

RESEARCH

Open Access



Educational case complexity (E-CAT) and clinical outcomes in undergraduate endodontics: associations with procedural mishaps and postoperative pain

Fatma Pertek Hatipoğlu¹ , Abdullah Özceylan¹ , Ömer Hatipoğlu^{2*} and Joao Filipe Brochado Martins³

Abstract

Introduction Case allocation in undergraduate dental education must balance student learning with patient safety. The Endodontic Complexity Assessment Tool (E-CAT) provides an objective framework for categorizing non-surgical endodontic cases by difficulty. This study aimed to evaluate the predictive value of E-CAT scores for procedural complications and postoperative pain (PP) in root canal treatments performed by undergraduate dental students.

Materials and methods This study was a prospective observational clinical cohort study. A total of 160 patients undergoing primary RCT on mandibular or maxillary molars diagnosed with irreversible pulpitis or pulp necrosis and symptomatic/asymptomatic apical periodontitis were included. Cases were scored using the E-CAT, categorizing complexity as low, moderate, or high. RCT were performed by 5th-year dental students under supervision. Procedural complications were recorded. PP was assessed preoperatively, and at 1-, 3-, 5-, and 7-days post-treatment using a visual analog scale. Data were analyzed statistically using Spearman correlation, Cramér's V, Chi-square, Kruskal-Wallis, Friedman tests, and Multivariable regression analyses ($p < 0.05$).

Results A total of 160 patients (50.6% female; mean age: 27.8 ± 10.9 years) were included. Most of the cases (55%) were categorized as moderate complexity (E-CAT score 6–11). Higher E-CAT scores were associated with longer treatment durations ($r=0.21$), more treatment sessions ($r=0.24$), and increased procedural complications, particularly file separation (Cramér's $V=0.251$) and working length loss ($V=0.216$). However, in adjusted count modeling, E-CAT did not independently predict the overall number of complications. Patients with higher E-CAT scores reported significantly greater PP on day 1 ($p < 0.001$) and required more postoperative analgesics (22.6% low vs. 73.7% high complexity, $p < 0.001$). PP reporting was slightly higher in complex cases, though without statistical significance ($p=0.067$). Anatomical complexity, especially reduced canal visibility ($V=0.262$) and apical morphology ($V=0.202$), showed the strongest associations with PP.

Conclusion E-CAT scores predicted both technical and patient-reported outcomes in undergraduate root canal treatments. Incorporating E-CAT into undergraduate curricula may improve case allocation, support individualized

*Correspondence:
Ömer Hatipoğlu
omerhtp@gmail.com

Full list of author information is available at the end of the article



© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

supervision, and enhance competency-based learning by aligning case complexity with student ability while reducing complications.

Keywords Endodontic education, Case complexity, Root canal treatment, Postoperative pain, Procedural errors, Undergraduate training

Introduction

In undergraduate dental education, the management of endodontic cases represents a critical intersection between student learning, patient safety, and treatment outcomes. Students' limited clinical experience may result in difficulties when managing complex cases, increasing the risk of procedural complications and postoperative discomfort for patients. Ensuring that students are allocated cases aligned with their skill level is therefore essential, both to safeguard patient care and to provide meaningful educational experiences. To support this process, structured case difficulty assessment tools have been developed, including the Restorative Index of Dental Treatment Need (RIOTN), EndoApp, Dutch Endodontic Treatment Index (DETI), and Endodontic Treatment Classification (ETC). More recently, the Endodontic Complexity Assessment Tool (E-CAT), developed by Essam [1], has emerged as a validated, digital tool designed to objectively categorize the complexity of non-surgical endodontic cases by considering patient- and tooth-specific factors [1]. By facilitating more accurate identification and anticipation of clinical challenges, E-CAT has the potential to positively influence treatment outcomes, including reducing the incidence of procedural complications as well as the incidence and severity of postoperative pain (PP) among undergraduate dental trainees [2].

Dental pain is a primary factor motivating patients to seek dental care. However, experiencing postoperative pain (PP) following procedures such as root canal treatment (RCT) may negatively influence their willingness to pursue future dental treatments [3]. While RCT is generally effective in relieving tooth pain and enhancing patient comfort and satisfaction [3–7], approximately 25% of patients report that PP significantly disrupts their daily activities [3, 8, 9]. PP typically arises from an acute inflammatory response triggered by mechanical, chemical, or microbiological injuries to the periapical and periodontal tissues [7]. Its intensity usually peaks within the first 48 h post-treatment and gradually subsides thereafter [10–15]. The reported prevalence of PP in the literature varies widely, from 3% to 58%, influenced by numerous factors such as patient demographics (e.g., age, sex), tooth-specific clinical parameters (e.g., preoperative pulp status, tooth type), procedural variables (e.g., irrigant type and concentration, instrumentation technique), case complexity, and operator experience [16–23].

Although previous research has assessed the relationship between E-CAT scores and procedural complications in undergraduate training [2], this study has largely focused on technical outcomes. Our study extends this work by evaluating both technical outcomes and patient-centered measures—such as the progression of PP and analgesic consumption—following treatments performed by undergraduate students. Therefore, the aim of this study was to investigate whether higher E-CAT scores, indicative of greater clinical complexity, are associated with increased rates of procedural complications, higher PP intensity, and greater analgesic use in patients treated by fifth-year undergraduate dental students.

Materials and methods

Study design

This study was a prospective observational clinical cohort study approved by the Recep Tayyip Erdoğan University Non-Interventional Ethics Committee on Recep Tayyip Erdoğan University (Approval No: 2025/38). The research was conducted at the Department of Endodontics, Faculty of Dentistry, Recep Tayyip Erdoğan University, from February 2025 to June 2025. All procedures adhered strictly to ethical guidelines, and written informed consent was obtained from both participating patients and dental students, in accordance with the principles of the Declaration of Helsinki.

The inclusion criteria were as follows:

- primary root canal treatment.
- mandibular or maxillary molars requiring endodontic therapy.
- pulp diagnosis of irreversible pulpitis.
- Pulp diagnosis of pulp necrosis combined with a periapical diagnosis of symptomatic or asymptomatic apical periodontitis.

The exclusion criteria were as follows:

- acute periapical abscess.
- teeth requiring additional restorative or surgical interventions.
- emergency-only visits/interventions (e.g., pain/swelling relief procedures such as access opening, pulpotomy/pulpectomy, or drainage without completion of definitive RCT at that visit).
- pregnant women.
- patients with severe anxiety or poor cooperation.

- subjects unable to comply with post-treatment follow-up visits.
- teeth with any previous endodontic access, instrumentation, or root canal treatment (including retreatment).
- patients who reported using systemic analgesics, antibiotics, corticosteroids, or other anti-inflammatory drugs prior to treatment.

All teeth were diagnosed by means of patient's history, pulp sensibility tests and digital periapical radiographs (radiolucent area around one or more root tips of the affected tooth).

Sample size calculation

Given the lack of similar prior studies, a medium effect size (0.5) was assumed, and the target statistical power was set at 90%. The analysis was performed using G*Power software with a significance level set at $\alpha = 0.05$, considering a correlation analysis and a two-tailed hypothesis test. The minimum required sample size was determined to be 85 participants.

E-CAT case difficulty classification

Prior to the study, an instructor (A.Ö.) conducted a pilot assessment using representative sample cases to verify accurate evaluation with the E-CAT system. To ensure reliability, an intra-observer consistency test was performed. The instructor reassessed the same cases after a four-week interval. Statistical analysis comparing the initial and repeated assessments showed excellent agreement ($ICC > 0.80$).

Each tooth was assessed using the E-CAT application (<https://www.e-cat.uk/#/>) before treatment by an experienced instructor with over 10 years of clinical teaching experience [1]. Difficulty scores and corresponding categories for each case were determined and recorded based on the E-CAT criteria. The E-CAT system classifies cases into three difficulty levels, as follows [1]:

- Easy Case (Class 1: Score 0–5): Low-risk cases with minimal potential for complications.
- Moderately Difficult Case (Class 2: Score 6–11): Cases requiring intermediate skills, presenting a moderate risk of complications.
- Difficult Case (Class 3: Score 12 and above): Complex cases requiring advanced management skills, with a high risk of complications and adverse outcomes.

The primary questions utilized in the E-CAT assessment, along with additional follow-up questions based on initial responses, are provided in Supplemental Material 1.

Patient demographics, clinical data, and analgesic consumption

Demographic data including sex, age, education level, presence of systemic diseases, smoking status, and regular medication use were obtained through a standardized patient questionnaire administered prior to the procedure. Diagnostic classifications (irreversible pulpitis, pulp necrosis and asymptomatic apical periodontitis, pulp necrosis and symptomatic apical periodontitis) were established based on clinical signs and symptoms, as well as radiographic evaluations, following the criteria of the American Association of Endodontists [24]. Tooth type (mandibular or maxillary molar) was recorded during clinical examination. Analgesic consumption data were collected during follow-up calls made for PP assessment using the Visual Analog Scale (VAS).

Technical and procedural complications encountered during treatment

Operators and standardized protocol

Treatments were performed by 47 fifth-year undergraduate students (18 male and 29 female; mean age: 23.0 ± 1.3 years) from the same academic cohort who received the same institutional preclinical and didactic endodontic training and performed RCT as part of the routine supervised clinical curriculum. At our institution, students enter the fifth-year clinical endodontic program after completing a minimum of 10 single-rooted root canal treatments during the fourth year. In the fifth year, they are additionally required to complete at least 10 molar root canal treatments under supervision as part of the competency-based clinical curriculum. Therefore, all operators had a common minimum level of undergraduate clinical exposure, although the exact number of previously completed root canal treatments for each individual student at the time of treating the study tooth was not recorded. To minimize procedural variability, a prespecified step-by-step protocol (including working-length determination, instrumentation, irrigation regimen, obturation, and definitive restoration) was followed in all cases under direct instructor supervision. No additional study-specific preoperative practical test was conducted to formally quantify baseline manual skill level.

After local anesthesia and rubber dam isolation, endodontic access cavity was prepared. Patency was confirmed with a #10 K-file, and working length (WL) was established 0.5–1.0 mm short of the radiographic apex using an electronic apex locator and a confirmatory radiograph. Canal preparation was performed using SCOPE-A 0.04-taper rotary Ni-Ti files (Gtech Dizayn Dental, Yozgat, Turkey) driven at 300 rpm and 1.5–2 Ncm, in accordance with the manufacturer's recommendations. The sequence consisted of coronal preflaring followed by glide path preparation and shaping to working

length using progressively larger 0.04-taper instruments. Canals were shaped to a minimum apical size of ISO 20/0.04, with further enlargement if clinically indicated, based on canal anatomy and initial apical diameter. Irrigation consisted of 2.5% NaOCl (~20 mL/canal) during instrumentation, followed by a final rinse of 17% EDTA (1 mL for 1 min) and saline. Following drying with paper points, canals were obturated via cold lateral condensation using an appropriate master cone and Adseal resin-based sealer (Meta Biomed Co., South Korea). Definitive restorations were immediately completed using an adhesive protocol and FGM paste composite (Dentscare Ltda., Brazil). Occlusion was adjusted, postoperative instructions were provided and a follow-up appointment scheduled.

Complication monitoring and management

Throughout the procedure, technical and procedural complications were documented. Although the documentation of complications was comprehensive and not limited to predefined categories, certain frequently observed complications were specifically monitored for statistical analysis. Specific complications monitored included:

- Faulty access cavity or perforation.
- WL loss (inability to re-establish the initial WL alongside loss of apical patency).
- Canal blockage (inability to progress apically due to debris).
- Ledge formation (deviation from the original canal path resulting in inability to negotiate to the true working length).
- File separation.
- Insufficient canal filling (short filling [> 2 mm from apex], insufficient compaction (presence of voids or poor compaction), overfilling, overextension, or overinstrumentation), as determined from postoperative radiographs and clinical records.

If a complication occurred, students attempted standardized corrective measures (e.g., re-establishing patency with small hand files, increasing irrigation, changing instruments, when indicated attempt bypass) under supervision. If the student could not resolve the issue, an experienced instructor took over; these cases were excluded from the study analysis. Final clinical and radiographic assessments of all completed cases were performed by a single calibrated examiner (A.Ö.).

PP assessment

PP was evaluated exclusively after the final obturation appointment; pain following interim sessions in multi-visit cases was not recorded. Patients were provided

with a manual VAS, 0–100 to record their pain levels. Assessments were conducted at five specific time points: pre-treatment (baseline), and at 1, 3, 5, and 7 days post-treatment. To ensure comprehensive and accurate data collection, a single researcher (A.Ö.) contacted each patient by telephone to verbally obtain and record VAS pain scores.

Patients were instructed to report the maximum pain experienced during each period. If analgesics were required, patients were asked to report the highest pain intensity experienced prior to taking the medication. This ensured that the recorded PP accurately reflected true PP levels unmitigated by analgesic use.

Statistical analysis

Statistical analyses were performed using Jamovi software (Version:2.3.28). Descriptive statistics were calculated to summarize demographic characteristics and clinical variables. Normality of continuous variables was assessed using the Shapiro-Wilk test. As the data were not normally distributed, their results are presented as median (interquartile range, IQR). Differences between independent groups were evaluated using the Kruskal-Wallis test, followed by the Dwass-Steel-Critchlow-Fligner pairwise comparison test for post-hoc analyses. For repeated measurements, the Friedman test was applied, with subsequent post-hoc analyses conducted using the Durbin-Conover comparison test. Categorical variables, including post-treatment complications and analgesic use, were analyzed using the Chi-squared test. Associations between postoperative pain, clinical factors, and procedural variables were explored using Spearman's rank correlation and Cramér's V.

In addition, multivariable regression models were performed to evaluate the independent effect of the E-CAT score on clinical outcomes while adjusting for potential confounders (sex, age, tooth type, initial diagnosis, and number of sessions). For complication counts, Poisson regression with robust standard errors was initially applied; in case of overdispersion, a Negative Binomial model was preferred, and incidence rate ratios (IRR) with 95% confidence intervals (CI) were reported. The independent association between E-CAT score and day-1 postoperative pain (VAS, 0–100) was evaluated using an ordinary least squares (OLS) multivariable linear regression model with HC3 heteroskedasticity-robust standard errors. The model included E-CAT score as the main predictor and adjusted for potential confounders (age, sex, tooth type, baseline diagnosis, and number of treatment sessions). Results are reported as unstandardized β coefficients with 95% confidence intervals (CI) and p-values. Model fit was summarized using R^2 . For analgesic use (binary outcome), logistic regression was applied, with odds ratios (OR) and 95% CI presented. Model fit indices

Table 1 Demographic attributes of the treated patients

	Overall (N = 160)
Gender	
Female	81 (50.6%)
Male	79 (49.4%)
Age	
Mean (SD)	27.8 (10.9)
Median (IQR)	26 (18–35)
Range	15.0–58.0
Education	
illiterate	1 (0.6%)
Primary School	23 (14.4%)
High School	91 (56.9%)
University	44 (27.5%)
PhD	1 (0.6%)
Systemic Disease	
Present	17 (10.6%)
None	143 (89.4%)
Smoking	
Yes	50 (31.2%)
No	110 (68.8%)
Medicine usage	
Yes	73 (45.6%)
No	87 (54.4%)
Diagnosis	
Asymptomatic devital	52 (32.5%)
Symptomatic devital	55 (34.4%)
Symptomatic vital	53 (33.1%)
Tooth Type	
Mandibular Molar	80 (50%)
Maxillary Molar	80 (50%)
E-Cat Score	
Low	53 (33.1%)
Moderate	88 (55.0%)
High	19 (11.9%)

included Akaike Information Criterion (AIC) for count models, McFadden's pseudo- R^2 for logistic regression, and R^2 for linear regression. All statistical tests were conducted at a two-sided significance level of $p < 0.05$.

Results

Baseline characteristics

The study included 160 patients with nearly equal sex distribution (50.6% female, 49.4% male) and an average age of 27.8 ± 10.9 years. The majority had completed high school (56.9%) and reported no systemic diseases (89.4%). Diagnoses were evenly distributed among asymptomatic apical periodontitis (32.5%), symptomatic apical periodontitis (34.4%), and irreversible pulpitis (33.1%). Mandibular and maxillary molars each accounted for exactly half of the treated teeth. Regarding case difficulty, 55.0% of cases had a moderate E-CAT score, 33.1% had a low score, and 11.9% were classified as high (Table 1).

Treatment duration and procedural complications

Spearman correlation analysis demonstrated significant associations between treatment duration, number of sessions, and E-CAT scores. Treatment duration strongly correlated with the number of sessions ($r = 0.85$). Weak positive correlations were observed between E-CAT scores and both treatment length ($r = 0.21$) as number of sessions ($r = 0.24$). Notably, the overall number of complications was not significantly correlated with treatment duration, number of sessions, or E-CAT scores (Fig. 1).

When analyzing procedural complications, the E-CAT score showed the strongest associations with file separation (Cramér's $V = 0.251$) and working length loss ($V = 0.216$). Moderate-to-weak associations were observed for other mishaps, such as overinstrumentation ($V = 0.160$) and canal blockage ($V = 0.141$), while

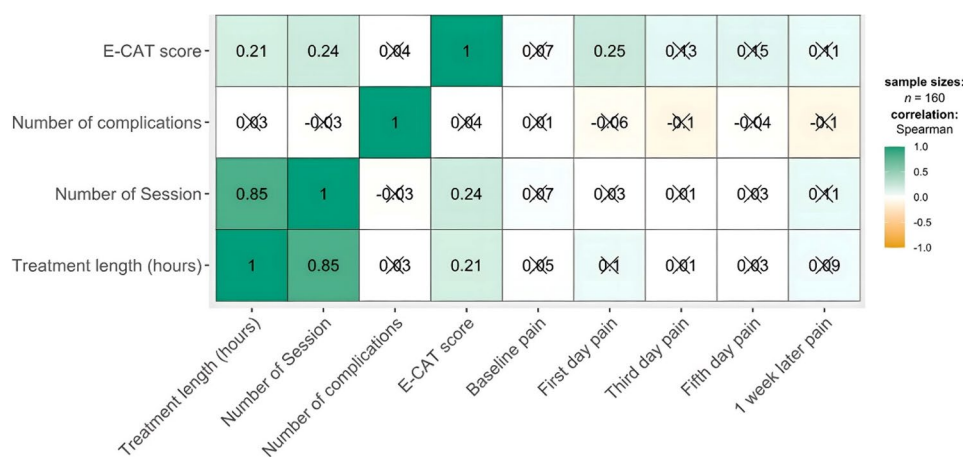


Fig. 1 Spearman Correlation Matrix of Treatment Parameters and Pain Progression. Correlation matrix boxes: green and orange boxes indicate positive and negative correlations, respectively (Colour tones indicate the strength of the correlation). Boxes without "X" indicate significance ($p < 0.05$). Numbers on the boxes are spearmen correlation coefficients

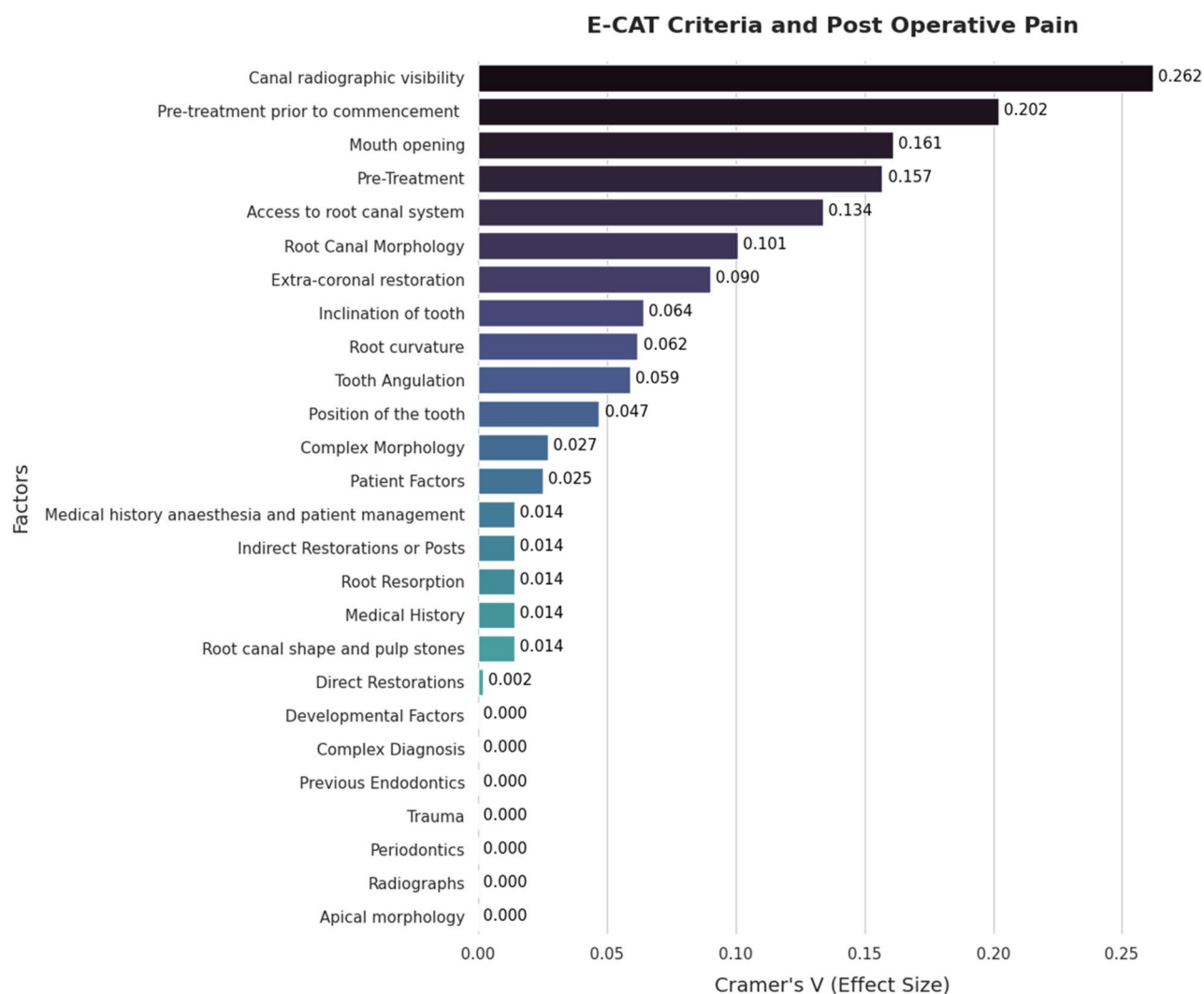


Fig. 2 Association Between Individual E-CAT Criteria and Postoperative Pain (Cramér's V Effect Sizes)

Table 2 Pain Progression Over Time in Patients with Different E-CAT Scores

	E-CAT Score			p-value
	Low (n = 53)	Moderate (n = 88)	High (n = 19)	
Baseline pain	60 (50) ^{A, a}	60 (50) ^{A, a}	60 (60) ^{A, a}	0.139 ¹
First day pain	30 (30) ^{A, a}	50 (60) ^{B, a}	60 (60) ^{B, a}	< 0.001 ¹
Third day pain	0 (10) ^{A, b}	0 (30) ^{A, b}	20 (55) ^{A, b}	0.058 ¹
Fifth day pain	0 (0) ^{A, c}	0 (10) ^{A, c}	0 (20) ^{A, c}	0.206 ¹
1 week later pain	0 (0) ^{A, c}	0 (0) ^{A, d}	0 (5) ^{A, c}	0.347 ¹
p-value	< 0.001 ²	< 0.001 ²	< 0.001 ²	
Median (IQR)				

¹ Kruskal Wallis test, Dwass-Steel-Critchlow-Fligner pairwise comparison

² Friedman test and Durbin-Conover comparison. Different superscript capital letters indicate significant differences within rows, while different lowercase letters indicate significant differences within columns

complications like overfilling ($V = 0.047$) showed negligible correlation (Fig. 2).

PP and analgesic use

PP significantly differed among patients with varying E-CAT scores. At baseline, pain levels were similar across all groups ($p = 0.139$). On the first day post-treatment, PP correlated positively with E-CAT scores ($r = 0.25$), with patients in the moderate and high E-CAT groups reporting significantly higher PP than those in the low group ($p < 0.001$) (Fig. 1; Table 2). By day three, PP levels decreased across all groups, however the high E-CAT group reported slightly higher PP, though this difference was not statistically significant ($p = 0.058$). By days five and seven, PP had further resolved with no significant differences among groups. Within each group, there was a statistically significant reduction in PP levels over time ($p < 0.001$) (Table 2).

Post-treatment analgesic usage was significantly associated with case complexity ($p < 0.001$), increasing sharply from 22.6% in the low E-CAT group to 73.7% in the high E-CAT group (Fig. 3; Table 3). Analgesic use was also strongly linked to reported PP intensity ($p < 0.001$), while demographic and clinical factors like sex, tooth type, and diagnosis showed no significant associations. Age showed a borderline relationship ($p = 0.054$), with higher analgesic usage in patients over 34 years old.

While the intensity of day-1 pain and the need for analgesics varied by complexity, the overall prevalence of reported PP at any time point was high across the board. Although PP prevalence trended upward with higher E-CAT scores (from 83.0% in the low group to 94.7% in the high group), this did not reach statistical significance ($p = 0.067$). Similarly, PP prevalence was not significantly affected by tooth type, diagnosis, sex, age or number of treatment sessions (all $p > 0.05$) (Table 4). Among specific

anatomical factors, reduced radiographic canal visibility (Cramér's $V = 0.262$) and complex apical morphology ($V = 0.202$) showed the strongest correlations with PP (Fig. 4). Moderate correlations were observed for root curvature (Cramér's $V = 0.161$) and complex diagnosis (Cramér's $V = 0.157$). Other factors, such as root canal morphology (Cramér's $V = 0.134$), access difficulty (Cramér's $V = 0.101$), and extra-coronal restoration (Cramér's $V = 0.090$), showed weaker but meaningful associations. Factors like tooth angulation, inclination, and patient-related aspects exhibited lower correlations (Cramér's $V < 0.07$) (Fig. 3).

Multivariable Regression Analysis

In the multivariable linear regression model adjusting for sex, age, tooth type, diagnosis, and number of sessions, the E-CAT score remained an independent predictor of

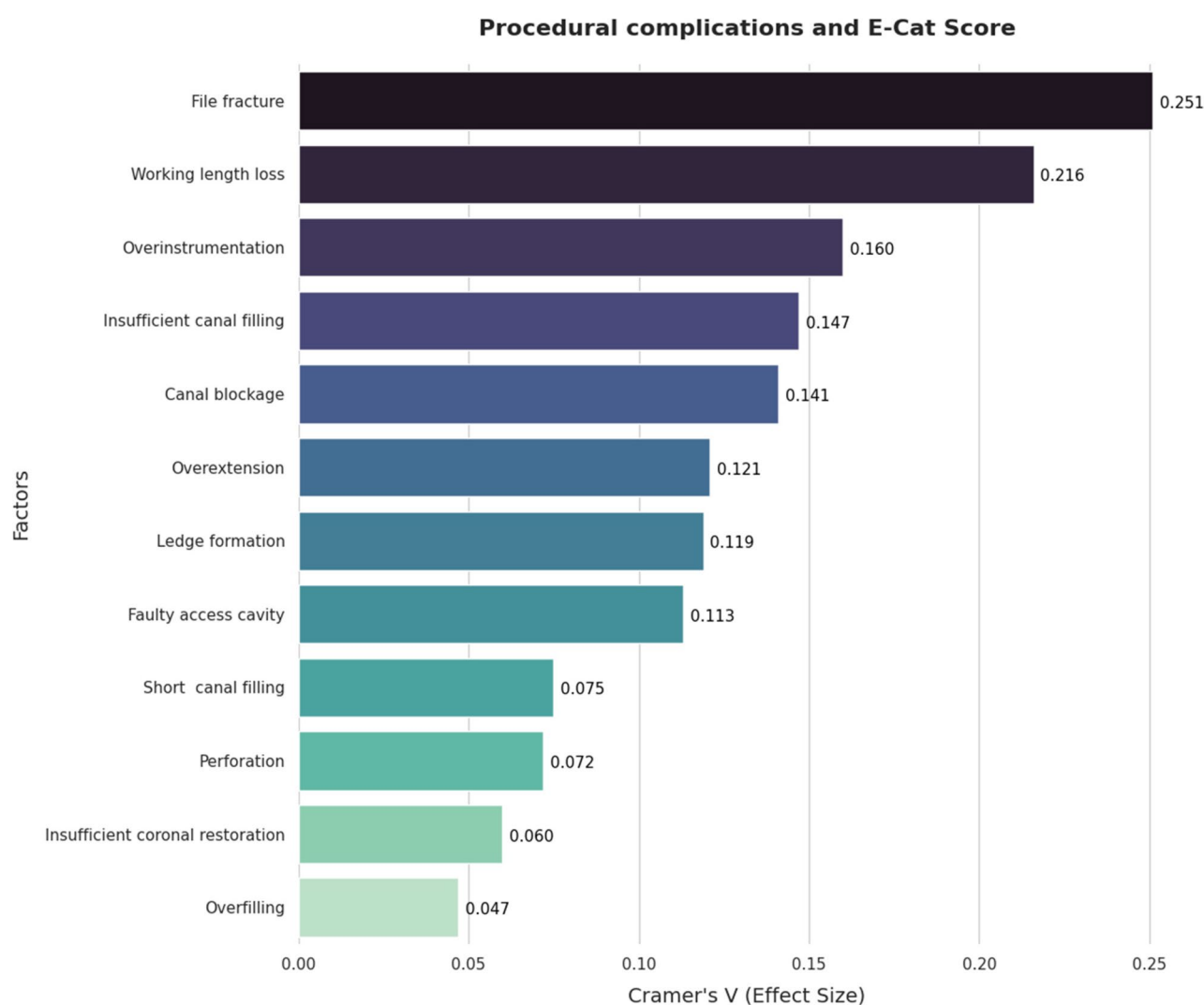


Fig. 3 Association between E-CAT Score and Individual Procedural Complications (Cramér's V Effect Sizes)

Table 3 Post-Treatment Analgesic Usage Based on E-CAT Score, Tooth Type, Diagnosis, Gender, Age, and Number of Sessions

	Analgesic Usage after treatment		p value
	Yes	No	
E-CAT Score			
Low (N=53)	12.0 (22.6%)	41.0 (77.4%)	<0.001 ¹
Moderate (N=88)	47.0 (53.4%)	41.0 (46.6%)	
High (N=19)	14.0 (73.7%)	5.0 (26.3%)	
Tooth Type			
Mandibular (N=80)	34.0 (42.5%)	46.0 (57.5%)	0.427 ¹
Maxillar (N=80)	39.0 (48.8%)	41.0 (51.2%)	
Diagnosis			
Asymptomatic_devital (N=52)	24.0 (46.2%)	28.0 (53.8%)	0.918 ¹
Symptomatic_devital (N=55)	26.0 (47.3%)	29.0 (52.7%)	
Symptomatic_vital (N=53)	23.0 (43.4%)	30.0 (56.6%)	
Gender			
Female (N=81)	36.0 (44.4%)	45.0 (55.6%)	0.761 ¹
Male (N=79)	37.0 (46.8%)	42.0 (53.2%)	
Age range			
<35 (N=119)	49.0 (41.2%)	70.0 (58.8%)	0.054 ¹
>34 (N=41)	24.0 (58.5%)	17.0 (41.5%)	
Number of Session			
1 (N=80)	33.0 (41.2%)	47.0 (58.8%)	0.453 ¹
2 (N=77)	38.0 (49.4%)	39.0 (50.6%)	
3 (N=3)	2.0 (66.7%)	1.0 (33.3%)	
Reported pain at any time			
Yes	73.0 (50.3%)	72.0 (49.7%)	<0.001 ¹
No	0.0 (0.0%)	15.0 (100.0%)	

¹ Chi-squared test

day-1 PP (β per 1-unit increase = 2.10; 95% CI: 0.36–3.84; $p=0.018$; $R^2=0.065$) (Table 5).

A logistic regression model further confirmed that higher E-CAT scores were significantly associated with greater odds of postoperative analgesic use (OR 1.20,

Table 4 Reported pain at any time based on E-CAT Score, Tooth Type, Diagnosis, Gender, Age, and Number of Sessions

	Reported pain at any time		p value
	Yes	No	
E-CAT Score			
Low (N=53)	44.0 (83.0%)	9.0 (17.0%)	0.067 ¹
Moderate (N=88)	83.0 (94.3%)	5.0 (5.7%)	
High (N=19)	18.0 (94.7%)	1.0 (5.3%)	
Tooth Type			
Mandibular (N=80)	74.0 (92.5%)	6.0 (7.5%)	0.416 ¹
Maxillar (N=80)	71.0 (88.8%)	9.0 (11.2%)	
Diagnosis			
Asymptomatic_devital (N=52)	48.0 (92.3%)	4.0 (7.7%)	0.251 ¹
Symptomatic_devital (N=55)	47.0 (85.5%)	8.0 (14.5%)	
Symptomatic_vital (N=53)	50.0 (94.3%)	3.0 (5.7%)	
Gender			
Female (N=81)	76.0 (93.8%)	5.0 (6.2%)	0.159 ¹
Male (N=79)	69.0 (87.3%)	10.0 (12.7%)	
Age range			
<35 (N=119)	106.0 (89.1%)	13.0 (10.9%)	0.252 ¹
>34 (N=41)	39.0 (95.1%)	2.0 (4.9%)	
Number of Session			
1 (N=80)	73.0 (91.2%)	7.0 (8.8%)	0.802 ¹
2 (N=77)	69.0 (89.6%)	8.0 (10.4%)	
3 (N=3)	3.0 (100.0%)	0.0 (0.0%)	

¹ Chi-squared test

95% CI: 1.06–1.36, $p=0.004$) (Table 6). This indicates that each one-unit increase in case difficulty corresponds to a 20% higher likelihood of analgesic intake. Within this model, patient age demonstrated a borderline association with analgesic use (OR 1.03, 95% CI: 1.00–1.07, $p=0.061$), while sex, tooth type, number of sessions, and initial diagnosis showed no significant effects (Table 6).

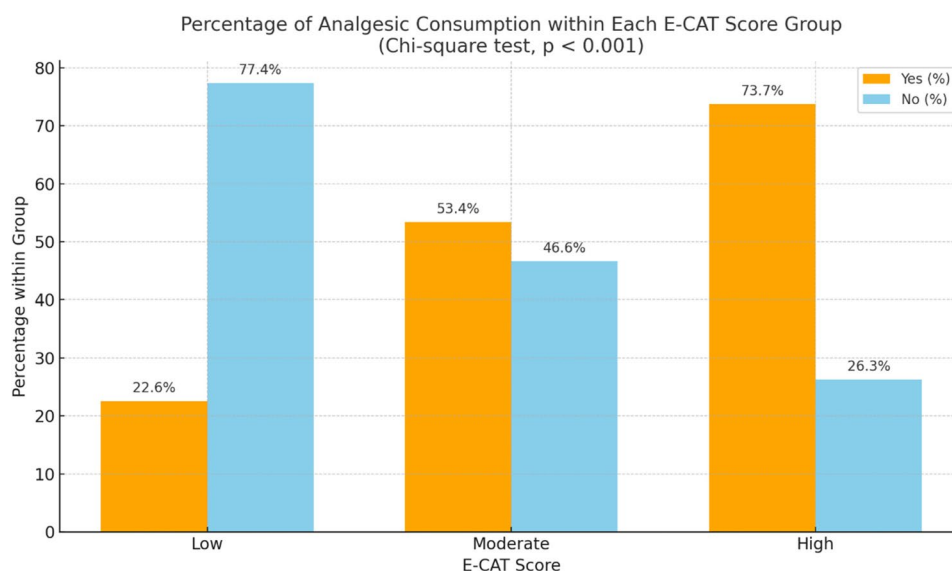
**Fig. 4** Distribution of Analgesic Consumption by E-CAT Score Groups

Table 5 Multivariable linear regression analysis of factors associated with day-1 postoperative pain

Predictor	β (HC3 robust)	95% CI	<i>p</i>
E-CAT score (per 1 unit)	2.10	0.36 to 3.84	0.018
Age (per year)	0.07	−0.39 to 0.54	0.756
Sessions (per 1 session)	−0.58	−9.78 to 8.63	0.902
Male (vs. Female)	−2.98	−12.34 to 6.37	0.532
Maxillar (vs. Mandibular)	−2.25	−11.77 to 7.28	0.644
Dx: Symptomatic devital (vs. Asymptomatic devital)	0.82	−10.70 to 12.34	0.889
Dx: Symptomatic vital (vs. Asymptomatic devital)	1.51	−10.00 to 13.03	0.796

Table 6 Analgesic Use Model (Odds Ratios, adjusted for confounders)

Predictor	OR	95% CI	<i>p</i> -value
E-CAT Score	1.20	1.06–1.36	0.004
Age	1.03	1.00–1.07	0.061
Number of Session	1.19	0.62–2.31	0.598
Gender_Male	1.33	0.67–2.61	0.412
Tooth type_Maxillar	1.00	0.50–1.99	0.998
Diagnosis_Symptomatic_devital	1.17	0.51–2.69	0.713
Diagnosis_Symptomatic_vital	0.89	0.37–2.10	0.784

Table 7 Complications Model (Incidence Rate Ratios, adjusted for confounders)

Predictor	IRR	95% CI	<i>p</i> -value
E-CAT Score	1.03	0.98–1.09	0.286
Age (per year)	1.00	0.99–1.02	0.785
Number of sessions	0.97	0.66–1.42	0.874
Male gender	1.09	0.80–1.50	0.589
Maxillary tooth	1.10	0.78–1.56	0.593
Diagnosis: Symptomatic devital	0.95	0.62–1.44	0.792
Diagnosis: Symptomatic vital	1.39	0.92–2.11	0.121

Conversely, when adjusting for the same confounding variables, E-CAT scores were not significantly associated with the total number of complications (IRR 1.03, 95% CI: 0.98–1.09, $p = 0.286$) (Table 6). This suggests that increasing case difficulty did not independently predict a higher risk of adverse events. Similarly, no other analyzed variables were significantly related to complication rates (Table 7).

Discussion

Our findings demonstrate that objective preoperative case assessment using E-CAT significantly predicts patient-centered outcomes among patients treated by 5th-year undergraduate dental students. In particular, higher E-CAT scores were associated with specific procedural complications in descriptive analyses, while multivariable regression analyses further demonstrated that E-CAT score independently predicted outcomes. After adjustment for potential confounders, increased

case complexity remained a significant predictor of both immediate (day-1) postoperative pain (PP) and the odds of postoperative analgesic use. These results strengthen the value of objective preoperative case assessment in undergraduate settings to support clinical decision-making, improve treatment efficiency, minimize mishaps, and enhance patient comfort [25]. Integrating E-CAT into dental curricula can facilitate appropriate case assignment based on student skill levels, promoting safer and more effective learning environments.

Anatomical complexity is a critical determinant of root canal treatment (RCT) difficulty and duration [26]. In line with previous studies [26], our study found strong correlations between treatment duration, the number of sessions, and E-CAT scores, reflecting increased complexity in cases with higher scores, largely because the study exclusively included molars, which present considerable anatomical challenges [26–29]. Limited mouth opening and difficult access to molars may further explain the increased treatment duration and higher complication rates observed in high E-CAT score cases. Interestingly, although complexity and complication severity correlated, no direct association emerged between the number of complications and individual factors such as treatment duration, session count, or E-CAT scores alone. This suggests that complications may be more influenced by factors like operator experience [30], patient-related variables [31], or unexpected anatomical variations rather than treatment length or complexity alone. Importantly, our complication analyses offer two complementary perspectives. Bivariate analyses (Cramér's V) indicated that specific procedural mishaps like file separation, WL loss, and overinstrumentation, were strongly related to case complexity. However, when complications were evaluated as an overall count in the multivariable regression, the E-CAT score was not an independent predictor of the total number of mishaps. This likely reflects the heterogeneity of complication types (with varying frequencies and clinical weights), potential dilution of signals when diverse events are pooled into a single count outcome, and limited precision for rare outcomes, particularly given the relatively small high-complexity subgroup. Therefore, our findings suggest that while E-CAT is highly effective at anticipating which specific severe complications might occur, the overall frequency of minor and major mishaps combined is likely influenced heavily by other factors, such as individual operator dexterity, patient cooperation, or unexpected anatomical variations [30, 31].

Even under direct clinical supervision, endodontic mishaps cannot be entirely prevented. These complications frequently stem from a novice operator's limited skills, knowledge, and experience [30, 32–34], making highly complex cases challenging even for experienced

practitioners [32]. Consistent with previous studies [29, 35], our findings indicate that complex cases (high E-CAT scores) managed by undergraduates have a correlation with specific procedural complications. For instance, ledges, blockages, and WL loss often result from imprecise instrumentation and a failure to maintain apical patency. Because accurate WL is critical for peri-apical healing [36, 37], teaching students to confirm and maintain patency throughout treatment as well as proper instrument handling may help mitigate these risks [38]. Similarly, a novice's lack of dexterity and inattention to coronal reference points frequently leads to overinstrumentation. The observed correlation between overinstrumentation and overextension seems therefore expected. Because the anatomic apical constriction is compromised during overinstrumentation, more technical skills are required to adapt a master point to achieve adequate obturation length and avoid overextension. Furthermore, while rotary Ni-Ti files enhance preparation efficiency, they inherently carry a higher risk of instrument separation compared to manual files [39, 40]. In our study, this finding likely reflects the limited clinical experience of undergraduate students with rotary instrumentation techniques. Consequently, additional preclinical training focused on tactile feedback, reference point maintenance, and rotary instrumentation dynamics is highly recommended to build technical proficiency before students manage complex clinical cases. By anticipating these specific procedural challenges, objective pre-assessment tools like E-CAT allow educators to provide targeted preoperative instruction and appropriate case allocation. Thus, while prior research [2] has explored E-CAT's predictive ability regarding procedural complications, our study extends its educational utility by linking these technical challenges directly to patient-centered outcomes, demonstrating how increased case complexity translates into higher PP and analgesic consumption.

PP following RCT typically peaks within the first 48 h and resolves within a week [41–44], a trajectory effectively captured by our 7-day assessment period. Although preoperative pain is a known predictor of PP [7, 15, 45–48], baseline pain levels did not differ significantly among our study groups ($p = 0.139$). This isolates procedural complexity as the primary driver of the observed variations in PP. Consequently, patients with higher E-CAT scores experienced significantly greater PP on day 1 ($p < 0.001$) and required significantly more analgesics. This elevated discomfort likely reflects the increased procedural trauma inherent in managing high-complexity cases. Specifically, reduced radiographic canal visibility and complex apical morphology were identified as strong predictors of PP, as these features complicate working length determination and canal negotiation for novice operators. Such challenges increase the likelihood of

mishaps like overinstrumentation, which directly exacerbates apical trauma and inflammation [49, 50]. Furthermore, while diagnoses and arches were evenly balanced, our study exclusive focus on molars which are consistently associated with higher PP rates [18, 19, 22, 23, 51]. Operator experience has previously been considered a factor influencing procedural outcomes and PP severity. While some studies report that more experienced dentists may perform more difficult treatments and therefore the levels of PP will be higher [16, 17], others [45, 52] reported minimal impact of operator experience on the incidence of PP. Our findings among undergraduate students suggest that intrinsic case complexity may outweigh operator experience as the primary determinant of PP. Identifying these high-risk cases preoperatively using E-CAT provides significant clinical value; it allows students to set accurate patient expectations, provide targeted counseling, and implement proactive pain management strategies. A key finding of this study, and one that warrants specific discussion, is the discrepancy between the overall prevalence of reported PP and the requirement for analgesics. While the E-CAT score showed a significant association with day-1 PP intensity and analgesic intake, it was not significantly associated with the mere report of pain at any time ($p = 0.067$). This can be explained by a clinical “ceiling effect” [53]. Because molar RCTs inherently cause some PP [18, 19, 22, 23, 51], a vast majority of patients across all groups (83.0% to 94.7%) experienced at least mild, transient sensation following treatment. However, while the presence of mild discomfort was similar across groups, the intensity of PP and the requirement for pharmacological intervention clearly differentiated the complexity levels. High-complexity cases resulted in a significantly higher likelihood of analgesic intake. Nevertheless, pain perception is a multifactorial experience profoundly influenced by psychological state, interpersonal dynamics, and other psychosocial variables [54]. Because these broader factors were not captured by our self-reported VAS assessments, the relationship between E-CAT scores and PP should be interpreted as associative rather than strictly causal, driven by a complex interplay of patient, operator, and procedural factors.

The ultimate goal of endodontic education is to develop students' theoretical knowledge, technical competence, and clinical judgment [55, 56]. While previous tools have aimed to guide case selection, this study is the first to evaluate the predictive value of E-CAT scores for both procedural complications and PP in the context of undergraduate endodontic training. E-CAT promotes structured, reflective case assessment and fosters communication between students and educators. By stratifying risk, it facilitates individualized supervision and more appropriate case allocation, offering a foundation

for more personalized and competency-based training [56, 57], which may improve student confidence, reduce errors, and enhance learning outcomes. These benefits are particularly relevant in undergraduate settings where the risk of error is high, and student anxiety may impair performance.

This study has several limitations. First, as a single-center observational cohort restricted to primary molar RCTs in a supervised undergraduate clinic, the findings may not fully generalize to other tooth types, retreatment cases, or more experienced operators. Second, E-CAT scoring relied on a single assessor, introducing potential observer bias. Third, methodological constraints, such as potential recall bias from telephone-based PP self-reports and the absence of specific subgroup analyses (e.g., by diagnosis or tooth position) could mask deeper clinical nuances. Additionally, the skewed distribution of E-CAT categories, featuring a relatively small high-complexity subgroup (11.9%), reflects real-world undergraduate case allocation but likely reduced statistical power for detecting some adjusted associations. Finally, although a standardized treatment protocol was enforced and all students belonged to the same academic cohort with a common minimum clinical exposure, treatments were performed by multiple operators. The exact number of previously completed root canal treatments per student at the time of the included case was not individually recorded. Therefore, operator-level experience could not be quantified directly, and residual confounding related to inter-operator variability in manual dexterity and prior clinical exposure, as well as unmeasured patient-level factors such as dental anxiety, cannot be entirely ruled out.

Future research should involve multicenter longitudinal studies that include a range of operator experience levels to assess the generalizability and predictive strength of E-CAT. Randomized educational trials evaluating the integration of E-CAT into clinical training programs may further support its widespread adoption.

Conclusion

Within the limitations of this single-center study, pre-operative E-CAT assessment independently predicted immediate PP and analgesic use, though it did not predict the overall complication count. Our findings support using structured complexity assessments to guide undergraduate case allocation and tailor clinical supervision. Crucially, incorporating E-CAT into the dental curriculum equips students to better inform patients regarding expected PP and medication needs, ultimately enhancing patient communication, clinical outcomes, and educational effectiveness.

Abbreviations

E-CAT	Endodontic Case Difficulty Assessment Tool
RCT	Root Canal Treatment

PP	Postoperative Pain
VAS	Visual Analog Scale
ICC	Intraclass Correlation Coefficient
IRR	Incidence Rate Ratio
OR	Odds Ratio
CI	Confidence Interval
AIC	Akaike Information Criterion
AAE	American Association of Endodontists

Authors' contributions

F.P.H. conceived and designed the study and supervised the project. A.Ö. conducted the experimental procedures and collected the data. Ö.H. performed the statistical analysis and contributed to data interpretation and manuscript revisions. J.F.B.M. drafted the main manuscript and critically revised the final version. All authors reviewed and approved the final manuscript.

Funding

No funding.

Data availability

The datasets generated and/or analyzed during the current study are not publicly available considering that we have not required consents to publish this data but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Non-Interventional Clinical Research Ethics Committee of Recep Tayyip Erdoğan University (Approval No: 2025/38).

Consent for publication

Written informed consent for publication of anonymized clinical data was obtained from all participating patients. No identifiable personal data or images are included in this article.

Competing interests

The authors declare no competing interests.

Author details

¹Department of Endodontics, Recep Tayyip Erdoğan University, Rize, Türkiye

²Department of Restorative Dentistry, Recep Tayyip Erdoğan University, Rize, Türkiye

³Department of Endodontology, Academic Center for Dentistry Amsterdam, University of Amsterdam and Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

Received: 9 October 2025 / Accepted: 15 April 2026

Published online: 28 April 2026

References

1. Essam O, Boyle E, Whitworth J, Jarad F. The endodontic complexity assessment tool (E-CAT): a digital form for assessing root canal treatment case difficulty. *Int Endod J*. 2021;54(7):1189–99.
2. Hatipoğlu FP, Akıncı L. Effectiveness of endodontic complexity assessment tool (E-CAT) on the undergraduate students in an endodontic training program and its predictive capability on complications. *Eur J Dent Educ*. 2023;27(2):409–17.
3. Law A, Nixdorf D, Aguirre A, Reams G, Tortomasi A, Manne B, Harris D, Group NDPC. Predicting severe pain after root canal therapy in the National Dental PBRN. *J Dent Res*. 2015;94(3suppl):S37–43.
4. Pawar AM, Bhardwaj A, Zanza A, Wahjuningrum DA, Arora S, Luke AM, Karobari MI, Reda R, Testarelli L. Severity of post-operative pain after instrumentation of root canals by XP-endo and SAF full sequences compared to manual instrumentation: A randomized clinical trial. *J Clin Med*. 2022;11(23):7251.
5. Multari S, Alovizi M, Berutti E, Corbella S, Taschieri S, Carpegna G, Scotti N, Comba A, Pasqualini D. Postoperative quality of life after single-visit root

- canal treatment performed with reciprocating shaping systems: An observational study. *Appl Sci*. 2020;11(1):273.
6. Law AS, Nixdorf DR, Rabinowitz I, Reams GJ, Smith JA Jr, Torres AV, Harris DR, Group NDPC. Root canal therapy reduces multiple dimensions of pain: a national dental practice-based research network study. *J Endod*. 2014;40(11):1738–45.
 7. Pak JG, White SN. Pain prevalence and severity before, during, and after root canal treatment: a systematic review. *J Endod*. 2011;37(4):429–38.
 8. Pochapski MT, Santos FA, de Andrade ED, Sydney GB. Effect of pretreatment dexamethasone on postendodontic pain. *Oral Surg Oral Med Oral Pathol Oral Radiol Endodontology*. 2009;108(5):790–5.
 9. Nekoofar MH, Sadeghipanah M, Dehpour AR. Evaluation of meloxicam (A cox-2 inhibitor) for management of postoperative endodontic pain: a double-blind placebo-controlled study. *J Endod*. 2003;29(10):634–7.
 10. Harrison JW, Baumgartner JC, Svec TA. Incidence of pain associated with clinical factors during and after root canal therapy. Part 2. Postobturation pain. *J Endod*. 1983;9(10):434–8.
 11. Ali SG, Mulay S, Palekar A, Sejjal D, Joshi A, Gufran H. Prevalence of and factors affecting post-obturation pain following single visit root canal treatment in Indian population: A prospective, randomized clinical trial. *Contemp Clin Dent*. 2012;3(4):459–63.
 12. Al-Negrish ARS, Hababeh R. Flare up rate related to root canal treatment of asymptomatic pulpally necrotic central incisor teeth in patients attending a military hospital. *J Dent*. 2006;34(9):635–40.
 13. Arora M, Sangwan P, Tewari S, Duhan J. Effect of maintaining apical patency on endodontic pain in posterior teeth with pulp necrosis and apical periodontitis: a randomized controlled trial. *Int Endod J*. 2016;49(4):317–24.
 14. Junior JAC, Coelho MS, Kato AS, Vivacqua-Gomes N, Fontana CE, Rocha DGP, da, Silveira Bueno CE. The effect of foraminal enlargement of necrotic teeth with the reciproc system on postoperative pain: a prospective and randomized clinical trial. *Journal of endodontics* 2016, 42(1):8–11.
 15. ElMubarak AHH, Abu-bakr NH, Ibrahim YE. Postoperative pain in multiple-visit and single-visit root canal treatment. *J Endod*. 2010;36(1):36–9.
 16. Walton R, Fouad A. Endodontic interappointment flare-ups: a prospective study of incidence and related factors. *J Endod*. 1992;18(4):172–7.
 17. García-Font M, Duran-Sindreu F, Calvo C, Basilio J, Abella F, Ali A, Roig M, Olivieri J-G. Comparison of postoperative pain after root canal treatment using reciprocating instruments based on operator's experience: A prospective clinical study. *J Clin experimental dentistry*. 2017;9(7):e869.
 18. Nagendrababu V, Gutmann JL. Factors associated with postobturation pain following single-visit nonsurgical root canal treatment: A systematic review. *Quintessence Int* 2017, 48(3):193–208.
 19. Magar Sr SS, Alfayyadh AY, Alruwaili KK, Almunahi HFF, Alsharari AHL, Magar SP, Almunahi HFF, Alsharari AH, Magar S. The determination of flare-up incidence and associated risk factors during endodontic treatment: an observational retrospective study. *Cureus*. 2022;14(11):e31424.
 20. Demenech LS, de Freitas JV, Tomazinho FSF, Baratto-Filho F, Gabardo MCL. Postoperative pain after endodontic treatment under irrigation with 8.25% sodium hypochlorite and other solutions: a randomized clinical trial. *J Endod*. 2021;47(5):696–704.
 21. Mostafa M, El-Shrief Y, Anous W, Hassan M, Salamah F, El Boghdadi R, El-Bayoumi M, Seyam R, Abd-El-Kader K, Amin S. Postoperative pain following endodontic irrigation using 1.3% versus 5.25% sodium hypochlorite in mandibular molars with necrotic pulps: a randomized double-blind clinical trial. *Int Endod J*. 2020;53(2):154–66.
 22. Segura-Egea JJ, Cisneros-Cabello R, Llamas-Carreras JM, Velasco-Ortega E. Pain associated with root canal treatment. *Int Endod J*. 2009;42(7):614–20.
 23. Arias A, De la Macorra J, Hidalgo J, Azabal M. Predictive models of pain following root canal treatment: a prospective clinical study. *Int Endod J*. 2013;46(8):784–93.
 24. AAE Consensus Conference Recommended Diagnostic Terminology. *Journal of Endodontics*. 2009, 35(12):1634.
 25. Huang D, Wang X, Liang J, Ling J, Bian Z, Yu Q, Hou B, Chen X, Li J, Ye L. Expert consensus on difficulty assessment of endodontic therapy. *Int J Oral Sci*. 2024;16(1):22.
 26. Chung SH, Chang J. Impact of endodontic case difficulty on operating time of single visit nonsurgical endodontic treatment under general anesthesia. *BMC Oral Health*. 2021;21:1–8.
 27. Ng YL, Glennon J, Setchell D, Gulabivala K. Prevalence of and factors affecting post-obturation pain in patients undergoing root canal treatment. *Int Endod J*. 2004;37(6):381–91.
 28. Fezai H, Al-Salehi S. The relationship between endodontic case complexity and treatment outcomes. *J Dent*. 2019;85:88–92.
 29. Haug SR, Solfeld AF, Ranheim LE, Bårdsen A. Impact of case difficulty on endodontic mishaps in an undergraduate student clinic. *J Endod*. 2018;44(7):1088–95.
 30. Ungerechts C, Bårdsen A, Frisstad I. Instrument fracture in root canals—where, why, when and what? A study from a student clinic. *Int Endod J*. 2014;47(2):183–90.
 31. Pesonen R, Tanner T, Käkilehto T, Oikarinen-Juusola K, Laitala M-L, Anttonen V. Usefulness of an endodontic case difficulty assessment form of root canal treatments in dental education in Finland. *Dentistry J*. 2021;9(10):118.
 32. Dzankovic A, Korac S, Tahmiscija I, Hadziabdic N. Endodontic Challenges Arising from Root Canal Morphology. 2024.
 33. Dechouniotis G, Petridis XM, Georgopoulou MK. Influence of specialty training and experience on endodontic decision making. *J Endod*. 2010;36(7):1130–4.
 34. McCaul L, McHugh S, Saunders W. The influence of specialty training and experience on decision making in endodontic diagnosis and treatment planning. *Int Endod J*. 2001;34(8):594–606.
 35. Alsulaimani RS, Al-Manei KK, Alsubait SA, AlAqeely RS, Al-Shehri SA, Al-Madi EM. Effects of clinical training and case difficulty on the radiographic quality of root canal fillings performed by dental students in Saudi Arabia. *Iran Endodontic J*. 2015;10(4):268.
 36. Tang L, Sun Tq G, Xj Z, Xd H, Dm. Tooth anatomy risk factors influencing root canal working length accessibility. *Int J Oral Sci*. 2011;3(3):135–40.
 37. Chugal NM, Clive JM, Spångberg LS. Endodontic infection: some biologic and treatment factors associated with outcome. *Oral Surg Oral Med Oral Pathol Oral Radiol Endodontology*. 2003;96(1):81–90.
 38. Buchanan L. Management of the curved root canal. *J Calif Dent Assoc*. 1989;17:18–25.
 39. Wolcott S, Wolcott J, Ishley D, Kennedy W, Johnson S, Minnich S, Meyers J. Separation incidence of protaper rotary instruments: a large cohort clinical evaluation. *J Endod*. 2006;32(12):1139–41.
 40. Lambrianidis T. Ledging and blockage of root canals during canal preparation: causes, recognition, prevention, management, and outcomes. *Endodontic Top*. 2006;15(1):56–74.
 41. Tsesis I, Faivishevsky V, Fuss Z, Zukerman O. Flare-ups after endodontic treatment: a meta-analysis of literature. *J Endod*. 2008;34(10):1177–81.
 42. Hepsenoglu YE, Eyuboglu TF, Özcan M. Postoperative pain intensity after single-versus two-visit nonsurgical endodontic retreatment: a randomized clinical trial. *J Endod*. 2018;44(9):1339–46.
 43. Basrani B, Tjäderhane L, Santos JM, Pascon E, Grad H, Lawrence HP, Friedman S. Efficacy of chlorhexidine and calcium hydroxide-containing medicaments against *Enterococcus faecalis* in vitro. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2003;96(5):618–24.
 44. Aslan T, Dönmez Özkan H. The effect of two calcium silicate-based and one epoxy resin-based root canal sealer on postoperative pain: a randomized controlled trial. *Int Endod J*. 2021;54(2):190–7.
 45. Glennon J, Ng YL, Setchell D, Gulabivala K. Prevalence of and factors affecting postpreparation pain in patients undergoing two-visit root canal treatment. *Int Endod J*. 2004;37(1):29–37.
 46. Oginni AO, Udoye CI. Endodontic flare-ups: comparison of incidence between single and multiple visit procedures in patients attending a Nigerian teaching hospital. *BMC Oral Health*. 2004;4:1–6.
 47. Polycarpou N, Ng YL, Canavan D, Moles D, Gulabivala K. Prevalence of persistent pain after endodontic treatment and factors affecting its occurrence in cases with complete radiographic healing. *Int Endod J*. 2005;38(3):169–78.
 48. Ali A, Olivieri JG, Duran-Sindreu F, Abella F, Roig M, García-Font M. Influence of preoperative pain intensity on postoperative pain after root canal treatment: A prospective clinical study. *J Dent*. 2016;45:39–42.
 49. Saini H, Sangwan P, Sangwan A. Pain following foraminal enlargement in mandibular molars with necrosis and apical periodontitis: a randomized controlled trial. *Int Endod J*. 2016;49(12):1116–23.
 50. Siqueira JF Jr. Microbial causes of endodontic flare-ups. *Int Endod J*. 2003;36(7):453–63.
 51. Muthukrishnan A, Owens J, Bryant S, Dummer P. Evaluation of a system for grading the complexity of root canal treatment. *Br Dent J*. 2007;202(10):E26–26.
 52. Wong AW-Y, Zhang S, Li SK-Y, Zhu X, Zhang C, Chu C-H. Incidence of post-obturation pain after single-visit versus multiple-visit non-surgical endodontic treatments. *BMC Oral Health*. 2015;15:1–11.

53. Desjardins P, Cooper S. Peripherally acting analgesics and antipyretics. *Pharmacology and Therapeutics for Dentistry St Louis, MO: Mosby-Year Book* 1998;281–296.
54. Gatchel RJ, Peng YB, Peters ML, Fuchs PN, Turk DC. The biopsychosocial approach to chronic pain: scientific advances and future directions. *Psychol Bull.* 2007;133(4):581.
55. Shah P, Duncan H, Abdullah D, Tomson P, Murray G, Friend T, Thomas S, Butcher S, Chong B. Comparison of two case difficulty assessment methods on cohorts of undergraduate dental students—A multi-centre study. *Int Endod J.* 2020;53(11):1569–80.
56. Fox K, Jarad F, Baaij A. The use of coaching to enhance students' learning, self-efficacy and performance in endodontics. *Int Endod J* 2025. Online ahead of print.
57. Shah P, Chong B. A web-based endodontic case difficulty assessment tool. *Clin Oral Invest.* 2018;22:2381–8.

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.