	F2	2
T50	GC	F2	3,5
T51	GC	F2	4
T52	GC	F2	3
T53	GC	F2	1
T54	GC	F2	4
T55	GC	F2	1
T56	GC	F2	2
T57	GC	F2	3
T58	GC	F2	2
T59	GC	F2	2
T60	GC	F2	7
T61	GC	F3	4
T62	GC	F3	13
T63	GC	F3	8
T64	GC	F3	5
T65	GC	F3	4
T66	GC	F3	4
T67	GC	F3	2
T68	GC	F3	3
T69	GC	F3	4
T70	GC	F3	4
T71	GC	F3	4
T72	GC	F3	3
T73	GC	F3	10
T74	GC	F3	5

T75	GC	F3	5
T76	GC	F3	6
T77	GC	F3	4,5
T78	GC	F3	2,5
T79	GC	F3	4
T80	GC	F3	3
T81	Control +	F2	15
T82	Control +	F2	16
T83	Control +	F2	18
T84	Control +	F2	17
T85	Control +	F2	19
T86	Control -	F2	1
T87	Control -	F2	1
T88	Control -	F2	2
T89	Control -	F2	1
T90	Control -	F2	1

Note. For each sample, dye infiltration was measured from the apical foramen to the most coronal stained point along the root canal. When both longitudinal halves were measurable, the average value was recorded. In the positive control group (non-obturated canals), full-length dye penetration was observed and recorded individually based on each root's length. In the negative control group, limited dye penetration (1–2 mm) was detected in all specimens, likely due to incomplete varnish coverage on the apical root surface rather than leakage through the canal system.

These individual measurements were used as the basis for the statistical comparison of apical sealing effectiveness between the tested obturation techniques and apical preparation sizes.

3.3 RESULTS ANALYSIS

The dye penetration values were measured in millimeters across four experimental groups and two control groups with 10 specimens in each group. For the group SC-F2, which corresponds to the Single Cone technique with an F2 apical preparation, the mean dye penetration was 3.98 mm and standard deviation of 2.29 mm in this group; the lowest value was 2 mm, while the highest was 12 mm. The SC-F3 group was also done with the Single Cone technique but with an F3 preparation, and the mean was 4.59

mm with a standard deviation of 2.12 mm; the values in this group ranged between 2 mm and 9 mm.

In the GC-F2 group-which has meaning under the GuttaCore technique and an F2 apical preparation-measured mean dye penetration of 3.00 mm and a standard deviation of 1.39 mm in this study. The minimum value observed in this group was 1 mm; the maximum was 7 mm.

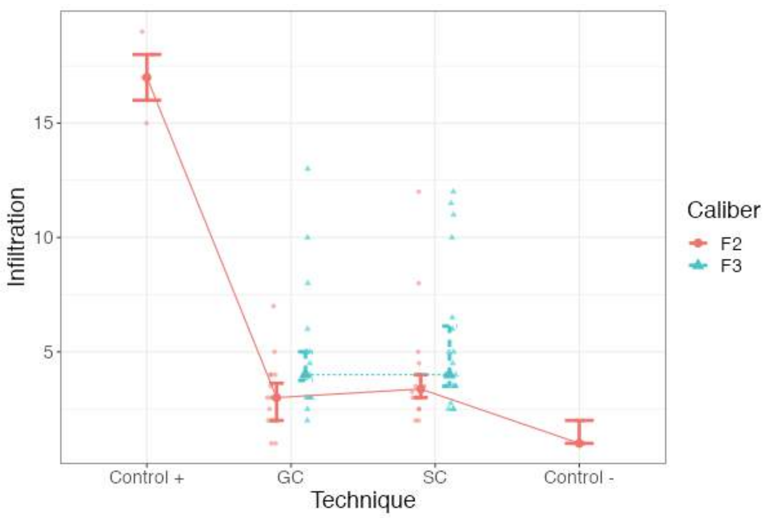
In the group GC-F3, which made use of a combination of the GuttaCore technique with the F3 apical preparation, the mean value was 4.90 mm and the standard deviation at 2.65 mm. The amount of dye penetration ranged between 2 mm and 13 mm. To the control groups, the positive one (Control (+)), where obturation was not made, showed penetration of 17.00 mm mean penetrated with 1.58 mm in standard deviation. Ranges recorded in this group were between 15 mm and 19 mm.

Finally, the negative control Group ("Control (-): in which specimens were sealed externally, had a mean dye penetration of 1.40 mm, with 0.55 mm standard deviation. The minimum number observed was 1, whereas the maximum was 2.

Considering this, Figure 25 displays mean values and error of mean illustrating the apical dye penetration parameters better across the different obturation procedures and apical preparation sizes.

Figure 25

Mean apical dye penetration (mm) and standard error according to obturation technique (SC, GC, and control groups) and apical preparation size (F2 and F3).



3.4 STATISTICAL ANALYSIS

- Hypothesis Testing

Before conducting the statistical analysis, the following hypotheses were established:

  - Null hypothesis (H_0): There is no significant difference in apical dye penetration among the experimental groups, regardless of obturation technique or apical preparation size.
  - Alternative hypothesis (H_1): There is a statistically significant difference in apical dye penetration between at least two of the experimental groups.

The significance level was set at $\alpha = 0.05$.

- Statistical methodology

All statistical analyses were performed using the open-source software Jamovi (version 2.3.28), which is based on the R programming language.

The Shapiro-Wilk test for normality was performed in each subgroup of the experiment. The results were as follows: SC-F2, $W = 0.684$ and $p = 0.006$, indicating a significant deviation from normality; SC-F3, $W = 0.674$ and $p < 0.001$, also indicating deviations from normality; GC-F2, $W = 0.899$ and $p = 0.040$, suggesting a slight but significant deviation from normality; and GC-F3, $W = 0.770$ and $p < 0.001$, confirming deviations from normality. This suggests that most experimental groups violated the assumption for normality.

Since the assumption of normality had been violated, a nonparametric alternative to one-way ANOVA was chosen. The Kruskall-Wallis test compares more than two independent groups without assuming normal distribution of the data and is appropriate for dependent variables that are continuous but measured across independent categorizations.

To compare the differences in apical dye penetration regarding the apical preparation size (F2 versus F3) and the obturation technique (Single Cone versus GuttaCore), two separate Kruskal-Wallis tests were performed, the data failing normal distribution.

The Kruskal-Wallis test demonstrated a statistically significant difference between dye penetration on the F2 versus F3 preparation groups ($\chi^2 = 12.1$, $p < 0.001$). The post hoc pairwise comparisons using the Dwass, Steel, Critchlow-Fligner method revealed that this difference was highly significant ($W = 4.91$, $p < 0.001$), indicating a meaningful apical preparation size effect on apical sealing performance.

On the other hand, comparing the obturation techniques, no statistically significant difference in dye penetration was observed between the Single Cone and GuttaCore groups ($\chi^2 = 1.08$, $p = 0.299$). Since the global test was not significant, post hoc comparisons were not done for this variable.

The Kruskal-Wallis tests rejected the null hypothesis (H0) for "apical preparation size" (F2 vs. F3), signifying that dye penetration differs significantly between these groups. However, since no statistical difference was found with reference to the variable "obturation technique" (Single Cone vs. GuttaCore), the null hypothesis was not rejected for that variable.

The evaluation of these statistical findings sets the basis for the interpretations and discussions of the sealing effectiveness in the following chapter.

4. DISCUSSION

The present in vitro study aimed to evaluate the apical sealing ability of two techniques of root canal obturation-the Single Cone (SC) and GuttaCore (GC) in combination with two different apical preparation sizes (F2 and F3) using the ProTaper Ultimate (PTU) system. Dye penetration measurement using 0.5% methylene blue solution allows quantifying apical microleakage. According to the results, the apical preparation size significantly influenced the extent of dye penetration, but the obturation technique used did not have a statistically significant difference.

Overall, for the mean leakage, the GC-F2 group had seen the less extent of leakage, at 3.00 mm. The largest extent of leakage was observed in the GC-F3 group, with about 4.90 mm. Irrespective of the technique employed, leakage definitely trended higher with the increased size of apical preparations. This could be said from the fact that larger apical preparations allow for broader exposure to potential microleakage opportunity where the obturation scheme may not optimally ensure complete adaptation in the apical third. The fact that the mechanical preparations don't touch all the walls of the SCR and that the internal anatomy of the RC's is irregular may also contribute to this. Conversely, narrower preparations may, therefore, enhance the mechanical sealing effect of the gutta-percha cone and sealer, especially in the SC technique.

While GC is expected to outperform SC because of its thermoplasticity and adaptability (Fracchia et al., 2020; Migliau et al., 2022), no statistically significant difference was found in this study. The contradiction lies in the fact that both techniques were applied with the same resin-based sealer (AH Plus Jet®), which is recommended to be used with GC in both the manufacturer instructions and the literature. Under bioceramic sealers, SC had better performance in more recent studies because bioceramic sealers give greater flow, bioactivity, and dimensional stability (Nouroloyouni et al., 2023; Jaha, 2024). Thus, this may have placed SC at a relative disadvantage in this study because it was not tested under its most favorable conditions. Also, all teeth selected for the present study had single, straight canals, which may have further contributed to minimizing the expected differences between the two techniques. In such simple anatomic cases, the SC technique, with a well-fit gutta-percha cone and a flowable sealer, may achieve adequate adaptation and sealing without relying on thermoplastic flow from carrier-based systems. In contrast, GC beneficiaries in curved or irregular canals where heated gutta-percha may adapt to complex morphology. The absence of this anatomical complexity in the sample may have neutralized the performance benefit normally associated with GC.

Therefore, the absence of significant differences in sealing ability observed in this study may reflect rather the tendency of the techniques to behave conjointly under a single resin-based sealer in a favorable anatomical setting than an evidence of their intrinsic equivalence. GC, in its ideal configuration, might not have been fully able to utilize its thermoplastic properties due to the apical preparation size being wide in the likes of F3. Since inadequate plasticization or centralization of the carrier in larger canals could compromise sealing, SC may well have adjusted to an appropriately fitting gutta-percha cone and flowable sealer in narrower preparations like F2, compensating for thermoplasticity.

The poor results of GC-F3 seem to indicate what one would expect from the theoretical advantages of GC yet might have been partially caused by technique-related factors in thermoplastic obturation pertaining to wider apical preparations. In these cases, the larger diameter in F3-sized canals allows for a more rapid dissipation of heat such that the GuttaCore cone is not sufficiently plasticized. If gutta-percha is not softened and pliable enough, it probably cannot adapt well to canal walls and afford filling of many irregularities, particularly in oval shapes of apical thirds. Additionally, larger canals have a more likely probability that the GuttaCore carrier would be centralized in the canal thus limiting its access and contact with all dentinal surfaces along the length of the canal, creating voids or gaps that allowed for the penetration of dye. In contrast, SC which is less dynamic, may have benefit from a better fitting cone in F3 canals, especially when used with a highly flowable sealer, thus lessening the effects of enlargement.

These results were only partly in line with previous studies indicating that SC, especially in combination with bioceramic sealers, leads to outcomes as good as more complicated procedures (Nouroloyouni et al., 2023; Jaha, 2024). Additionally, it is important to note that the resin-based sealers used in this study have been shown to be more susceptible to degradation than bioceramic sealers over time, which might influence the long-term success of SC obturations (Boutsioukis & Arias-Moliz, 2022).

The dye penetration test was preferred as the method for its straightforwardness and accessibility. However, several limitations of this approach must be appreciated. As in the foundational chapter and the literature described (Camps & Pashley, 2003; Muliyar et al., 2014), methylene blue dye has a very small molecular size, which tends to overestimate compared to bacterial penetration. Methylene blue solution was adjusted for neutral PH 7-the pH-an attempt to minimize bias that relates to pH-related dentin demineralization, as it would most likely create artificial increase infiltration.

According to clinical protocols, the working length was determined in this study by inserting a size 015 K-file until it appeared at the apical foramen, then subtracting 0.5 mm to represent the location of the apical constriction. This modification was made to respect the anatomical landmark which is generally considered the physiological endpoint for instrumentation and obturation. Recently published literature showed that apical constriction should typically be found between 0.3 and 0.9 mm coronally to the apical foramen, depending on the individual root anatomy and the type of tooth (Piasecki et al., 2018; Teixeira et al., 2021). Dye penetration was, however, measured from the anatomical apex. Although common in in vitro studies, this methodological choice may bias towards a small over-reporting of leakage values, particularly if obturation is performed precisely up to the working length, which further supports caution taken while making differences in measurement based on dye use.

Moreover, a certain amount of variation in the results can be attributed to the operator's technique and inexperience and sample anatomy. Even though strict criteria for inclusion were applied, natural root canal anatomy shows significant differences from one specimen to another, and even with standardization of instrumentation, one does not hold ideal homogeneity. In addition, some aberrant values noted in SC-F3 and GC-F3 groups may indicate specimens with anatomical aberrancy or poor obturation placement. Though such outliers are retained for statistical analysis to keep representation of the sample, they highlight the need for clinician skill as well as anatomical complexity in endodontic outcomes.

The slightly increased dye penetration in the negative control group (mean = 1.40 mm) indicates that sealing with varnish and glass ionomer cement has perhaps not been totally effective. This strengthens the idea that even minor procedural mistakes can influence experimental outputs and must thus be accounted for in the interpretation.

In short, this study demonstrates that apical preparation size is a significant factor affecting microleakage; with regard to sealing, the apical preparation size F2 showed better sealing qualities than F3. However, with the conditions evaluated, no significant difference was observed between the obturation techniques SC and GC. These results are supportive of the fact that simple techniques such as SC may also result in clinically acceptable outcomes, especially under controlled conditions and appropriate materials.

It is important to acknowledge some inherent limitations in this study, including variability in specimen anatomy, potential operator influence, and the simplified in vitro conditions, which cannot fully replicate the complexity of the clinical environment. The variability observed within groups - particularly in specimen showing unusually high or low penetration - highlights the multifactorial nature of apical leakage and the need for cautious interpretation of individual data points.

In fact, future researches would benefit for using more biologically relevant testing methods, such as bacterial leakage or micro-CT imaging, and including bioceramic sealers to assess the performance of SC techniques. In addition, investigating the impact of minimally invasive shaping strategies combined with obturation approaches could be a new aspect of finding optimal strategies in endodontic success.

5. CONCLUSION

This in vitro study helped us to evaluate the apical sealing efficacy of two obturation techniques, Single Cone and GuttaCore®, at two apical preparation sizes (F2 and F3) using the ProTaper Ultimate system with methylene blue dye for leakage assessment was carried out in this study. Results obtained indicated a statistically significant difference in apical preparation size when microleakage was concerned; that is, usage of narrower apical diameters (F2) led to improved sealing performance, regardless of the techniques employed. Notably, even the theoretical advantages of having GuttaCore's thermoplasticized carrier-based design did not lend itself to statistically significant superiority over the Single Cone method under conditions studied. This fact supports the possible view that if high-quality resin-based sealers were employed and standardized conditions were maintained, then relatively simpler techniques might lead to equivalent results-an endodontic philosophy of being minimally invasive towards the root structure. The use of neutral pH methylene blue helped reduce the common bias from dye-induced demineralization, thus strengthening the reliability of the findings. This study offers a clinically relevant insight and would motivate researchers to further pursue the bioceramic sealers and even more biomimetic models for assessment of obtained long-term performance of obturations, albeit being restricted by in vitro circumstances.

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APPENDICES

APPENDIX A – ETHICS COMMITTEE APPROVAL

Official approval issued by the Ethics Committee of FCS-UFP, authorizing the execution of the present research protocol.

Comparison of apical sealing capacity of two obturation techniques : Obturation Technique of Single Cone vs obturation with Guttacore®

UNIVERSIDADE FERNANDO PESSOA

Exma. Senhora
Prof. Doutora Sandra Gavinha
Diretora da FCS

Nº	Data
FCS/MIMD – 625/24-2	29 de Outubro de 2024

Exma. Senhora Professora Doutora,

A Comissão de Ética apreciou a ressubmissão do projeto de investigação apresentado por Olivier Patrick Philippe Clavier, intitulado "Comparação da capacidade de selamento apical de duas técnicas de obturação: Técnica de obturação de cone único Versus Obturação com Guttacore®", a realizar no âmbito do Mestrado Integrado em Medicina Dentária.

O objetivo principal deste estudo é efetuar um estudo in vitro para aferir a capacidade de selamento apical em dentes monorradiculares a 1mm, 3mm e 5mm do ápice, utilizando na preparação do sistema de canais radiculares, dois diâmetros de última lima e na sua obturação, duas técnicas diferentes.

A Comissão de Ética da Universidade Fernando Pessoa considera que todas as questões colocadas foram respondidas de forma adequada pelo que não há condicionantes éticos a colocar à realização do mesmo.

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

Com os melhores cumprimentos,

A Presidente da
Comissão de Ética da UFP

Inês Lopes Cardoso

Autorizado

29-10-24

APPENDIX B – DECLARATION OF TOOTH SAMPLE ORIGIN

Declaration describing the origin of the extracted teeth used in this study. The samples were obtained from a dental clinic in France, where patients sign a general informed consent upon their first visit. No personal or clinical data were collected. Full anonymity of all samples was ensured.

Comparison of apical sealing capacity of two obturation techniques : Obturation Technique of Single Cone vs obturation with Guttacore®

Declaration of Tooth Sample Origin

The teeth used in the present study were obtained from a private dental clinic located in France. Upon their first appointment, all patients at this clinic routinely sign a general informed consent form authorizing the use of extracted teeth for educational and scientific research purposes.

The teeth were donated voluntarily and anonymously, without any personal, clinical, or identifying data being collected. The selection and handling of the samples followed all applicable ethical guidelines. The study protocol involving these biological samples was submitted to the Ethics Committee of FCS-UFP and received a favorable opinion (see Appendix A).

This declaration is issued to attest to the legal and ethical origin of the dental samples used in this investigation.

Porto, 14/05/2025

Olivier Clavier

Comparison of apical sealing capacity of two obturation techniques : Obturation Technique of Single Cone vs obturation with Guttacore®

APPENDIX C – SAMPLE OF PATIENT CONSENT FORM

Example of the general consent form signed by patients at the French dental clinic, authorizing the use of extracted teeth for scientific and academic research purposes.

The original documents are presented in French.

Comparison of apical sealing capacity of two obturation techniques : Obturation Technique of Single Cone vs obturation with Guttacore®

Questionnaire médical

Ce questionnaire médical et confidentiel est destiné à l'usage exclusif de votre chirurgien-dentiste dans le cadre de son exercice professionnel. Il sera conservé dans votre dossier patient. Toutes les indications renseignées sont soumises au secret médical.

Informations générales

Nom .... Prénom(s) :..

Date de naissance :... Taille :.. Poids :..

Adresse (N°, voie, code postal, ville) :..

Téléphone :...................................... Mail :..

Profession :...

Motif de la consultation :...

Date de votre dernière visite chez un chirurgien-dentiste :..

Nom du précédent chirurgien-dentiste :..

Nom du (des) médecin(s) traitant(s) ou spécialiste(s) :...

Prenez-vous actuellement des médicaments ? ○ Oui ○ Non

Si oui, lesquels ?...

Pour quel problème de santé ? :..

....

Êtes-vous à jour de vos vaccins ? ○ Oui ○ Non

Soins dentaires

Avez-vous peur du dentiste ? ○ Oui ○ Non

Avez-vous déjà eu des anesthésies locales dentaires ? ○ Oui ○ Non Si oui, avez-vous eu des problèmes ? ○ Oui ○ Non

Avez-vous déjà eu des complications à la suite de soins dentaires ?

Allergie ? ○ Oui ○ Non

Malaise - Perte de connaissance ? ○ Oui ○ Non

Hémorragie ? ○ Oui ○ Non

Femmes

Etes-vous enceinte ? ○ Oui ○ Non Si oui, nombre de semaines/mois :..

Allaitez-vous ? ○ Oui ○ Non

⟶

Avez-vous ou avez-vous eu des problèmes de santé ?
Si oui à l'item concerné, cochez le rond correspondant et précisez la date ou depuis combien de temps.

Maladies cardiaques	Précisions Date/Durée
O Hypertension artérielle	
O Infarctus du myocarde	
O Angor/Angine de poitrine	
O Cardiopathie congénitale	
O Pacemaker	
O Endocardite infectieuse	
O Prothèse valvulaire cardiaque	
O Arythmie	

Maladies du sang	Précisions Date/Durée
O Hémophilie	
O Autres troubles de la coagulation :	
O Saignement abondant après une coupure	

Maladies respiratoires	Précisions Date/Durée
O Asthme	
O B.P.C.O	
O Apnée du sommeil	
O Autre :	

Maladies rénales	Précisions Date/Durée
O Insuffisance Rénale	
O Dialyse	
O Autre :	

Maladies neurologiques	Précisions Date/Durée
O Epilepsie	
O Maladie de Parkinson	
O Accident Vasculaire Cérébral	
O Autre :	

Allergies	Précisions Date/Durée
O Antibiotique	
O Iode	
O Latex	
O Métal :	
O Anesthésie	
O Autre :	

Autres maladies	Précisions Date/Durée
O Maladie rare :	
O Maladie auto-immune :	

Maladies endocriniennes	Précisions Date/Durée
O Diabète	
O Désordre thyroïdien :	

Maladies ORL	Précisions Date/Durée
O Sinusite - Type : O Unilatérale ou O Bilatérale	

Maladies digestives	Précisions Date/Durée
O Reflux gastro-œsophagien	
O Ulcère digestif	
O Cirrhose	
O Maladie de Crohn / Rectocolite Hémorragique	
O Autre :	

Maladies infectieuses	Précisions Date/Durée
O Hépatites - Type :	
O VIH - Charge virale :	
O Herpès - Zona :	
O Autre :	

Cancer	Précisions Date/Durée
O Antécédent de cancer - Type :	
O Cancer actif - Type :	
O Radiothérapie cervico-faciale (tête/cou)	
O Chimiothérapie	

Maladies osseuses ou articulaires	Précisions Date/Durée
O Ostéoporose - Traitement :	
O Rhumatisme inflammatoire chronique	
O Prothèse articulaire (hanche, genoux...)	
O Autre :	

Consommation de substances	Précisions Date/Durée
O Tabac – Nb cigarettes/jour :	
O Alcool – Nb verres/jour :	
O Cannabis	
O Autre :	

Autres problèmes de santé	Précisions Date/Durée
O Violences subies au cours de la vie (pendant l'enfance, au travail, à la maison...)	
O Dépression	
O Tétanie/Spasmophilie	
O Autre :	

J'autorise le Docteur .... à l'utilisation, si le cas se présente, de dents extraites à des buts de test de nouveauté en cabinet, à une recherche odontologique en milieu hospitalo-universitaire mais aussi pour l'entraînement pour les travaux pratiques d'étudiant en odontologie.

○ Oui ○ Non

« Je certifie que les informations fournies au chirurgien-dentiste sont complètes et m'engage à lui signaler toute modification de mon état de santé. »

Date : Signature du patient :