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Article

An Observational Study on Pain Occurrence After Root Canal Treatment: Role of Operator Experience When Using a Bioceramic Sealer

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Abstract: Background and objectives: Post-operative pain (POP) is a common complication after root canal treatment and is influenced by various clinical and patient-related factors. The present study evaluated the incidence and intensity of POP following root canal treatment using a bioceramic sealer, performed by operators with different levels of experience. Material and methods: A total of 115 patients were included in this prospective observational study. Patients were treated by operators with different levels of experience: postgraduate students (PGSs) and endodontic specialists (ESs). Standardized protocols were used in two distinct appointments: an instrumentation visit and an obturation visit. Obturation was performed using the continuous wave condensation technique and Total Fill Hi-Flow BC Sealer (TFHF). POP, mastication discomfort, and sleep disturbance were assessed at 24, 48, and 72 hours after the instrumentation and obturation phases using a numeric rating scale (NRS). Results: The results indicate significantly higher POP after the instrumentation phase, compared to the obturation phase ($p < 0.001$). The pain intensity progressively decreased over time for both phases. No significant differences were observed between the PGS and ES groups regarding POP, mastication discomfort, or sleep disturbance at any time. Sealer extrusion did not significantly impact POP ($p > 0.05$). Conclusions: This study found that operator experience does not significantly influence POP when a standardized protocol is followed. The use of TFHF with the continuous wave condensation technique was associated with minimal POP.

Keywords: bioceramic sealer; calcium silicate sealer; operator experience; postgraduate student; endodontic obturation

1. Introduction

Root canal treatment is a procedure aimed at retaining the tooth through the treatment of dental pulp and periradicular diseases [1]. Endodontic pathologies are recognized to have a prevalence comparable to that of other dental disorders. Therefore, endodontontology postgraduate training is needed for clinicians to provide high-quality care for patients undergoing endodontic therapy [2].

Post-operative pain (POP) is an unpleasant but frequent complication after root canal therapy. A systematic review has shown that POP has a prevalence of 3 to 58% in the investigated cases [3], while a clinical trial reported up to 19% of patients experiencing severe pain [4]. The anticipation and handling of POP is an essential part of the endodontic treatment, as it may be a stressful factor for both the patient and operator, and may require an unscheduled emergency appointment [3]. When pain occurs following treatment, it may hinder the trust of the patient towards the operator, even if it does not influence the long-term outcome [5]. A randomized clinical trial reported that sometimes POP can exceed the pre-operative level of pain [6]. This may be due to the progress of the inflammatory process due to apical instrumentation [7], as well as chemical or microbial injuries of periapical tissues [8]. Patient-related factors like initial diagnosis [9–11] or tooth type [4,12] and treatment-related factors like the number of visits [13–16], instrumentation or obturation techniques [17–20], or obturation material [21,22] are linked to POP.

Among root canal obturation techniques, warm vertical compaction using the continuous wave of condensation (CWC) technique is generally preferred by endodontists [23]. CWC softens and alters the gutta-percha phase, allowing a better fit to the root canal wall with fewer voids, and fewer radiographic translucencies [23–25].



The use of bioceramic sealers has become popular among operators due to their advantages such as bioactivity-enhancing periapical healing and biocompatibility [26]. A systematic review concluded that bioceramic sealers have good biological and physico-chemical properties, when compared to conventional sealers [27], with a retrospective analysis reporting an overall success rate of 90.9% [28]. Calcium silicate-based sealers were primarily developed for cold obturation techniques [29]. Consequently, Total Fill Hi-Flow BC Sealer(TFHF)—a pre-mixed and pre-loaded injectable sealer—was developed to allow the use of warm obturation techniques alongside bioceramic sealers [30], with better in vitro results compared to Total Fill BC Sealer [31].

A meta-analysis of nine randomized clinical trials showed that post-operative pain (POP) was significantly lower after root canal obturation with calcium silicate-based sealers, compared to resin-based sealers [32]; however, when compared directly, studies showed no difference between the two sealer types [33,34].

While several studies have analyzed POP after obturation using bioceramic sealers designed for cold obturation techniques [35,36], to the best of our knowledge, no study has investigated the pain after continuous wave condensation obturation along with TFHF. The operator's experience has been shown to influence the POP after root canal treatment [4,21,37], but no study has analyzed the influence of the operator's experience on POP after root canal obturation with bioceramic sealers. The influence of the obturation on POP can be clarified and evaluated by splitting the treatment into two visits and differentiating it from the POP associated with the pre-operative status [10] and the mechanical preparation of the root canal [38].

Therefore, this study aimed to evaluate and compare the incidence and intensity of POP after root canal treatment performed by two groups of operators with different experience levels using THF and CWC.

The tested research hypotheses will be as follows:

- a. There is no difference in the incidence and degree of POP after the instrumentation and obturation phases of root canal treatments performed by postgraduate students and endodontic specialists;
- b. Pulpal and periapical diagnosis, case difficulty, and sealer extrusion have no significant effects on POP.

2. Materials and Methods

Patient selection

This prospective observational clinical cohort study was approved by the Ethics Committee of the University of Medicine and Pharmacy "Iuliu Hatieganu" Cluj-Napoca, Romania, under approval number AVZ38 from 12.03.2024. The "Strengthening the Reporting of Observational Studies in Epidemiology" (STROBE) statement was used in preparing the study report (Table A1) [39]. All participants signed an informed consent form. All methods were performed in accordance with the Declaration of Helsinki.

Patients referred for endodontic treatment to the Endodontics Department of the University of Medicine and Pharmacy of Cluj-Napoca within a period of 12 months were selected for this prospective study. Before treatment, the medical and dental history of the patients was recorded. Gender, age, tooth number, periapical condition, pulp diagnosis, occlusion, and proximal contacts were registered. The exclusion criteria included immunosuppressed patients, patients under 18 or over 75 years old, pregnancy, consumption of antibiotic medication before treatment, teeth with previous root canal treatments, external or internal resorptions, open apexes, and root canals that made it impossible to negotiate to the apical constriction. The required sample size was calculated using G*Power 3.1 software (Kiel, Germany) for a statistical power of 0.8, with a significance threshold of 0.05 and a 0.3 effect size.

A total of 115 patients were considered eligible for this study (Figure 1). The patients were treated (as they presented or were referred to) by three endodontic specialists (ES) with at least 5 years of experience in this field or by three postgraduate students (PGSs) enrolled in the endodontics residency program. No randomization or blinding took place. A total of 59 patients were treated by ESs, while PGSs treated 56 patients. The treatments were performed in two visits: the instrumentation phase and the obturation phase. This protocol (i.e., in which patients require two visits) is commonly used in the endodontic department where the study took place, and it was used for all patients. Before the beginning of the study, a presentation was held for calibration, and training regarding the protocol was performed on extracted teeth by both ESs and PGSs. All of the PGSs were supervised by an operator accustomed to the protocol but did not interfere with the treatment.

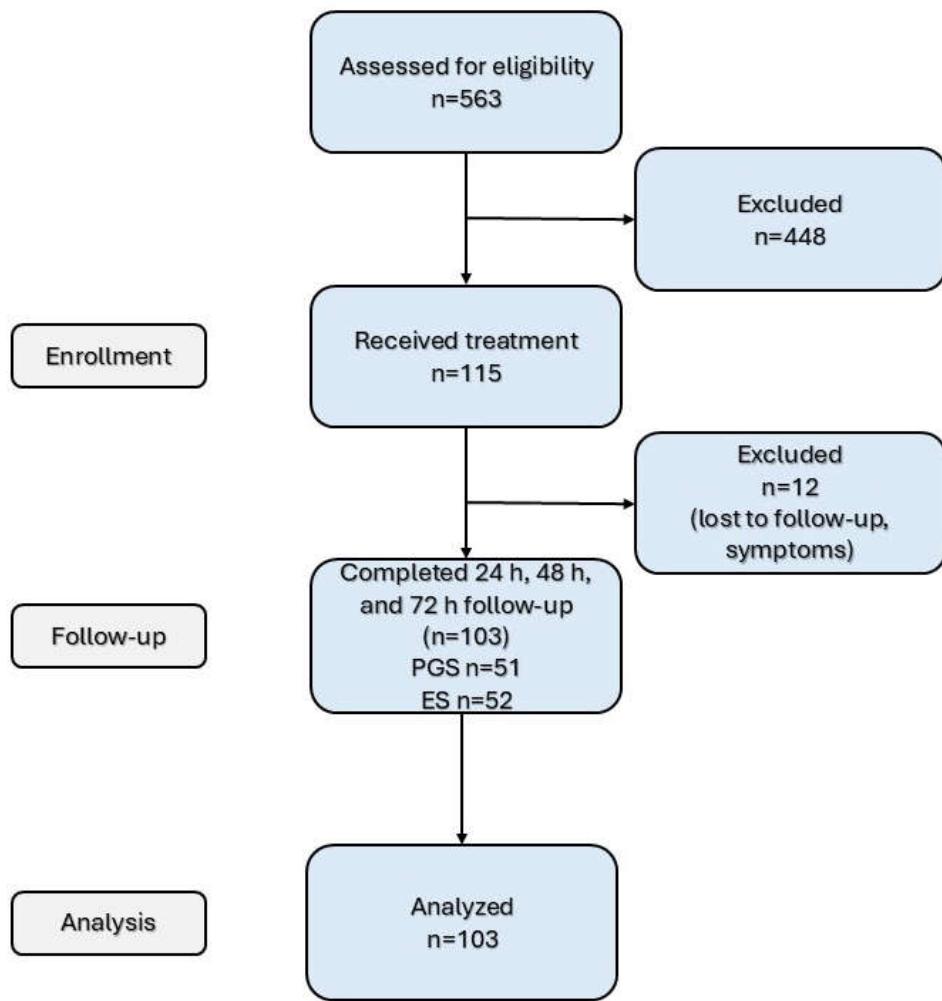


Figure 1. Flow chart of patient enrollment.

2.1. First visit—instrumentation phase

In the first visit, each patient underwent a periapical radiograph examination (Planmeca, Helsinki, Finland), which was analyzed by one of the ESs taking part in this study, and teeth were classified as having lesions of endodontic origin (LEO) when a loss of lamina dura and periodontal ligament enlargement bigger than 2 mm was present [6]. The pulpal status was assessed using the cold test (Cerkamed, Stalowa Wola, Poland) and classified as healthy pulp, reversible pulpitis, irreversible pulpitis, and pulp necrosis [40]. Teeth with reversible pulpitis were excluded from this study. The peri-radicular status was checked using percussion and palpation. The case difficulty was assessed using the American Association of Endodontists (AAE) endodontic case difficulty assessment form [41]. After anesthesia with articaine containing 2% adrenaline (Septodont, Saint Maur des Fosses, France) and rubber dam isolation, the access cavity was prepared using sterile round burs (Edenta, St. Gallen, Switzerland) and Endo-Z burs (Dentsply, Konstanz, Germany). The working length was determined via a 10 K-File (VDW, Munich, Germany) and an apex locator (Root ZX, Morita, Japan), using the middle green line on the display. The Pro Taper Ultimate (Dentsply, Konstanz, Germany) rotary system was used to prepare the root canals mechanically, following the manufacturer's instructions. Root canal irrigation consisted of 2 ml NaOCl 5.25% (Cerkamed, Stalowa Wola, Poland) between each instrument. Apical patency was checked with a 10 K-File entering 0.5 mm longer than the working length [42]. The root canal was dried with paper points and dressed with temporary calcium hydroxide (Cerkamed, Stalowa Wola, Poland). Then, a sterile cotton pellet was put inside the pulp chamber, and a provisional filling (Coltosol, Coltene, Altstatten, Switzerland) was placed. Each patient received a POP assessment form (Figure A1). If needed, the patients were instructed to administer 400 mg of ibuprofen and record any analgesic administration on the form.

2.2. Second visit—obturation phase

In the second visit, which took place 5 to 14 days after the first one, the current symptomatology of patients was assessed, and those with any degree of symptomatology at the second visit were excluded from the study. Anesthesia was again obtained using articaine containing 2% adrenaline (Septodont, Saint Maur des Fosses, France), and rubber dam isolation was performed. The provisional coronal filling was removed using an ultrasound scaler (Woodpecker, Guilin, China). Root canals were irrigated with 2 ml NaOCl (Cerkamed, Stalowa Wola, Poland), and the working length was reconfirmed using an electronic apex locator (Root ZX, Morita, Japan) and a 15 K-File (VDW, Munich, Germany). The apical diameter was measured with Ni-Ti K Files (Dentsply, Konstanz, Germany) using the following method: the Ni-Ti K File corresponding in size to the last Pro Taper Ultimate rotary file used was tried at the working length; if no resistance and binding sensation was found, the next Ni-Ti K File in size was used until a binding sensation was present [43]. The obturation technique used was the continuous wave condensation (CWC) technique, as described by Buchanan [44]. The corresponding Pro Taper Ultimate gutta-percha cone (Dentsply, Konstanz, Germany) was selected as a master cone and checked for tug-back at the working length, and then 0.5 mm was cut from the tip. Final irrigation consisted of 5 ml EDTA 17% (Cerkamed, Stalowa Wola, Poland), followed by 5 ml NaOCl (Cerkamed, Stalowa Wola, Poland). The root canal was dried using paper cones, and Total Fill BC Hi-Flow (FKG Dentaire, La Chaux-de-Fonds, Switzerland) sealer was applied inside the canal using the master cone. The gutta-percha cone was cut at the level of the root canal orifice using an electrically activated heated plugger (Kerr, Kloten, Switzerland) and condensed with a stainless-steel plugger (Kerr, Kloten, Switzerland). Next, the heat plugger was used to condense the master cone up to 4 to 6 mm shorter than the working length, followed by a pre-fitted stainless steel plugger. Next, backfill was performed using a gutta-percha injection gun (Kerr, Kloten, Switzerland). A provisional filling (Coltosol, Coltene, Altstatten, Switzerland) was placed, and a periapical radiograph was used to check the quality of the root canal (Figure 2). A blinded operator with at least 5 years of experience, who did not participate in patient treatment, assessed the radiographs and classified the outcome as short (>1 mm), adequate (<1 mm), correct, or over-obturation. The patient received a POP assessment form. If needed, the patients were instructed to administer 400 mg of ibuprofen and record any analgesic administration on the form.



Figure 2. Examples of cases performed by PGSs (a,c pre-operative radiograph; b,d post-operative radiograph) and ESs (c, pre-operative radiograph; d, post-operative radiograph).

2.3. Post-operative pain assessment

Each patient received two forms (Figure A1) for POP assessment: one after the preparation phase and one after the obturation phase. Patients were instructed to mark the pain intensity on a numeric rating scale (NRS) on a horizontal line containing values from 0 to 10 [45]. The values were described as follows: 0, no pain; 1–3, mild pain; 4–6, moderate pain; 7–10, severe pain [45]. All values equal to or higher than 1 were considered as POP presence. Along with the pain intensity, the patient was asked to mark on an NRS the discomfort related to mastication and any degree of sleep disturbance caused by pain. These three indicators were assessed at 24, 48, and 72 hours after the treatment [46].

2.4. Statistical analysis

One-way repeated analysis of variance (ANOVA) for independent samples was conducted to evaluate differences among groups regarding continuous variables. Tukey and Bonferroni post hoc tests were performed for pairwise comparisons between groups. In the case of categorical variables, the statistical difference was evaluated via the chi-squared test. For all analyses, the threshold for statistical significance was set at $p < 0.05$. All graphical representations and analyses were performed using the JASP software (JASP Team 2024, JASP version 0.19.0).

3. Results

A total of 103 selected patients were eligible for this study, and 12 patients were eliminated due to symptoms requiring an extra appointment, missed appointments, or failure to return pain assessment forms. The data belonging to excluded patients was removed from the analysis. Table 1 presents the demographic aspects of the two groups.

Table 1. Demographics and distribution of clinical features.

Factor	PGS	ES	Total	P ^a
Age¹	42.3 ± 17.2	42.2 ± 15.3	42.3 ± 16.7	0.980
Gender	Female	33	34	0.940
	Male	18	18	
Tooth type	Anterior	15	7	22
Tooth type	Premolar	10	9	0.100
	Molar	26	36	
AAE Difficulty	Minimum	19	14	0.500
	Moderate	14	15	
	High	18	23	
Pulp status	Vital (healthy)	8	8	0.990
	Pulpitis	25	25	
	Necrosis	18	19	
Percussion	Positive	15	20	0.330
	Negative	36	32	
LEO	No	34	34	0.700
	Leo < 2 mm	9	12	
	Leo > 2 mm	8	6	
Extrusion	Yes	11	20	0.060
	No	40	32	
Obturation quality	Correct	39	46	0.280
	Adequate	8	3	

Short	1	0	1
Overfilling	3	3	6

¹ Mean \pm standard deviation (SD); p, significance between groups (PGS and ES); LEO, lesion of endodontic origin; ^a $\alpha < 0.05$.

A total of 33 (32.3%) patients reported no POP after 24 hours from the instrumentation visit for the whole cohort, while 70 (67.6%) complained of POP. Following the obturation phase, 53 (51.9%) patients reported the absence of POP, while the rest experienced POP (Table 2).

Table 2. Presence or absence of POP 24 h after the instrumentation phase or obturation phase for the two groups.

	POP	PGS	ES	total	P ^{1,a}
Instrumentation phase	No	17 (34.0%)	16 (30.7%)	33 (32.3%)	0.946
	Yes	34 (66.0%)	36 (69.2%)	70 (67.6%)	
Obturation phase	No	23 (46.0%)	30 (57.6%)	53 (51.9%)	0.279
	Yes	28 (54.0%)	22 (42.3%)	50 (48.0%)	
	P ^{2,a}	0.311	0.010		

p¹, significance between groups (PGS and ES) for the two phases ; p², significance between phases (instrumentation or obturation) for each group; ^a $\alpha < 0.05$.

POP, mastication discomfort, and sleep disturbance decreased from 24 to 72 h for the whole cohort (Figure 3); thus, the results of Tukey and Bonferroni post hoc tests for the whole cohort showed that the POP, mastication discomfort, and sleep disturbance were significantly higher ($p < 0.001$) after the instrumentation phase than after the obturation one. When evaluating POP during the three days, it was observed that it progressively diminished from 24 h to 48 h ($p < 0.001$) and from 48 h to 72 h ($p = 0.02$) after the instrumentation phase. The same was noticed for the obturation phase, with significant differences for 24 h POP level compared to those registered at 48 h ($p < 0.001$) and for 48 h compared to 72 h ($p < 0.01$). Mastication discomfort gradually decreased in both preparation and obturation phases from 24 h to 48 h ($p < 0.001$) and from 48 h to 72 h ($p = 0.02$ for the first appointment and $p < 0.001$ for the second one; Table 3). Significant differences were found between the two appointments for POP and mastication discomfort at 24 h ($p < 0.001$), 48 h, and 72 h ($p < 0.01$). The same was observed for sleep disturbance at 24 h ($p < 0.01$), 48 h, and 72 h ($p < 0.05$).

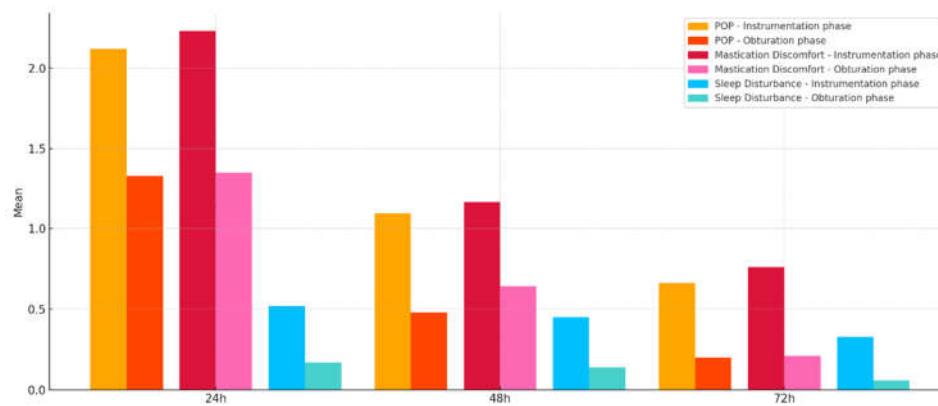


Figure 3. Mean values for POP, mastication discomfort, and sleep disturbance evaluation at 24 h, 48 h, and 72 h after instrumentation and obturation phases for the whole cohort.

Table 3. Mean difference and significance between different timepoints for instrumentation and obturation phases regarding POP, mastication discomfort, and sleep disturbance.

	Instrumentation phase	Obturation phase
POP	24 h vs. 48 h	1.03*

	24 h vs. 72 h	1.46*	1.13*
	48 h vs. 72 h	0.43***	0.27**
	24 h vs. 48 h	1.06*	0.71*
Mastication discomfort	24 h vs. 72 h	1.48*	1.14*
	48 h vs. 72 h	0.42**	0.43*
	24 h vs. 48 h	0.08	0.04
Sleep disturbance	24 h vs. 72 h	0.19	0.12
	48 h vs. 72 h	0.12	0.08

*p < 0.001; **p < 0.01; ***p < 0.05.

POP, mastication discomfort, and sleep disturbance at 24, 48, and 72 hours for the PGS and ES groups are presented in Figures 4a and 4b. The comparison between the PGS and ES groups regarding the instrumentation or obturation phases showed no significant differences for either POP, mastication discomfort, or sleep disturbance for the three days (p > 0.05). The same was observed when comparing results at 24, 48, and 72 hours (p > 0.05).

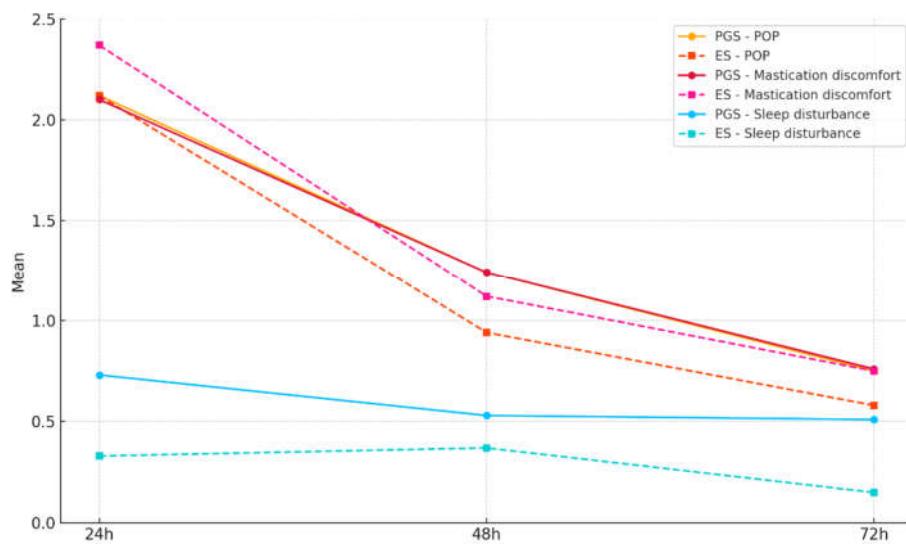


Figure 4. a. POP, mastication discomfort, and sleep disturbance for PGSs and ESs at 24, 48, and 72 h following the instrumentation phase.

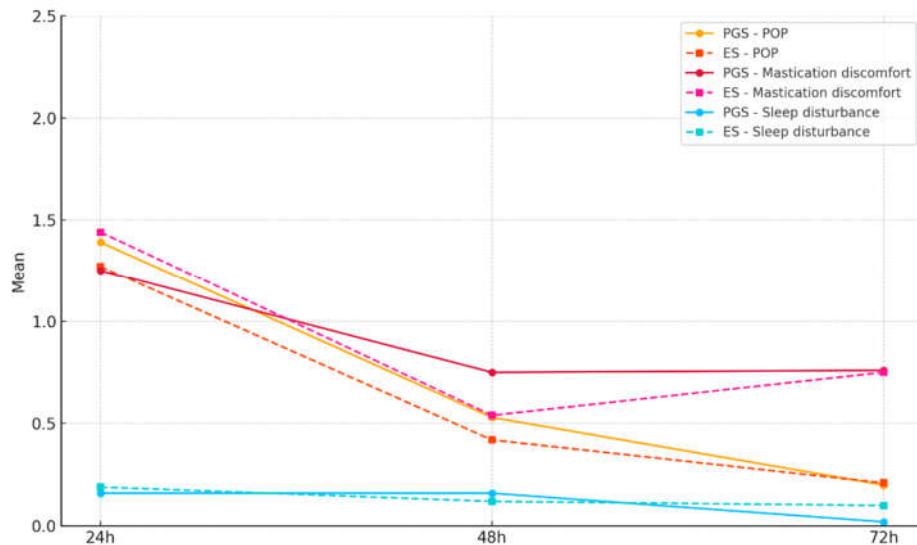


Figure 4. b. POP, mastication discomfort, and sleep disturbance for PGSs and ESs at 24, 48, and 72 h following the obturation phase.

Within groups, a significant difference was observed in the ES category at 24 h between instrumentation and obturation phases for POP and mastication discomfort ($p < 0.01$), with the preparation phase having higher values. No difference was found for sleep disturbance. Within the PGS group, all three parameters (POP, mastication discomfort, and sleep disturbance) were significantly ($p < 0.05$) higher after the instrumentation appointment.

Regarding pre-operative percussion status, a positive response induced a significantly higher POP for all three days following the instrumentation visit ($p < 0.001$), while, when considering the obturation phase, the percussion test showed no statistical difference for POP ($p = 0.67$).

No significant differences were found for the two phases regarding the influence of the presence of LEO bigger or smaller than 2 mm on POP, mastication discomfort, or sleep disturbance ($p > 0.05$). The same was observed for the pulpal status (i.e., vital, pulpitis, or necrosis; $p > 0.05$).

Regarding sealer extrusion, no significant differences were found after the obturation phase ($p = 0.33$), regardless of the operator's experience. Sealer extrusion incidence can be seen in Table 1 and was limited in all cases to the area close to the apical foramen. At the same time, gutta-percha over-obturation happened in 6 cases, all 1 mm or less, while a short obturation was reported only in 1 case. No significant differences ($p > 0.05$) in POP were observed at 24 h, 48 h, and 72 h after the obturation appointment, regardless of the obturation quality.

Concerning the AAE difficulty, regarding the obturation visit, a moderate difficulty revealed a significantly higher POP ($p < 0.01$) compared to minimum difficulty for the whole cohort. No differences between high and moderate ($p = 0.069$) or high and minimum ($p = 0.499$) difficulty were found. AAE difficulty did not influence the instrumentation visit ($p > 0.05$). When the PGS and ES groups were compared, no differences ($p > 0.05$) were found regarding POP, mastication discomfort, or sleep disturbance regarding the influence of the case difficulty in either of the two separate visits.

No differences between tooth types (i.e., anterior, premolar, molar) regarding POP, mastication discomfort, or sleep disturbance were found ($p > 0.05$).

Regarding analgesics, 20 patients used one dose of 400mg ibuprofen after the instrumentation phase, and 10 after the obturation visit. No significant influence ($p > 0.05$) was observed on POP evolution for the patients who took analgesics.

4. Discussion

Post-operative discomfort is a potentially distressing factor in endodontics, which sometimes exceeds the pre-treatment level of pain [32]. Our findings contribute to understanding factors influencing POP following endodontic treatment, particularly concerning the influence of operator experience and the choice of obturation materials. No significant differences were observed between the ES and PGS groups regarding the incidence and degree of POP after root canal treatment. Therefore, the first research hypothesis was accepted.

The POP level experienced after root canal treatment has been shown to be affected by a combination of treatment-dependent factors (ability of eliminating the infection/inflammation and of reducing pressure and swelling), including the type of rotary file, shaping techniques, irrigation solutions, and obturation technique used, as well as patient-dependent variables such as age, sex, general health condition (immune response, ability of repairing and regenerating the periapical tissues), pulpal and periapical diagnosis, pre-operative discomfort, and tooth anatomy [19,47].

Several clinical trials have studied POP following obturation with bioceramic sealers reporting similar pain values to those obtained in this study, despite differences in instrumentation and obturation protocols [21,34,48]. Meanwhile, Tan et al. reported a higher percentage of patients with no POP and fewer patients with mild or very mild POP, in contrast to the present study [33]. The reason might be the different POP assessment forms and the use of a single cone technique in Tan et al.'s research.

Endodontic treatment performed in multiple visits, as it was done in the present study, is common and allows for thorough cleaning of complex root anatomies [49]. Two systematic reviews have concluded that it may lead to lower immediate POP and flare-ups [13,15], though several studies have reported no significant differences compared to single-visit treatments [14,16,50]. Instrumentation can cause bacterial extrusion and apical injuries, leading to inflammation and POP. [51]. Different clinical trials have reported that mechanical glidepath [6] and 1.3% NaOCl irrigation could

reduce POP [52], while rotary instrumentation was shown in a meta-analysis to exhibit less debris extrusion and lower POP [53].

The pulpal and periapical diagnosis has been demonstrated in other studies to affect the post-treatment pain following the endodontic procedure [9,47]. In our study, only positive percussion—an important procedure for deciding the diagnosis—significantly influenced POP for the instrumentation visit ($p < 0.001$). Therefore, the second research hypothesis was partially accepted. Tenderness to percussion tests before treatment has been found by several clinical trials to influence the intensity of POP after the instrumentation visit, despite different instrumentation protocols and POP assessment forms [9,11,54]. Regarding the POP following the obturation phase, no difference between positive and negative percussion tests was reported, similar to the results reported by Jang et al [9]. One study has reported no difference in the degree or duration of POP after the endodontic procedure between vital and non-vital teeth, despite dissimilar obturation techniques, confirming the present findings [55]. However, a prospective study using different instrumentation protocols reported that vital pulp might predict a higher POP [56]. In the present study, tooth vitality testing was performed using the cold test because of equipment limitations, even though the electric pulp test was reported to be more accurate in a systematic review [57]. Regarding periapical translucencies, some studies have shown that the presence of a radiolucent lesion might result in higher POP [10,58], while another study found a lower POP when the patients presented radiographic apical translucency [59]. Differences in treatment protocols, definitions of apical lesions, and POP assessment may be the causes for these discrepancies. In the present study, no differences were found when periapical lesions were present or not.

As in other studies [4,9], tooth type (anterior, premolar, or molar) did not influence POP, even though previous findings suggested that molars are associated with higher POP due to their complex root anatomy and increased likelihood of apical tissue disruption during instrumentation and obturation [12,47]. When AAE difficulty was compared in our research, the patients reported higher scores in medium-difficulty cases (compared to minimum difficulty) for the obturation phase, while no difference was observed for the instrumentation phase. Thus, the conflicting results may be due to different study designs and a uniform protocol applied in our study by practitioners with current or completed advanced endodontic training.

The CWC technique used for obturation in the present study was demonstrated to exhibit good dentinal tubule penetration and less void formation, particularly when used with TFHF [24]. However, another study reported that this technique could create thermal injuries in the peri-radicular tissues, produced by the temperature increase on the root surface, thus increasing the incidence of POP [60]. Similar to Ali et al.'s study, in this research, low POP levels were registered when asymptomatic teeth were obturated [20].

Regarding sealer extrusion, different studies have reported no difference in POP between Ah-Plus and Endosequence BC sealers [34,36], or between resin- and calcium silicate-based materials [61]. Although bioceramic sealers seem to exhibit more extrusion than other materials, several investigations have reported no correlation between calcium silicate-based sealer extrusion and POP [33,36,61], as observed in the present study ($p > 0.05$). In contrast, one prospective clinical trial has reported a direct correlation between sealer extrusion and POP [21]. These different results may be due to differences in study design, treatment protocol, number of visits, or obturation techniques.

When comparing the POP outcomes between the two groups of operators, no significant difference was observed between them ($p > 0.05$). The clinical implication of these findings could reflect the importance of careful supervision of less-experienced operators, which could minimize the risk of potential mistakes such as over-instrumentation and over-obturation that may lead to higher POP. This may suggest that training programs should instruct trainees to implement a consistent protocol to be used during treatment. The influence of the operator's experience on the outcome and POP of endodontic treatments has been studied for a long time. A prospective study has reported that undergraduate students had better results in terms of flare-ups than those treated by postgraduate students or specialists, suggesting that the cause might be the longer duration spent cleaning and shaping [62]. In contrast, two studies comparing general dentists and endodontic specialists reported no difference in POP [4,63], while several studies have reported a low POP incidence and good treatment outcomes in treatments performed by postgraduate or undergraduate students [21,64].

The pain assessment in this study was conducted using a numeric rating scale (NRS)—a widely recognized and validated tool for quantifying subjective pain intensity [65]. This method has been shown to provide reliable and reproducible measurements of pain intensity across diverse clinical settings [66]. The simplicity of this scale allowed for the collection of data regarding several symptoms such as POP, mastication discomfort, and sleep disturbance. Assessments were conducted at 24, 48, and 72 hours after each treatment phase, in order to capture the evolution of the pain. This

timeframe aligns with established recommendations for monitoring post-operative discomfort in endodontic studies, as the peak of inflammatory response and associated pain typically occurs within the first 24–48 hours [67].

Regarding pre-medication, a clinical trial has reported that the use of non-steroidal anti-inflammatory drugs (NSAIDs) prior to treatment reduced the POP following the endodontic treatment [68]. In the current study, before the obturation visit, no patient took any NSAID. Antibiotic medication has been found not to affect POP in a systematic review [69]; however, we excluded any patient who took antibiotics before the first and second visits.

When interpreting the results of this study, several limitations should be considered. The single-center design of this study may lead to potential biases, such as the characteristics and inadequate blinding of patients and operators, as well as equipment quality, potentially limiting the generalizability of the findings. The non-random allocation may have affected the consistency and comparability of the outcomes. The supervisor's feedback to PGSS may positively impact the treatment quality. A long-term follow-up would also be necessary to obtain a broader perspective on these findings. The study design focused exclusively on a single type of bioceramic sealer and a specific obturation technique (CWC), which may not fully reflect the diverse clinical scenarios encountered in routine practice. Further, the reliance on patient-reported outcomes introduces a degree of reporting bias. Additionally, factors such as individual pain thresholds, pre-operative anxiety, and variations in anatomical complexity were not fully accounted for. Finally, the study's exclusion criteria—such as the absence of symptomatic cases at the obturation phase—may not apply to all clinical conditions.

Future research should aim to address the limitations of this study by conducting randomized clinical trials and including multi-center trials to increase the generalizability of findings. Comparative studies exploring different bioceramic sealers, obturation techniques, and instrumentation systems are needed to establish optimal strategies for POP minimization. Additionally, investigations should focus on long-term outcomes, such as periapical healing and re-treatment success, when using bioceramic sealers. These could create a benchmark for proposing clinical guidelines regarding standardized protocols for trainee programs and usual clinical practice. Advanced imaging modalities such as cone-beam computed tomography (CBCT) could enable more precise evaluations of sealer extrusion and obturation quality. Furthermore, the role of adjunctive therapies—including pre-medication with NSAIDs, corticosteroids, or other analgesics—should be explored in greater detail. Studies that integrate patient-specific factors, such as pre-operative anxiety, anatomical variations, and genetic predispositions to pain sensitivity, would enable a more comprehensive understanding of POP in the endodontic context.

5. Conclusions

This study provides important insights into the factors influencing POP. The findings highlight the influence of treatment protocols, materials, and patient-specific factors. Operator experience did not affect POP when standardized protocols were followed. POP was more pronounced after the instrumentation phase than the obturation phase, emphasizing the potential impact of the shaping procedure and apical tissue injuries. Positive percussion influenced POP after the instrumentation phase, but not following the obturation phase, while sealer extrusion and case difficulty had no influence on POP. The use of a bioceramic sealer designed for warm obturation techniques, such as TFHF, demonstrated minimal POP, supporting its application in modern endodontic practice.

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Data Availability Statement: Data available on request from the authors due to restrictions (privacy, ethics, patient data).

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AAE	American Association of Endodontics
ESs	Endodontics specialists
CWC	Continuous wave condensation
LEO	Lesion of endodontic origin
NRS	Numeric rating scale
NSAID	Non-steroidal anti-inflammatory drug
POP	Post-operative pain
PGSs	Postgraduate students
SD	Standard deviation
TFHF	Total Fill Hi-Flow BC Sealer

Appendix A

Table A1. STROBE Statement Checklist – for cohort studies.

	Item No	Recommendation	Article section
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	Abstract - material and methods
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Abstract
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2 nd , 6 th paragraph
Objectives	3	State specific objectives, including any prespecified hypotheses	7 th , 8 th paragraph
Methods			
Study design	4	Present key elements of study design early in the paper	Patient selection – 1 st , 3 rd paragraph
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Patient selection 2 nd , 3 rd paragraph; Figure 1
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	Patient selection – 2 nd paragraph; POP assessment form
		(b) For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	First visit; POP assessment form
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	POP assessment form



Bias	9	Describe any efforts to address potential sources of bias	<i>Patient selection – 3rd paragraph; Second visit; POP assessment form</i>
Study size	10	Explain how the study size was arrived at	<i>Patient selection – 3rd paragraph</i>
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	<i>Statistical analysis</i>
Statistical methods	12	<p>(a) Describe all statistical methods, including those used to control for confounding</p> <p>(b) Describe any methods used to examine subgroups and interactions</p> <p>(c) Explain how missing data were addressed</p> <p>(d) If applicable, explain how loss to follow-up was addressed</p> <p>(e) Describe any sensitivity analyses</p>	<i>Statistical analysis</i> <i>Statistical analysis</i> <i>No missing data</i> <i>Results – 1st paragraph</i> <i>None (low N)</i>
Results			
Participants	13*	<p>(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed</p> <p>(b) Give reasons for non-participation at each stage</p> <p>(c) Consider use of a flow diagram</p>	<i>Figure 1</i> <i>Results – 1st paragraph</i> <i>Figure 1</i>
Descriptive data	14*	<p>(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders</p> <p>(b) Indicate number of participants with missing data for each variable of interest</p> <p>(c) Summarise follow-up time (eg, average and total amount)</p>	<i>Table 2</i> <i>Results – 1st paragraph</i> <i>Figure 1</i>
Outcome data	15*	Report numbers of outcome events or summary measures over time	<i>Results – 2nd paragraph</i>
Main results	16	<p>(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included</p> <p>(b) Report category boundaries when continuous variables were categorized</p> <p>(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period</p>	<i>No confounders/control variables.</i> <i>Results – 2nd paragraph</i> <i>Results – 2nd paragraph</i>
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	<i>Patient selection – 3rd paragraph</i> <i>Power analysis</i>

Discussion

Key results	18	Summarise key results with reference to study objectives	1 st paragraph; 5 th paragraph
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13 th paragraph
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	1 st paragraph; Conclusions
Generalisability	21	Discuss the generalisability (external validity) of the study results	Discussions – 13 th paragraph; 14 th paragraph
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	None

Patient form

OPERATOR	
PACIENT	
DATE	

Instrumentation appointmentObturation appointment

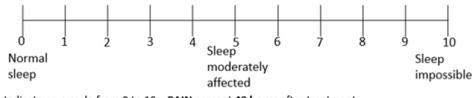
Indicate on a scale from 0 to 10 – PAIN present 24 hours after treatment:



Indicate on a scale from 0 to 10 – MASTICATION DISCOMFORT present 24 hours after treatment:



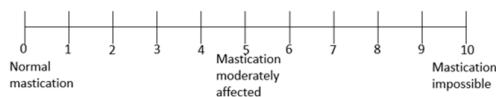
Indicate on a scale from 0 to 10 – if you had SLEEP DISTURBANCE in the FIRST NIGHT after treatment:



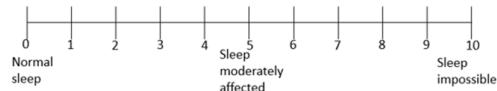
Indicate on a scale from 0 to 10 – PAIN present 48 hours after treatment:



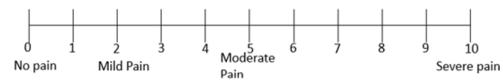
Indicate on a scale from 0 to 10 – **MASTICATION DISCOMFORT** present **48 hours** after treatment:



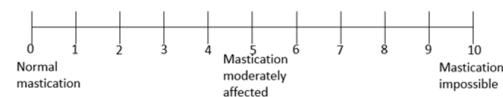
Indicate on a scale from 0 to 10 – if you had **SLEEP DISTURBANCE** in the **SECOND NIGHT** after treatment:



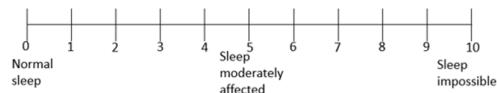
Indicate on a scale from 0 to 10 – **PAIN** present **72 hours** after treatment:



Indicate on a scale from 0 to 10 – **MASTICATION DISCOMFORT** present **72 hours** after treatment:



Indicate on a scale from 0 to 10 – if you had **SLEEP DISTURBANCE** in the **THIRD NIGHT** after treatment:



Please write any analgesic (400mg Ibuprofen) administration:

- First day:
- Second day:
- Third day:

Signature:

Figure A1. a. POP patient assessment form—page 1. b. POP patient assessment form—page 2.

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