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Vital Pulp Therapy for Treatment of Definitive Mature Teeth with Symptomatic Irreversible Pulpitis: Retrospective Study

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Vital Pulp Therapy for Treatment of Definitive Mature Teeth with Symptomatic Irreversible Pulpitis: Retrospective Study

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ABBREVIATIONS LIST

VPT – Vital Pulp Therapy

TPV – Terapia Pulpar Vital

AAE – American Association of Endodontists

ESE – European Association of Endodontists

NSRCT– Nonsurgical Root Canal Treatment

TENC – Tratamento Endodôntico Não Cirúrgico

DPC – Direct Pulp Capping

PP – Partial Pulpotomy/Pulpotomia Parcial

FP – Full Pulpotomy

PT – Pulpotomia Total

CH – Calcium Hydroxide

HCSCs - Hydraulic Calcium Silicate Cements

MTA – Mineral Trioxide Aggregate

BD – Biodentine™ (Septodont, Saint-Maur-des-Fossés, France)

CEM – Calcium Enriched Mixture Cement

PMNs – Polymorphonuclear Leukocytes

NaOCl – Sodium Hypochlorite

ABSTRACT

Introduction: Pulpitis is an inflammatory condition caused by harmful stimuli, with a high global prevalence. In cases of definitive mature teeth diagnosed with irreversible pulpitis, the traditional approach (NSRCT - Non-Surgical Root Canal Treatment) can have limitations, leading to the emergence of vital pulp therapy (VPT) as a viable alternative. As a less invasive therapy, it provides a new perspective on preserving pulp's vitality. This study assessed, retrospectively, the long-term prognosis of VPT in definitive mature teeth with symptomatic irreversible pulpitis, treated with hydraulic calcium silicate cements. **Materials and Methods:** 24 patients (26 teeth) were referred to endodontic appointments diagnosed with symptomatic irreversible pulpitis, according to the American Association of Endodontists criteria. Information such as age, sex, type of tooth, time to achieve hemostasis, type of pulpotomy, and biomaterial, were collected for a more criterious evaluation of the prognosis of VPT. All cases were intraoperatively assessed to exclude necrosis or the impossibility to achieve hemostasis, leading to a clinical decision. The clinical follow-up evaluation was based on thermal sensitivity and percussion, and clinical signs and symptoms of inflammation/infection. The presence/absence of dentinal bridge and periapical tissue condition were evaluated by radiographs. Comparisons between types of pulpotomy were performed (t-test and chi-square test). Kaplan-Meier analysis was conducted on the overall sample and stratified by type of pulpotomy to determine survival. The log-rank test compared strata. Cox regression investigated the effect of hemostasis strategy and the impact of age on success. **Results:** Intraoperative assessment excluded 4 teeth due to pulp necrosis or impossibility of achieving hemostasis and 22 teeth remained viable for VPT. Age and hemostasis strategy promotion did not have a significant impact on survival. Partial pulpotomy (n=8) and full pulpotomy (n=14) had success rates of 87.50% and 92.86%, respectively, with no significant differences ($p>0.05$). Biodentine was the predominant choice (81.82%). **Conclusion:** Although preoperative diagnosis is limited, intraoperative pulp tissue assessment is crucial for case selection. Both types of pulpotomy are successful in managing definitive mature teeth diagnosed with symptomatic irreversible pulpitis under strict antiseptic conditions, adequate hemorrhagic control, and appropriate restoration, providing a less invasive alternative to NSRCT. There is a need for widespread education on VPT's effectiveness, emphasizing the need for further studies to establish case selection and outcome evaluation criteria.

Keywords: Vital pulp therapy; Irreversible pulpitis; Pulpotomy

RESUMO

Introdução: A pulpite é uma condição inflamatória provocada por estímulos prejudiciais, com elevada prevalência global. Em casos de dentes definitivos maturos diagnosticados com pulpite irreversível, a abordagem tradicional (TENC – Tratamento Endodôntico Não Cirúrgico) pode apresentar limitações, sendo a terapia pulpar vital (TPV) uma alternativa viável. Dada esta opção menos invasiva, esta atinge uma nova perspetiva no que toca à preservação da vitalidade pulpar. Este estudo avaliou, retrospetivamente, o prognóstico da TPV em dentes com pulpite irreversível, tratados com cimentos hidráulicos à base de silicato de cálcio. **Materiais e Métodos:** 24 pacientes (26 dentes) foram encaminhados para a consulta de endodontia com diagnóstico de pulpite irreversível sintomática, de acordo com os critérios da Associação Americana de Endodontistas. Informações como a idade, sexo, tipo de dente, tempo de hemóstase, tipo de pulpotomia e biomaterial, foram recolhidas com o intuito de realizar uma avaliação criteriosa do prognóstico da TPV. Os casos foram avaliados intraoperatoriamente para excluir necrose ou impossibilidade de alcançar a hemóstase, levando a uma escolha clínica. Nos controlos, a avaliação clínica foi baseada na sensibilidade térmica e percussão, e sinais e sintomas clínicos de inflamação/infeção. A presença/ausência de ponte dentinária e o estado dos tecidos periapicais foram avaliados através de radiografias. Foram realizadas comparações entre os tipos de pulpotomia (teste-t e teste qui-quadrado). A análise de Kaplan-Meier foi conduzida na amostra geral e estratificada por tipo de pulpotomia, para estimar a sobrevivência. O teste log-rank comparou os estratos. A regressão de Cox investigou o impacto da estratégia de hemóstase e da idade no sucesso. **Resultados:** A avaliação intraoperatória excluiu 4 dentes devido a necrose pulpar ou impossibilidade de alcançar hemóstase, restando 22 dentes viáveis para TPV. A idade e a estratégia de promoção de hemóstase não demostraram impacto significativo na sobrevivência. A pulpotomia parcial (n=8) e a pulpotomia total (n=14) exibiram taxas de sucesso de 87.50% e 92.86%, respetivamente, sem diferenças significativas (p>0.05). O BD foi a escolha predominante (81.82%). **Conclusão:** Embora o diagnóstico pré-operatório seja limitado, a avaliação intraoperatória do tecido pulpar é crucial para a seleção de casos. Ambos os tipos de pulpotomia apresentam sucesso no tratamento de dentes definitivos maturos com pulpite irreversível sintomática, sob condições antissépticas rigorosas, controle hemorrágico adequado e restauração apropriada, sendo uma alternativa menos invasiva que o TENC. Existe a necessidade de instrução sobre a eficácia da TPV, enfatizando a necessidade de estudos que estabeleçam a seleção de casos e critérios de avaliação de resultados.

Palavras-chave: Terapia pulpar vital; Pulpite irreversível; Pulpotomia

INTRODUCTION

Pulpitis is a dental condition in which inflammation of the pulp tissue occurs in response to harmful stimuli, including chemical, physical, or microbial origin.[1–3] An example of an insult is the carious process[3], which enhances and intensifies the inflammatory response as it progresses towards the pulp tissue.[1,2] This is an important factor to consider since, according to the Global Oral Health status report of the World Health Organization (WHO), in 2022, the estimated global average prevalence of caries in permanent teeth was 29%, which means more than 2 billion individuals. Middle-income countries report 75% of cases of untreated caries in permanent teeth.[4]

The clinical diagnosis of pulp status, whether it is healthy, exhibiting reversible pulpitis, or irreversible pulpitis, relies on an evaluation of past and present signs and symptoms, the extent of adjacent caries, responsiveness to sensitivity tests and percussion, and the radiographic condition of the periapical tissues.[1,5] According to the American Association of Endodontists, pulpitis is regarded as reversible when we remove the stimulus and the pulp can return to a normal condition.[1,5,6] In irreversible pulpitis, the pulp condition has less chance to be reverted to normal if no other intervention arises than the removal of irritant factors.[1,7] The indicators of this stage can be preoperative spontaneous or elicited severe pain and pulp exposure. However, these indicators need to be carefully considered, since they may not inevitably correspond to an irreversible inflammatory condition of the entire pulp.[7,8] Recent studies showed that pulp inflammation occurs by compartments and it progressively migrates apically, which means that it is often restricted to the coronal pulp next to carious lesions, remaining the rest of the pulp uninflamed and viable.[1,8] Furthermore, the existence of a connection between the vascular and neural components of the pulp tissue makes it possible to coordinate the majority of the physiologic and pathologic reactions of the tooth, including responses to the carious process.[9]

Histologically, in irreversible pulpitis, we can find areas of coagulation or liquefaction necrosis, greatly colonized by bacteria and enclosed by PMNs, localized to very specific areas of the pulp chamber, near the deep carious decay.[1] In addition, it is frequent to find a normal histologic pulp in areas of the pulp chamber away from the carious site and the radicular pulp is usually with normal architecture in those cases.[10,11]

The diagnosis process is also intricate by the fact that irreversible pulpitis can be presented in two forms: symptomatic or asymptomatic, differing between them by the presence or absence of subjective and objective findings (e.g. response to thermal stimuli, decays or fractures that may invade the pulpal space, deep restorations), demanding elaborate interpretation skills.[5]

As new perspectives in pulp biology have emerged, the traditional criteria for diagnosis of (ir)reversible pulpitis has been challenged over the years.[5,6,9] Clinical studies have demonstrated that removal of the inflamed pulp tissue can allow the preservation of the remaining uninflamed pulp, therefore, pulpitis can turn into a reversible stage, and pulp tissue return to a healthy status.[8] To foster the adoption of minimally invasive treatment option to deal with pulp inflammation, a new terminology has been proposed and introduced: initial pulpitis, mild pulpitis, moderate pulpitis, and severe pulpitis, in ascending order of extent of the inflammation and all related, also, to suggestions of VPT of different levels of invasiveness.[7]

VPT has long been accepted for primary teeth with pulp inflammation and permanent immature teeth.[2,8] Furthermore, the American Association of Endodontists (AAE) Position Statement on Vital Pulp Therapy advocates that the prediagnosis of irreversible pulpitis can be indicated for a more conservative treatment and not necessarily submitted to a conventional treatment modality, known as pulpectomy.[13] In light of these findings, VPT has been buttressed and various reports have demonstrated successful outcomes in mature teeth with irreversible pulpitis.[8,10,11,14–16]

The procedural steps of nonsurgical root canal treatment (NSRCT) are well known. This chemical and mechanical treatment involves cleaning and disinfection, instrumentation, and obturation of all root canals, under aseptic conditions and rubber dam isolation.[17] When the treatment is performed correctly, there is a high success rate for teeth to remain healthy, centered on radiographic and clinical evaluation, several years after the intervention.[8] However, cross-sectional studies of root-filled teeth have revealed high prevalence values of inadequate root fillings and apical periodontitis. This fact indicates failure of the procedure, leading to outcomes lower than expected.[18] Furthermore, pulpectomies are treatments that can be costly, technically demanding, and more invasive, thereby increasing the risk of fracture if final restoration is not performed with the adequate level of cusp coverage and protection from the occlusal forces.[18] These procedures do not preserve the proprioceptive sensation[18] and may not always effectively alleviate pain and discomfort.[7,18,19] Therefore, post-treatment apical periodontitis may emerge and require later non-surgical or surgical retreatment.[7,8,18]

All these facts are leading to a possible paradigm shift in the indications and contraindications of these procedures, highlighting the importance of maintaining pulp vitality.[7,11,13,18,20] With advancements in our understanding of pulp biology, the utilization of bioactive materials, and improved comprehension of technical aspects in tissue handling, there has been a shift towards discussing less invasive treatment options.[7,8,11,20]

VPT is related to the concept of minimally invasive dentistry.[7,8,21] The quantity of removed or retained pulp tissue depends on the hemorrhage control and clinical tissue appearance.[13] The primary objectives of these approaches are twofold: firstly, to preserve pulp viability and its physiological and defensive functions, and secondly, to minimize the removal of healthy tooth tissue, thereby reducing the risk of tooth weakening.[7] Technically, VPT begins with the removal of the carious lesion, followed by the actual pulp tissue amputation, which may involve partial or complete removal of the coronal pulp tissue. After achieving hemostasis, a biomaterial is applied as a capping agent, and finally, a definitive restoration is placed to complete the treatment.[17]

Direct pulp capping (DPC) is performed by the application of a bioactive material directly over the exposed dental pulp tissue, without pulp tissue removal.[12,22] This is an advantageous treatment because it preserves the function and structural integrity of teeth, it requires less working time and equipment, and it is more cost-effective compared with the NSRCT.[22,23] Compared to DPC, partial pulpotomy (PP) is a more invasive approach, comprising the removal of, at least, 2-3 mm of coronal affected pulp, with some pulp chamber tissue left in place.[16] It maintains cell-rich coronal pulp tissue and guarantees continuous deposition of cervical dentine, preventing teeth from weakness.[10,16] In contrast, full pulpotomy (FP) concerns the removal of the whole coronal pulp tissue till the level of the entrance of root canal orifices.[16,24] Compared to PP, it is a less challenging technique, provides higher chances of removing infected and irreversibly inflamed tissue, although it is more invasive.[10,16,24]

The capacity of pulp healing after the removal of irritation factors and the conjugation with biomaterials have expanded the scope of pulp vitality preservation.[11] When the carious process progresses and an intense inflammatory stimulus occurs the odontoblasts are harmed, lowering the number of these cells.[12] Therefore, the odontoblast secretory activity can be affected and reparative dentinogenesis is triggered, leading to human dental stem cells proliferation and its migration to the injured local.[12,22] These cells can differentiate into odontoblast-like cells and secrete reparative dentin into dentinal bridge form, protecting the pulp tissue and stimulating its healing.[22] Materials used in VPT are expected to stimulate cell migration, proliferation and differentiation, leading to reparative processes.[22]

Hence, pulp-capping materials should possess a range of properties including biocompatibility, bioactivity, antimicrobial potential, effective sealing ability, preservation of pulp vitality, radiopacity, ease of handling, dimensional stability, and the ability to withstand forces generated during mastication and placement of restorations.[25,26]

For decades, calcium hydroxide (CH) has been the gold standard pulp-capping material.[25–27] However, this material has some drawbacks, including the potential for pulp surface inflammation and necrosis, the formation of dentin bridges with numerous tunnel defects that can compromise sealing, gradual dissolution in oral fluids, and poor adhesion to dentin.[25]

To address the inherent limitations of the aforementioned material, hydraulic calcium silicate-based cements (HCSCs) were developed.[27] Examples of HCSCs include mineral trioxide aggregate (MTA), calcium-enriched mixture cement (CEM) and Biodentine™ (BD; Septodont, Saint-Maur-des-Fossés, France), were developed. These biomaterials have the capacity to effectively seal the pulp wound interface and allow pulp healing.[8]

MTA is a bioactive material composed of Portland cement – tri-calcium and di-calcium silicate, and bismuth oxide as a radiopacifier.[25] It is the gold standard material for VPT and it has other clinical applications such as perforative root resorption defects repair, surgical root-end fillings, root and pulp chamber perforations repair and apexification procedures.[25] This material is biocompatible, and has inductive capacity for dentin-bridge neoformation, allowing pulp healing.[25,26] It presents antimicrobial and sealing properties.[26] Nevertheless, clinically, MTA has various drawbacks like discoloration potential, high cost, long setting time, poor handling and difficulties in handling.[26]

All these disadvantages have given rise to the development of alternative materials, as Biodentine™ (Septodont, Saint-Maur-des-Fossés, France).[26] BD is a tricalcium silicate-based material, having similar composition and clinical applications to MTA.[25,26] It has biocompatible and bioactive properties, as well as, it is appropriate for use in direct posterior restorations, furcal perforations, retrograde filling, and pulp capping.[25] Furthermore, BD can be considered a dentine substitute, in means that it has shown good results regarding dentin-bridge formation.[26] Likewise, this material offers some favorable improvements of various properties such as easier handling, lower setting time and less coronal discoloration.[24,26,27]

Apart from these materials, there are others can be suitable alternatives as pulp capping agents, such as premixed HCSC with putty consistency, such as TotalFill BC Putty.[27]

The success of these therapies and the clinical decision-making on when and how to apply them is based on the inflammatory state of the pulp and the preoperative diagnosis, although, nowadays, we need to rely on the intraoperative evaluation to make a definitive decision on whether to apply VPT or proceed with NSRCT.[1,20]

In this regard, the primary aim of this study was to evaluate, retrospectively, the long-term prognosis of VPT in definitive mature teeth with symptomatic irreversible pulpitis, treated with HCSCs.

MATERIALS AND METHODS

Study Design

This was a retrospective cohort study, conducted following the recommendations of the Ethics Committee of the Faculty of Medicine of the University of Coimbra. The protocol applied to patients was conducted in accordance with the principles of the Helsinki Declaration.

All patients were informed about the details of the study and its protocol. A written informed consent was obtained before the evaluation. Data was collected and codified, treated with confidentiality, guaranteeing the total anonymity of the participants.

Case Recruitment

Patients referred to endodontic appointments at the University Hospital Center of Coimbra. For standardization of the participants in this study, we used inclusion criteria as stated below:

1. Being included in the national healthcare system;
2. Being in the age range of 7-80 years;
3. Cases treated between 2018 and 2023;
4. Definitive mature teeth with symptomatic irreversible pulpitis following the criteria established by the American Association of Endodontists;
5. Teeth restorable without intra-radicular retention;
6. All the included cases must have been performed by the same calibrated and experienced operator;
7. Being prepared for recalls.

Methodology

One single calibrated and experienced professional performed the clinical procedure, following standard protocol and aseptic precautions. During the procedure, intraoperative information was collected such as pulp tissue consistency and color, blood flow, time required for hemostasis, hemostasis promotion strategy, type of pulpotomy and applied biomaterial. Cases with signs of complete pulp chamber necrosis (coagulative or liquefactive) or which was not achieved after 6 minutes of compression were treated with NSRCT.

The steps of the clinical procedure equally performed for all cases are outlined as follows:

1. Preoperative clinical and demographic data collection – Clinical history filling;
2. Orthopantomography and apical radiographs, to evaluate and plan the procedure;
3. Realization of thermal sensitivity and percussion tests, to reach a definitive preoperative diagnosis according to the AAE classification[6] and Wolters' *et al.* proposal[7];
4. Application of inferior alveolar nerve block (3% mepivacaine without vasoconstrictor) followed by buccal infiltrative anesthesia (2% lidocaine with vasoconstrictor 1:80,000), for mandibular teeth, and just buccal infiltrative anesthesia for maxillary teeth;
5. Rubber dam isolation;
6. Cavity preparation, using a bur in handpiece with water coolant and excavation of carious lesion with a large round bur in a low-speed handpiece;
7. Cleansing of the cavity with a disinfectant, 3% sodium hypochlorite, before pulp exposure occurs;
8. Changing for a new sterilized high-speed diamond burr and amputation of part or complete coronal pulp tissue;
9. Intraoperative pulp tissue evaluation, with magnification, to assess areas of pulp necrosis or infection;
10. Bleeding assessment and hemostasis achievement by gentle pressure with a sterile cotton pellet for 2 minutes, repeated twice if it was necessary; If hemostasis was not achieved, in cases of PP, additional removal of pulp tissue was considered and/or application of 2 additional periods of pressure to achieve hemostasis; At this stage, 3% NaOCl or 4ºC sterile saline solution was used;
11. Gentle application of a first layer of a biomaterial as a capping agent;
12. Placement of a definitive restoration under rubber dam isolation, if possible, or, if not, a temporary restoration;
13. Postoperative periapical radiograph of the treated tooth.

It is known that teeth submitted to VPT should be followed up, clinical and radiographically.[2] According to the position statement of the European Society of Endodontology, VPT cases should be appraised 6 and 12 months postoperatively and yearly, if necessary, for the subsequent 4 years[28]. In this study, patients were recalled for clinical and radiographic evaluation at 6, 12, 24 and 36 months postoperatively.

Evaluation Criteria

1. Primary outcome

The primary outcome was determined according to clinical signs and symptoms of pulpal pathosis - tooth integrity, maintenance of pulp vitality and regression of clinical signs and symptoms. Therefore, outcome assessment involved conducting clinical and radiographic examinations.

Clinical success was defined as the absence of objective signs of inflammation/infection recorded during the follow-up exam, as well as spontaneous or persistent pain, pain or discomfort on chewing, tenderness to palpation or percussion, swelling, sinus tract or abnormal mobility. Moreover, the presence of a functional and integrate coronal restoration is assessed.

The follow-up guidelines expressed by the ESE refer that teeth should have a positive response to thermal sensitivity tests, within acceptable limits. However, in teeth where FP was performed, these orientations indicate that an unresponsive test is expected and deemed acceptable.[28] The results of these tests were classified as “Normal”, “Exacerbated” or “Negative”.

Furthermore, radiographic success results were defined for teeth with absence of apical radiolucency, presence of a new apical radiolucency, or its regression, root resorptions pulpal calcification or abnormal contour and width of the periodontal ligament.

The treatment was deemed successful if it fulfilled the criteria for both clinical and radiographic success.

2. Secondary outcome

The secondary outcome is based on tooth survival. In the event of failure of the previously performed VPT, there is the possibility of performing a NSRCT, which allows the tooth to continue its function.

Preliminary search and data recording

Data was collected and organized in Microsoft Excel™ based on clinical and radiographic notes. The form included data from the performed intervention and the follow-up appointments.

Statistical Considerations and Analysis

In this study, the sample size contemplates 24 patients and 26 treated teeth. After data collection, pre and intraoperative clinical and demographic data statistical analysis was performed using RStudio software 2023.06.0+421 “Mountain Hydrangea” for Windows.

Continuous variables were described as mean and standard deviation and categorical variables with absolute and relative frequencies. Comparisons between types of pulpotomy were performed using independent samples t-test and chi-square test with MonteCarlo simulations adjusted *p*-value.

Kaplan-Meier analysis was conducted on the overall sample and stratified by type of pulpotomy to determine the estimated survival. The log-rank test was used to compare strata. Cox regression was used to further investigate the effect of the hemostasis strategy, as well as the impact of age, on success.

RESULTS

Preoperative information

A total of 24 patients, with equal distribution for gender, were referred to endodontic appointments, comprehending a total of 26 teeth diagnosed with symptomatic irreversible pulpitis, according to the AAE classification. In addition, all teeth were preoperatively classified by Wolters' system proposal, presenting 9 (34.61%) teeth and 17 (65.38%) teeth with moderate and severe pulpitis, respectively.

Within the 26 included teeth, 10 (38.46%) were maxillary and 16 (61.54%) mandibular. Among them, molars were the most frequent (69.23%, 18/26), followed by premolars (26.92%, 7/26) and canines (3.85%, 1/26).

Intraoperative information

Of the 26 teeth preoperatively diagnosed with symptomatic irreversible pulpitis, 4 (15.38%) were excluded after intraoperative pulp tissue assessment. Of these, 3 were excluded due to an intraoperative diagnosis of pulp necrosis (1 of them with liquefactive necrosis) and 1 due to an impossibility to achieve hemostasis after 6 minutes. These cases were immediately approached with NSRCT. Thus, after all exclusions, 22 teeth remained viable to proceed to VPT.

The age range was in between 20 and 56 years (32.95±10.54 years). Age did not demonstrate a significant influence on the outcome of the treatments, as the differences were not statistically significant ($p>0.05$).

Following the previous instructions for hemostasis promotion, the strategies included 3% NaOCl in 68.18% (15/22) of the cases and sterile saline solution in 31.82% (7/22) of the cases. In most cases, 72.73% (16/22), needed 2 minutes to achieve hemostasis, while the remaining, 27.27% (6/22), took 4 minutes (**Table 1**), with a mean time of 2.55±1.15 minutes. According to Cox regression analysis, the hemostasis strategy, 3% NaOCl (n=15) or 4ºC sterile saline solution (n=7), was not related to differences in risk of failure ($p>0.05$).

At this stage, 36.36% (8/22) of the teeth were subjected to PP, and 63.64% (14/22) to FP. **Figure 1** represents the Wolters' diagnostic frequency (moderate or severe pulpitis) by the type of pulpotomy (PP/Moderate pulpitis: 5; PP/Severe pulpitis: 3; FP/Moderate pulpitis: 4; FP/Severe pulpitis: 10).

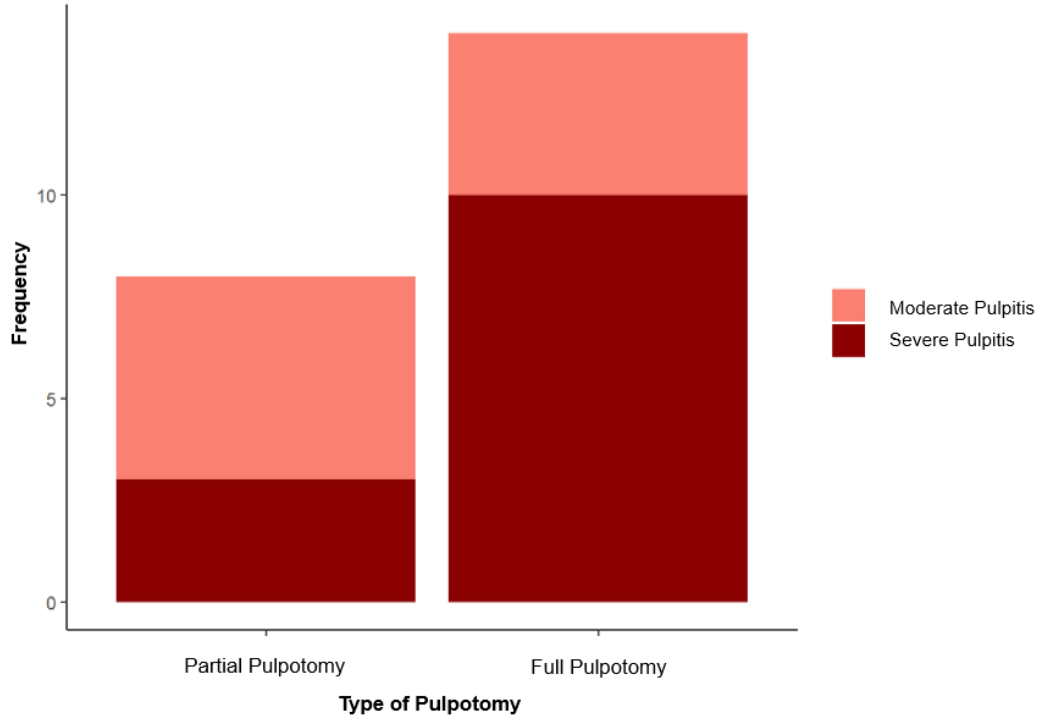

Figure 1. Wolters' diagnostic frequency (moderate or severe pulpitis) by type of pulpotomy.

As represented in **Table 1**, BD was the predominant choice (81.82%, 18/22), while MTA was applied in 18.18% (4/22). All cases of PP were treated with BD (100.00%, 8/8) and, for FP, 4 cases (28.57%) were treated with MTA and 10 (71.43%) with BD. There was no significant impact of biomaterial on the outcome of the treatment approach ($p>0.05$).

Definitive restorations were applied immediately (in the first appointment) in 9.01% (2/22) of the cases, delayed in 54.54% (12/22) of them and in 36.36% (8/22) of them, no definitive restoration was performed (**Table 1**). The teeth that were not submitted to immediate restoration left the appointment with a provisional glass ionomer restoration (Ketac ™ Fil).

Table 1. Independent variable according to treatment group.

Independent variable	Category	Partial Pulpotomy n=8 (36.36%) [Mean±SD or n (%)]	Full Pulpotomy n=14 (63.64%) [Mean±SD or n (%)]	*p*-value (95% CI)	Total n=22 (100%) [Mean±SD or n (%)]
Age	NA	35.39±8.93	31.57±11.44	0.429	32.95±10.54
Gender	Female	4 (50.00%)	8 (57.14%)	0.688	12 (54.54%)
	Male	4 (50.00%)	6 (42.86%)		10 (45.45%)
Arch	Maxillary	3 (37.50%)	7 (50.00%)	0.759	10 (45.45%)
	Mandibular	5 (62.50%)	7 (50.00%)		16 (54.54%)
Preoperative pain	Yes	3 (37.50%)	10 (71.43%)	0.187	13 (59.09%)
	No	5 (62.50%)	4 (28.57%)		9 (40.91%)
Tenderness to vertical percussion	Positive	4 (50.00%)	10 (71.43%)	0.386	14 (63.64%)
	Negative	4 (50.00%)	4 (28.57%)		8 (36.36%)
Tenderness to horizontal percussion	Positive	1 (12.50%)	2 (14.29%)	1.00	3 (13.64%)
	Negative	7 (87.50%)	12 (85.71%)		19 (86.36%)
Preoperative apical radiolucency	Yes	1 (12.50%)	3 (21.43%)	1.00	4 (18.18%)
	No	7 (87.50%)	11 (78.57%)		18 (81.82%)
Preoperative diagnosis (Wolters)	Moderate	5 (62.50%)	4 (28.57%)	0.188	9 (40.91%)
	Severe	3 (37.50%)	10 (71.43%)		13 (59.09%)
Bleeding time	2 minutes	5 (62.50%)	11 (78.57%)	0.190	16 (72.73%)
	4 minutes	3 (37.50%)	3 (21.43%)		6 (27.27%)
Biomaterial	MTA	0	4 (28.57%)	0.253	4 (18.18%)
	Biodentine	8 (100.00%)	10 (71.43%)		18 (81.82%)
Definitive restoration	Immediate	0	2 (14.29%)	0.559	2 (9.01%)
	Delayed	5 (62.50%)	7 (50.00%)		12 (54.54%)
	Non performed yet	3 (37.50%)	5 (35.71%)		8 (36.36%)
Treatment outcome	Success	7 (87.50%)	13 (92.86%)	0.832	20 (90.91%)
	Failure	1 (12.50%)	1 (7.14%)		2 (9.01%)

SD = Standard Deviation; CI = Confidence Interval; NA = Not Applicable;

Postoperative and follow-up-related information

In this study, we defined overall success as the absence of radiographic signs of apical pathology and clinical absence of signs and symptoms of inflammation/infection. Therefore, after estimating the overall survival (Kaplan-Meier analysis), the result was 90.90% success, with an overall mean follow-up time of 20 months (minimum: 2 months; maximum: 36 months). These results are illustrated by an overall survival curve in **Figure 2**.

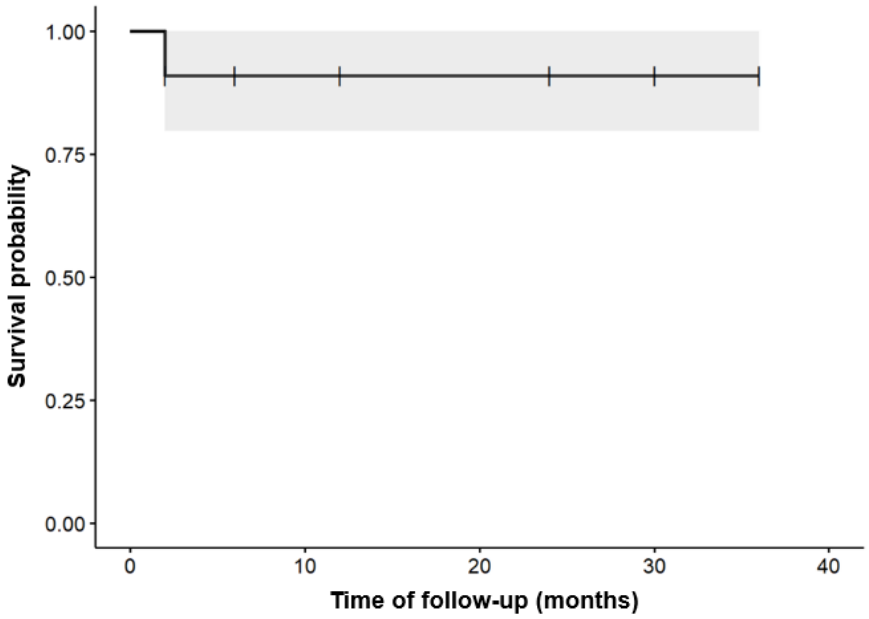

Figure 2. Overall survival curve - Survival probability over follow-up time (months).

Furthermore, an analysis of the survival probability based on the time of follow-up and the type of pulpotomy (PP or FP) was conducted. Then a Kaplan-Meier survival curve stratified by type of pulpotomy was ensured (**Figure 3**), showing a success rate of 87.50% (95% CI: 0.67-1.00) in PP and 92.86% (95% CI: 0.80-1.00) in FP. The curve is monotonous due to the low number of events (failures). A Logrank test was applied to compare the two strata, showing no significant differences between PP and FP (p>0.05).

Among the evaluated cases, one patient in which FP was performed, was followed-up at 12 months and at the 36-month follow-up she appeared with the first session of NSRCT initiated. The patient mentioned that she had visited a private dental clinic, where she was informed of the need to proceed with this conventional treatment, which we assume that was due to misjudgment

by the professional, regarding that the patient only reported temporary restoration fracture and absence of any signs or symptoms indicative of pulp inflammation.

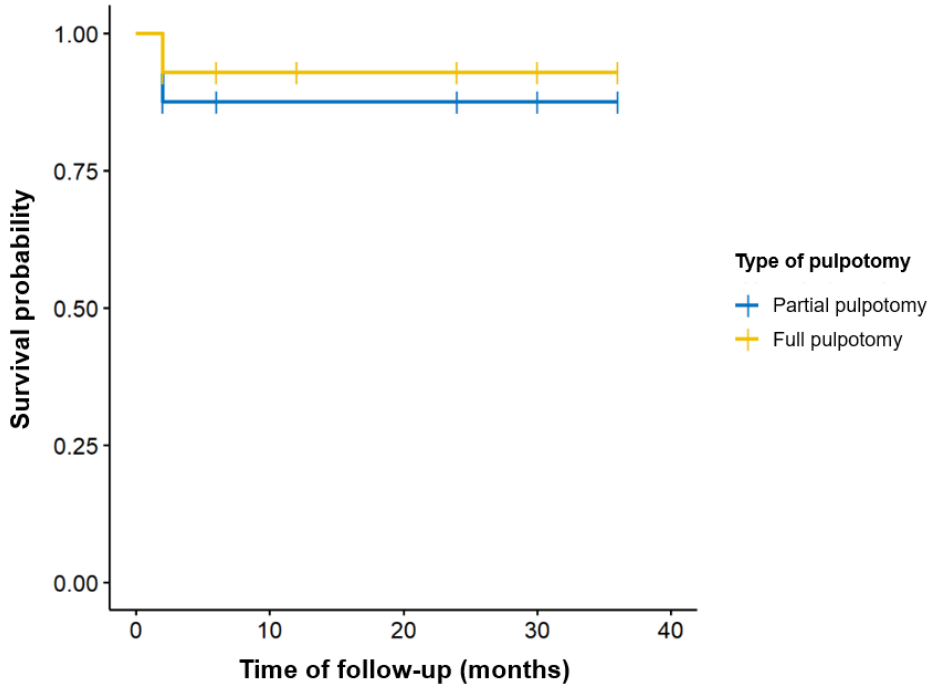

Figure 3. Survival probability curve stratified by type of pulpotomy and each time of follow-up (months).

The mean follow-up time of each type of pulpotomy was not statistically different (PP: 20.00±14.58; FP: 20.43±14.01; $p>0.05$).

Two patients were excluded, one in each group, due to an early failure, at 2 months, as there were present clinical symptoms (clear pain reaction to thermal stimuli) and apical radiolucency. Both cases were subsequently managed with NSRCT.

Figures 4 and 5, illustrate clinical images of the procedure and preoperative, postoperative and follow-up periapical radiographs, of FP in the first mandibular left molar and PP in the first maxillary left molar, respectively.

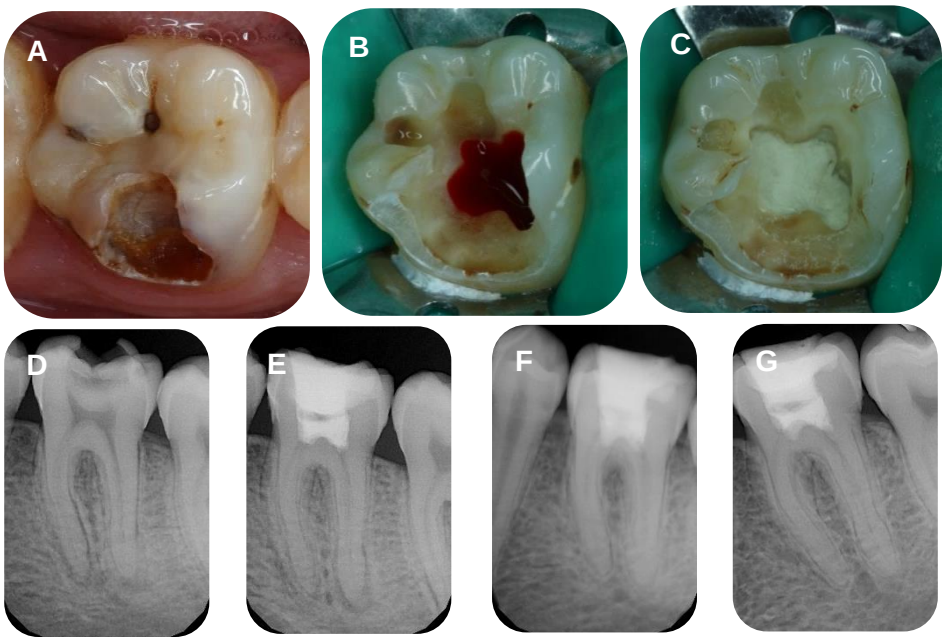

Figure 4. FP in a first mandibular left molar. (A) Preoperative clinical aspect; (B) Intraoperative pulp tissue assessment; (C) Biomaterial application; (D) Preoperative, (E) immediate postoperative, (F) 12 and (G) 30-month follow-up periapical radiographs.

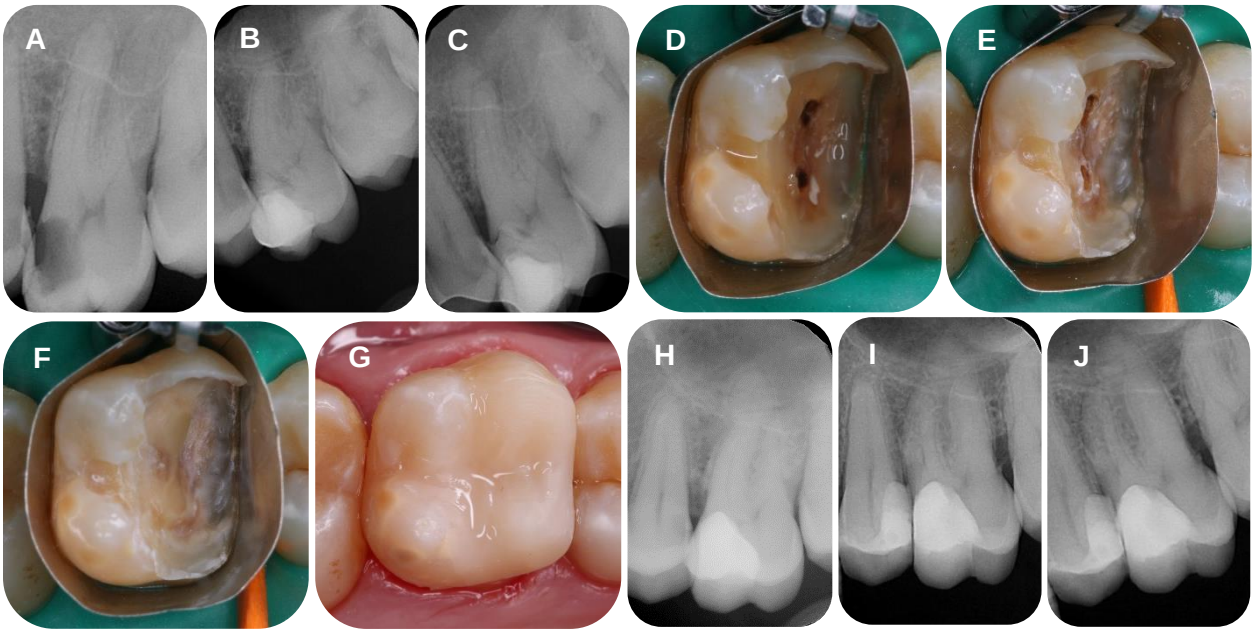

Figure 5. PP in a first maxillary left molar. (A) Preoperative and (B) immediate postoperative periapical radiographs; (C) 12-month follow-up with signs of leakage at the cervical interface of restoration; (D) Second appointment with positive response to cold test and intraoperative observation of BD dissolution and remnants of the blood clot formed over the area of pulp tissue excision; (E) Clinical confirmation of the existence of complete dentinal bridges; (F) Application of a glass ionomer cement base (Vitrebond™ Fil), (G) Definitive restoration; (H) 24, (I) 30 and (J) 36-month follow-up periapical radiographs.

DISCUSSION

In this retrospective study, which comprised data from 26 patients that met the selection criteria, the aim was to evaluate the clinical and radiographic outcomes of different VPT modalities (PP and FP) performed on permanent mature teeth with symptomatic irreversible pulpitis.

VPT procedures were performed under measured conditions and the outcomes revealed high success rates, with a mean follow-up time of 20.27±13.87 months, as shown in the results. This fact is in line with recent prospective clinical studies and randomized clinical trials, with larger sample sizes and higher levels of scientific evidence.[10,16,30]

In addition, preoperative and intraoperative factors were evaluated to determine their potential impact on the treatment outcome.

Preoperative factors

Preoperatively, all cases were diagnosed with irreversible pulpitis in means of the traditional AAE classification, as it was an inclusion criterion. All teeth were likewise classified by Wolters' *et*. al proposed system as moderate or severe pulpitis.

Based on the available data, it is currently suggested that factors such as gender and type of tooth may not have a significant influence on the outcomes of VPT.[31] The influence of age on the outcome remains unclear. In the majority of studies, age does not appear to exert a significant influence, either positive or negative.[2,8,32,33] However, certain clinical studies including a wide range of patients' age show a tendency for improved outcomes of younger ages[32,34] and other studies have young aged-restricted samples.[35,36] In the present study, the patient's age ranged from 20-56 years (32.95±10.54 years) and there was no significant impact of this factor in the survival of VPT treatments (p>0.05). Thereby, this issue remains open to debate.

Intraoperative factors

Intraoperatively, direct observation of the pulp tissue is crucial, providing reliable supplementary information, regarding its state, and dictating the procedure pathway.[12,13] A healthy pulp exhibits a consistent red color, homogeneous appearance, and continuous blood-filled tissue, without any yellowish liquefied areas or dark non-bleeding zones.[12,29] In addition, the intensity of bleeding has been proposed as a marker for the extent of pulp inflammation, indicating the necessity for further tissue removal, hoping to achieve hemostasis.[2,12,27] Thus, identification of any potential necrotic tissue that needs to be removed is crucial before attempting to control

bleeding. It is essential to enable clinical assessment of inflammation levels prior to the application of a suitable biomaterial.[16] Thus, persistent bleeding despite efforts to achieve hemostasis is considered a contraindication to VPT, and NSRCT is advised as an alternative.[2]

Case selection remains a challenge since the current clinical decision-making process is still reliant on intraoperative assessment of pulp tissue and the ability to control bleeding, rather than the preoperative clinical diagnosis.[13] Nowadays, the available techniques for assessing the association between inflammatory status and the healing capacity of the affected tissue are constrained.[13,28,37] Recently, it has been shown that there is a correlation between the amplified expression of certain inflammatory molecular indicators (cytokines, enzymes, inflammatory mediators and growth factors) and pulp tissue inflammation.[37] Consistent with other studies, this one emphasizes the need and advantages of routinely implementing disease biomarkers to assess pulpal viability and potentially indicate prognosis.[13,28,37] Otherwise, without a clinically accessible inflammation molecular test, the color and intensity of pulp bleeding upon exposure can attend as a marker of inflammation.[28,37]

The protocol of this study involved using 3% NaOCl for disinfection of the contaminated dentin. This disinfectant is antimicrobial, acts on the disinfection of the dentin-pulp interface and removes the present biofilm.[13,18] Even though it was not used in this study, chlorhexidine (0.2-2.0%) is another frequently used disinfectant.[28]

Hemostasis was achieved by applying a sterile cotton pellet soaked in either 3% NaOCl (n=15) or 4ºC sterile saline solution (n=7) for a maximum of 6 minutes (mean: 2.55±1.15 min), although suggested durations may vary and remain a topic of debate.[18] There is a tendency to consider 10 minutes as the maximum threshold for achieving hemostasis.[16,38,39] It is known that NaOCl, in concentrations between 0.5-5%, can be used in direct contact with pulp tissue, granting hemostasis, chemically dissolving the blood clot and fibrin, and clearance of damaged cells at the site of exposure.[13,18] While the sterile saline solution is commonly used for hemostasis, its disinfection properties are inferior when compared to NaOCl.[18,28] On the other hand, the application of cryotherapy, as cold sterile saline solution, can be an add-on tool in vasoconstriction promotion and, consequently, hemorrhage control.[27,40] In this study, the hemostasis strategy was not related to differences in risk of failure (p>0.05).

In the present study, upon clinical intraoperative observation, 4 cases were excluded due to pulp necrosis (n=3), or hemostasis could not be achieved within 6 minutes (n=1), NSRCT was initiated. This fact is in harmony with recent studies, showing 20[32] to 30%[16] of eligible cases excluded after intraoperative pulp tissue evaluation.

In this study, FP was applied in 14 teeth, while 8 were subjected to PP. There was a tendency to perform FP in cases of severe pulpitis and PP in cases of moderate pulpitis. This shows a positive correlation between the preoperative diagnosis and the level of pulp tissue breakdown and inflammation. These observations echoes findings from a clinical study, showing that teeth diagnosed with severe pulpitis treated by PP showed significantly lower success compared to teeth with lower levels of preoperative pulp inflammation.[30]

Furthermore, the influence of biomaterials on VPT prognosis has been shown in various studies.[35,41,42] The utilization of HCSCs in VPT procedures has gained significant traction, and MTA stands out as one of the commonly employed tricalcium silicates.[13]

It is known that the biomaterial can provide microleakage avoidance, which is a key factor for success. Despite this factor not being part of the clinical evaluation, it is expected for MTA and BD to lead to an ongoing formation of continuous and regular dentinal bridge, protecting pulp vitality by filling the area of the amputated pulp.[22,27]

Since the evaluated cases were carried out in the pre-graduate learning environment, some of the procedures faced constraints, including time limitations, resulting in the immediate placement of a temporary restoration (Ketac™ Fil). Among the cases, 9.01% of definitive restorations were placed immediately, 54.54% were delayed and 36.36% at the time of follow-up remained with temporary restoration. This is against the treatment recommendations of desirable placement of a definitive restoration, as the minimum possible period is pointed out as an essential element for achieving success.[12,13] The potential benefits of immediate restoration encompass advantages such as minimizing microleakage, protecting the biomaterial layer and reducing post-operative sensitivity.[12,13] Nevertheless, despite the suboptimal coronal restoration conditions in this study, the success rates remained at a high level.

Follow-up and prognosis

Postoperative responses rely on the regenerative capabilities of the remaining pulp and the healing conditions of the individual patient.[43] The potential complications of pulpotomy normally arise from either an inflammatory process or bacterial infection.[43] The reduction of local tissue pressure and inflammatory response provides fast pain relief in cases of undergone pulpotomy, as the intensity of pain is linked to the extent of the damaged pulp tissue.[19]

In recent reports, the outcome of VPT has been compared based on the type of pulpotomy.[10,14,16] To determine the outcome of each approach, it was necessary to perform clinical and radiographic assessments. We can highlight that clinical monitoring cases of FP can be more

challenging than cases of PP, regarding the possible absence of response to sensitivity testing, in cases of FP.[33] Possibly, the inclusion of electrical tests in the postoperative evaluation could potentially improve the accuracy and predictability of results, considering the existence of discrepancies between thermal sensitivity and electrical tests.[44]

In this study, the results of follow-up examinations show high success rates in both treatments (FP: 92.86%; PP: 87.50%), although there were no significant differences between them ($p>0.05$). The apparently higher success rate of FP over PP, in this study, can be attributed to the larger sample size of FP procedures. However, some studies refer that, when possible, PP should be considered, as it is a more conservative approach.[10] Nevertheless, this choice, as aforementioned, depends on the extent of tooth decay and inflammation, and largely relies on the subjective judgment of the dentist.

The overall success rate observed in this study was high (90.90%), which can potentially be attributed to meticulous case selection, strict aseptic technique, use of magnification for intraoperative pulp tissue assessment and use of HCSCs as capping materials.

CONCLUSION

Definitive mature teeth diagnosed with irreversible pulpitis can be successfully treated with PP and FP, with no significant difference between the two approaches.

With the use of antiseptic measures, isolation, adequate hemorrhagic control and appropriate definitive coronary restoration, the application of VPT with HCSCs has demonstrated its viability in alternative to NSRCT. It is a less invasive and more conservative approach, particularly concerning pulp vitality and proprioception, and, in case of failure, we still have the possibility to resort to NSRCT.

There is a need to provide and encourage learning about VPT, at all educational levels. This is a progressing field, and a lack of knowledge in this area can compromise the effectiveness of the application of these techniques in the population. According to current evidence, this study allows us to demonstrate to professionals that the adoption of VPT is a viable alternative in the treatment of mature permanent teeth with irreversible pulpitis.

Moreover, this study highlights the necessity of conducting other studies with a longer follow-up period. It is crucial to verify the appropriate indications for its use and establish the relevant criteria required to evaluate its outcome.

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APPENDIX

Table I. Composition and properties of the biomaterials applied in this study.

Biomaterial		MTA	Biodentine ™
	Composition	- Tri-calcium silicate - Di-calcium silicate - Tricalcium aluminate - Tetracalciumaluminoferrite: Calcium sulphate Bismuth oxide Calcium oxide Silicon oxide Aluminium oxide	- Tricalcium silicate - Dicalcium silicate - Calcium carbonate - Zirconium oxide - Iron oxide
Properties	Biocompatibility	Similar	Similar
	Bioactivity	Higher	Lower
	Antibacterial and antifungal activity	Lower	Higher
	Stimulation of dentin neoformation	Higher	Lower
	Setting time	Longer	Faster
	Handling	More difficult	Easier
	Tooth discoloration	Discoloration potential	Less discoloration potential
	Radiopacity	Higher	Lower
	Solubility	Lower	Higher
	Porosity	Higher	Lower
	Microleakage	Higher	Lower
	Sealing ability	Lower	Higher
	Compressive strength	Lower	Higher
	Cost	Higher	Lower