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Evaluation of Occupational Stress in Endodontics Using Smartwatch Technology

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Abstract

Occupational stress in dentistry, particularly during endodontic procedures, impacts practitioners' health and performance. This study introduces a novel approach using real-time Heart Rate (HR) data from Apple Watch technology to assess physiological responses potentially indicative of occupational stress among endodontists. Materials and Methods: Twelve endodontists participated in this study, treating 119 patients. In a controlled clinical environment, HR was continuously monitored with the Apple Watch, and data were recorded via the Cardiogram app, capturing HR variations across treatment stages. Results: Significant HR fluctuations were observed during procedurally demanding stages such as local anesthesia and rubber dam placement. The endodontist's HR, as a physiological proxy for stress, was significantly influenced by the treatment difficulty level, stage, and the patient's age. Conclusions: Using Apple Watch technology, our study revealed significant HR variations during different endodontic treatment stages, suggesting fluctuating physiological responses that may reflect occupational stress. Elevated HR was noted during patient examination and rubber dam placement, particularly in complex cases. These preliminary findings suggest that HR monitoring via wearable technology may serve as a useful, albeit indirect, indicator of occupational stress during endodontic procedures. Future studies with larger samples and additional validated stress biomarkers are needed to confirm these observations.

Keywords: occupational stress; endodontics; heart rate; Apple Watch; smartwatch; wearable technology; root canal treatment; physiological stress

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1. Introduction

In today's fast-paced world of modern dentistry, stress poses a common challenge that impacts the lives and careers of practitioners globally [1–4]. The modern concept of stress, as we know it today, originated from Hans Selye's research in the 1950s, where he distinguished between stressors and the conditions they induce [5,6]. According to Selye, stress is a syndrome marked by co-occurring symptoms or signs that trigger a heightened state within the system. This response leads to resilience and, eventually, exhaustion when faced with demands or environmental stimuli that challenge the organism's balance [5,6].

Over time, stress has evolved from being perceived merely as a personal concern to being recognized as a significant societal and workplace issue that affects individuals across various demographics, including gender, nationality, education, and occupation [1,7–9]. Healthcare providers have specifically emphasized the widespread nature of stress, with work-related stress estimated to impact at least a third of the workforce [3]. Stress-related factors are recognized for their role in influencing the development of numerous diseases, contributing to lifestyle-related illnesses that account for at least half of all premature deaths [1–3,10]. Dentists, in particular, face multiple stressors during their practice, which can compromise their health [4]. These stressors stem from dental procedures, office management, patient-dentist relationships, and interactions with assistants. Research indicates that general practice dentists may experience higher levels of physical and mental health challenges than other health professionals [2,4,8,10]. According to the National Institute for Occupational Safety and Health (NIOSH), there were approximately 27,000 suicides among the working-age population in the United States in 2005, equating to a rate of 13.54 per 100,000 individuals. This statistic positions suicide as one of the top five causes of death within this demographic [11]. Between 2003 and 2021, the percentage of dentists experiencing significant anxiety daily more than tripled, as reported by the ADA [12]. Among the ten dentists surveyed, eight personally knew another dentist who had died by suicide [12]. Multiple studies have demonstrated that stress adversely affects decision-making and cardiovascular and autonomic nervous system function [13].

Among dental treatments, endodontic procedures frequently induce occupational stress among dentists, dental students, and even endodontists [14]. Occupational stress in endodontic treatments can stem from several factors, such as limited direct visibility of the working area and the anatomical variability and complexity of the root canal system, endodontic complications (such as broken instruments, sodium hypochlorite accidents, perforations, and ledges), and challenges in managing patient behavior [15–19].

Previous studies on dental stress were primarily conducted using questionnaires [1,8,14,17,20,21]. Questionnaire studies on stress, though valuable for efficiently gathering large amounts of data, often encounter several limitations. These studies can be vulnerable to response bias, as participants may not accurately recall or might underreport their stress levels due to social desirability or a lack of self-awareness [22,23]. While efficient for data collection, questionnaires may oversimplify the dynamic nature of stress and fail to capture all relevant factors, potentially resulting in incomplete findings. Therefore, their results should be interpreted cautiously and complemented with other research methods for a holistic understanding of stress [22,23]. Vital signs, neural activity (EEG), electrocardiogram (ECG), skin temperature, and skin conductance response (electrodermal activity) offer crucial insights into an individual's health status [24]. However, a significant challenge lies in making this health information more accessible outside clinical settings. Advances in the technology and accessibility of health-related wearable devices have grown dramatically over the last decade [25], making it easier for nonpatient populations to monitor physiological measurements such as Heart Rate (HR) [26]. Some of the most popular wearable devices are watch-like devices that provide reliable HR estimates derived from wrist-pulse signals [25,27,28].

Most devices, including the Apple Watch, use photoplethysmography (PPG) technology. This method involves a light source shining onto the skin and a photodetector measuring the intensity of the reflected light. HR estimates are obtained from pulsatile changes in this reflected light, which result from variations in blood flow with each heartbeat [25,29]. Previous studies have validated the use of HR assessment via Apple Watch for monitoring stress [25,27,29], even in extreme environmental conditions such as cold and heat stress situations [30,31].

To date, no study has evaluated stress levels during endodontic treatment using wearable technology. This study aims to assess endodontists' stress levels throughout various stages of endodontic procedures using an Apple Watch.

2. Materials and Methods

This observational study was reported in accordance with the Preferred Reporting Items for Observational Studies in Endodontics (PROBE) 2023 guidelines [32]. The study was prospectively registered at ClinicalTrials.gov (Protocol Registration and Results System [PRS]; Identifier: NCT07498348). The study protocol was reviewed and approved by the Institutional Review Board (IRB) of the University of Illinois Chicago (UIC), Office for the Protection of Research Subjects (Approval No. STUDY2026-0077). All participating endodontists provided written informed consent prior to enrollment. Patient consent was obtained in accordance with the approved IRB protocol, using IRB-stamped consent forms.

2.1. Study Population

The study population consisted of endodontists who met specific inclusion criteria: they were classified as ASA 1 or ASA 2 [33], and they treated patients also categorized as ASA 1 or ASA 2. Eligible participants performed primary root canal treatment (RCT) or previously initiated therapy. Dentists with cardiovascular disease (CVD), those on beta-blocker medication, and those undergoing surgical treatment were excluded from the study. Clinicians with a known history of anxiety disorders, depression, or other psychiatric conditions were additionally excluded, as such conditions and their pharmacological treatments may independently affect HR measurements. The treating dentist evaluated the treatment difficulty level according to the AAE Endodontic Case Difficulty Assessment Form and Guidelines [34]. A score between 1 and 10 was assigned and subjectively evaluated by the dentist, with 1 indicating minimal difficulty and 10 indicating high difficulty. For analytical purposes, cases with a score of 1–5 were categorized as low difficulty, and cases with a score of 6–10 were categorized as high difficulty. Regarding patient age, patients under 18 years were classified as pediatric patients, and those aged 18 or older were classified as adult patients.

2.2. Data Registration and Acquisition

The endodontists were each provided with an individual Apple Watch Series 9 (Apple, Cupertino, CA, USA), with one dedicated device per clinician used throughout the study period, two hours before the commencement of their shift. They were instructed to wear it continuously throughout their entire shift. To ensure continuous HR monitoring, the participant launched the "Tai Chi" workout on Apple Watch and kept it active throughout the procedure. Subsequently, data were collected using the Cardiogram app (San Francisco, CA, USA; Ver. 3.7.29), downloaded from the App Store. The collected data were extracted to a CSV file using an Apple iPhone (Apple, Cupertino, CA, USA). For each treatment, a standardized form was completed, including the treatment stages and parameters that may influence stress levels during endodontic treatment. These factors include the type of treatment (primary RCT or previously initiated therapy), the difficulty level of the treatment, the patient's age, the endodontist's age and gender, and the endodontist's Perceived Stress Questionnaire (PSQ) score. All procedures were performed by board-certified endodontists under magnification (dental loupes or dental operating microscope), with dental assistance, using rotary instrumentation systems. Clinicians were aware of the study purpose, but were not informed of the specific hypotheses being tested, and the data recording was performed by the researcher rather than the clinicians, minimizing performance bias.

Each treatment procedure was defined according to the following stages, established a priori by the research team before data collection: (1) Patient presentation, from the moment the patient entered the treatment room until the start of the examination; (2) Patient examination, including both clinical and radiographic assessments; (3) Informed consent; (4) Local anesthesia administration; (5) Rubber dam placement; (6) Access cavity preparation and identification of root canal orifices; (7) Root canal preparation; (8) Obturation; and (9) Final X-ray. The start and end times of each stage were documented in real time by the attending researcher, who was present throughout all procedures. Complications during treatment were recorded, including abnormal patient reactions, perforations, separated instruments, pain, bleeding, and saliva leakage. HR sampling was recorded continuously at approximately 5 s intervals by the Apple Watch during the "Tai Chi" workout mode, and individual HR readings were assigned to the corresponding treatment stage based on the recorded timestamps.

We used the Perceived Stress Questionnaire (PSQ) to assess the endodontist's mental stress profile, to validate the HR and stress monitor app, and to determine whether baseline stress levels affect HR during root canal treatments [35]. The researcher was present at the clinic before the treatment, ensuring the endodontist completed the PSQ. Additionally, the researcher measured HR by recording resting rates 30 min before treatment and documenting HR at different stages of the procedure, noting the start and end times for each stage.

The participating endodontists completed the PSQ twice: on the day they began participating in the research and at the end of the research. The dentists answered questions on a scale of 1 ("rarely") to 4 ("usually") to indicate how frequently they experience specific emotions related to stress. PSQ results are presented on a scale of 30 to 120 points, with all scores calculated by subtracting 30 from the raw score and dividing it by 90. The PSQ score ranges from 0 to 1, where 0 represents the lowest level of perceived stress and 1 the highest [35].

2.3. Statistical Analysis

Statistical analysis was performed using multi-level modeling to account for the nested structure of time, patient characteristics, RCT difficulty, and changes in stress levels. Normality of the HR data was assessed using the Shapiro–Wilk test and visual inspection of Q-Q plots. Given the large number of repeated HR measurements per participant and the confirmed approximate normality of the continuous HR outcome within the mixed-effects modeling framework, Pearson correlation was deemed appropriate for assessing linear associations involving HR. For the non-parametric PSQ scores, a Wilcoxon signed-rank test was applied. No corrections for multiple comparisons were applied in this exploratory study, though this limitation is acknowledged. A one-way ANOVA was used to compare HR levels by treatment type and difficulty, and Pearson correlation assessed the relationship between education and HR. Mixed-effects models evaluated the effect of treatment stage on HR, accounting for individual differences in baseline HR and other factors. We used mixed-effects models to assess how treatment stage was moderated by both difficulty level and patient age (<18, 18+). A Wilcoxon test was used to compare PSQ scores between two measurement points. Statistical significance was set at 0.05. The initial sample size was calculated assuming a 5% significance level, 80% power, and a moderate effect size, requiring a minimum of 40 treatments. Results are reported as means ± standard deviation (SD) for continuous normally distributed variables, and as medians with interquartile ranges for non-parametric data.

3. Results

3.1. Study Sample and Descriptive Statistics

A total of 12 endodontists (3 male, 9 female) provided treatment for 119 patients, comprising 35 individuals under 18 years of age and 84 individuals aged 18 years or older. Across all clinical procedures, the practitioners' HR ranged from 54 to 144 beats per minute (bpm), with a mean HR of 81.87 ± 10.26 bpm and a median of 81.00 bpm. Overall HR variations corresponding to each treatment stage are presented in Figure 1. All root canal treatments were completed in a single visit. No complications were noted during treatment.

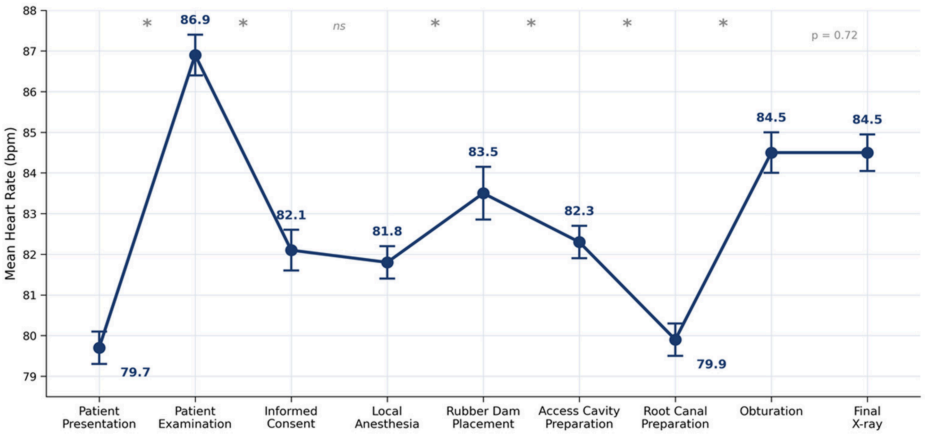


Figure 1. Mean Practitioner Heart Rate Across Endodontic Treatment Stages with Consecutive Pairwise Comparisons. Mean practitioner heart rate (bpm) recorded at each of the nine standardized endodontic treatment stages: (1) Patient Presentation, (2) Patient Examination, (3) Informed Consent, (4) Local Anesthesia, (5) Rubber Dam Placement, (6) Access Cavity Preparation, (7) Root Canal Preparation, (8) Obturation, (9) Final X-ray. Data represent means ± 95% confidence intervals (error bars and shaded band; n = 119 treatments, 12 endodontists). Significance brackets above the line indicate consecutive pairwise comparisons (Wilcoxon signed-rank test): * $p < 0.001$; ns = not significant. A statistically significant overall negative linear trend across stages was identified (mixed-effects model, $p = 0.02$).

3.2. Heart Rate Fluctuations Across Treatment Stages

A significant negative association was identified between the overall progression of the treatment stage and practitioner HR ($p < 0.001$), indicating a general trend of decreasing HR as the procedure advanced. However, analysis of consecutive treatment stages revealed significant fluctuations (Figure 1). A significant increase in HR was recorded during the transition from the patient presentation stage to the initial examination ($p < 0.001$). This was followed by a significant decrease during the informed consent phase ($p < 0.001$). HR significantly spiked again during rubber dam placement ($p < 0.001$). Subsequently, HR significantly decreased during access cavity preparation and the identification of root canal orifices ($p < 0.001$), a trend that continued through the root canal preparation phase ($p < 0.001$). Finally, an increase in HR was observed during the obturation phase, which then stabilized with no significant changes during the final radiographic evaluation ($p = 0.721$).

3.3. Influence of Case Difficulty and Interaction Effects

A significant positive relationship was found between the clinical difficulty level and practitioner HR ($p < 0.001$), demonstrating that more complex cases elicit higher physiological stress responses (Figure 2). Furthermore, a significant interaction between the treatment stage and case difficulty was observed ($p < 0.001$). While both variables independently influenced HR, the impact of specific treatment stages on HR was amplified as case difficulty increased. Generally, high-difficulty treatments were associated with

higher HRs across almost all stages ($p < 0.001$). Notably, an exception occurred during the root canal preparation phase, in which higher HRs were recorded during low-difficulty treatments than during high-difficulty treatments ($p < 0.001$).

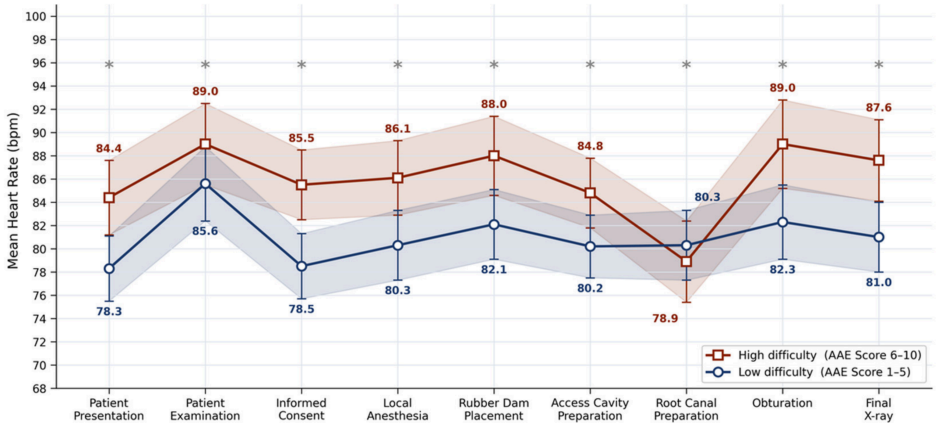


Figure 2. Practitioner Heart Rate by Treatment Stage, Stratified by Case Difficulty. Mean practitioner heart rate (bpm) at each treatment stage, stratified by case difficulty: High difficulty (AAE Score 6–10; red) and Low difficulty (AAE Score 1–5; blue). Data represent means ± 95% CI (error bars and shaded bands). Significance brackets at each stage indicate between-group comparisons (Mann–Whitney U test): * $p < 0.001$ at all stages. High-difficulty cases were associated with significantly elevated practitioner HR across all nine stages. An inversion was observed at Stage 7 (Root Canal Preparation), where Low-difficulty cases showed marginally higher HR than High-difficulty cases (78.9 vs. 80.3 bpm), likely reflecting practitioner desensitization during technically routine canal preparation in more complex cases.

3.4. Patient Demographics and Perceived Practitioner Stress

Patient age demonstrated a significant positive correlation with practitioner HR ($p = 0.009$), indicating that treating older patients was associated with an elevated physiological stress response (Figure 3). Regarding subjective stress assessments, among the 12 participating endodontists, seven reported an increase in Perceived Stress Questionnaire (PSQ) scores, and five reported a decrease. The overall mean change in PSQ scores was 2.7%; however, this difference was not statistically significant ($p = 0.891$).

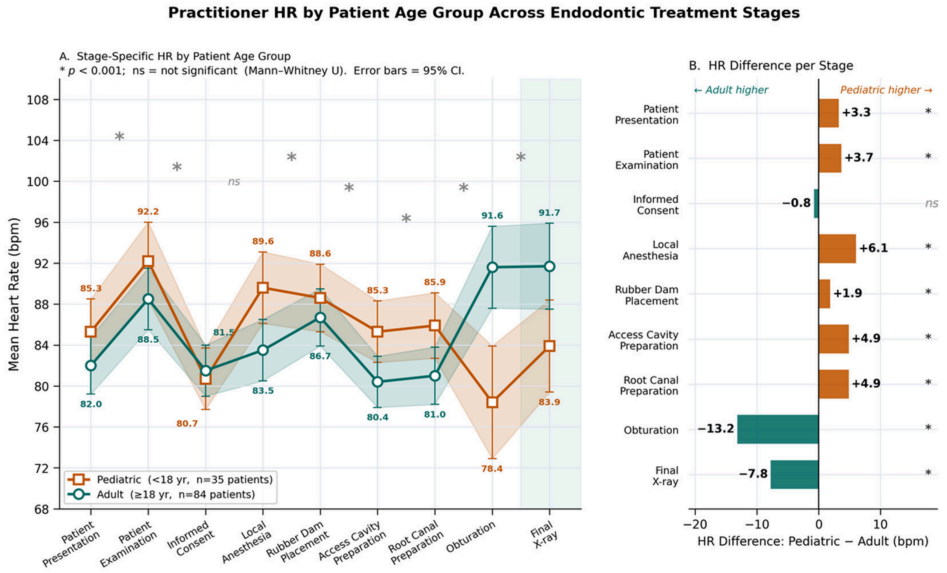


Figure 3. Practitioner Heart Rate by Patient Age Group Across Endodontic Treatment Stages. Panel (**A**): Mean practitioner HR (bpm) at each treatment stage, stratified by patient age group: Pediatric

(age < 18 years, n = 35 patients; orange) and Adult (age ≥ 18 years, n = 68 patients; teal). Error bars and shaded bands represent 95% CI. Significance markers above each stage indicate between-group comparisons (Mann–Whitney U test, two-sided): * $p < 0.001$; ns = not significant. The shaded green region highlights the crossover at stages 8–9, where adult practitioner HR significantly exceeded pediatric HR. Panel (**B**): HR difference (Pediatric − Adult, bpm) per stage. Orange bars indicate stages where pediatric patient treatment was associated with higher practitioner HR; teal bars indicate stages where adult treatment was associated with higher HR. Significance markers are shown to the right of each bar (Mann–Whitney U test): * $p < 0.001$; ns = not significant.

4. Discussion

Stress has emerged as a widespread health risk in dentistry, greatly affecting the well-being and performance of dental professionals [1,2,13,14,36]. Previous studies [14,36–39] have assessed the impact of dental treatment on dentists' stress levels, but most relied on questionnaires or interviews. A systematic review [40] examining the impact of stress on dentists' clinical performance identified a gap in the literature, noting a lack of empirical evidence quantifying this impact. In the present study, we utilized a wearable device (Apple Watch) to objectively monitor HR throughout endodontic procedures. To our knowledge, this is the first study to examine the relationship between occupational stress-related physiological changes and HR in endodontics or any other dental specialty using wearable technology. Recent studies have validated the use of HR assessment via Apple Watch for stress monitoring [25,27–29,41,42] and demonstrated that wearable devices are effective in quantifying occupational stress. The population was selected according to categories of the American Society of Anesthesiologists Classification, and we included only patients with ASA I (normal and healthy) and ASA II (mild to moderate systemic disease). Patients classified as ASA III or above require a stress reduction protocol and other treatment modifications when dental treatment is indicated [43]. Endodontists with a history of cardiac or psychiatric conditions, including those taking beta-blocker medications, were excluded to minimize confounding effects on HR measurements [44–46]. Apple Watch HR measurements have been previously validated and demonstrated good reliability during both relaxation and mental stress conditions in healthy individuals [25]. It was also found that the physiological stress response was associated with a unique autonomic nervous system profile, as measured using the Apple Watch [47].

Our results reveal that HR changes were observed at different stages of the RCT. A significant rise in HR was observed during the examination and informed consent phases, particularly in complex cases (Figure 2). This increase can be attributed to the need for the clinician to explain potential complications, such as file separation, perforations, and possible treatment failure, during these stages [48–50]. These discussions likely contribute to increased stress and anxiety for both the patient and the clinician, resulting in elevated HR levels. The local anesthetic injection is a common stressor for many dentists [51], and it is often accompanied by various complications that require careful consideration in dental practice [18,19,21]. In our study, we observed an increase in HR during placement of the rubber dam, consistent with prior research [52]. Dentists might feel uncomfortable during rubber dam placement due to negative patient reactions [53]. Some patients may have never encountered a rubber dam before and may feel apprehensive or resistant to its use [53–55], which can create a challenging environment for the dentist and potentially increase stress during this stage of treatment.

Local anesthesia is crucial for effective endodontic treatment [56]. Ensuring that patients do not experience pain during the procedure is both an ethical obligation and a crucial element of high-quality care [56,57]. However, local anesthesia can also be associated with complications, such as nerve injury and altered sensation [58,59]. Many cases of nerve injury reported in endodontic treatments are associated with the use of local

anesthesia [60,61], which may contribute to elevated HR and increased stress for the dentist. These complications can add to the overall stress experienced during the treatment. During access cavity preparation, identification of root canal orifices, and root canal preparation, endodontic technical challenges may exist, e.g., complicated anatomy, dental anomalies, resorptions, iatrogenic errors, and previous endodontic interventions [62,63]. The challenges of navigating and managing these complexities may contribute to heightened stress during the procedure [64]. Stress-related complications can also occur during the obturation stage [63,65], including extrusion of root canal filling materials, mechanical damage, and decision-making regarding endodontic treatment in one or two visits [66,67].

Patients' stress levels may significantly affect the participating dentists' stress levels, thereby influencing the validity of HR levels measured during root canal treatments and compromising our conclusions [40]. Anxious and uncooperative patients are consistently ranked among the most significant occupational stressors by dental practitioners and have been shown to negatively impact clinician well-being and performance [68]. In this study, we observed that during the stages of root canal treatment (local anesthesia administration, rubber dam placement, root canal preparation, and obturation), HR was higher in younger patients (Figure 3). However, this difference was not statistically significant ($p > 0.05$). Conversely, the mean heart rate across all treatment stages was significantly higher in adult patients, contradicting the existing literature, which reports that pediatric dentistry practitioners report higher stress levels due to patient management [69,70]. To better understand these findings, we recommend conducting a larger study.

This study aims to pave the way for future research focused on evaluating stress-related factors during various dental procedures. Recognizing and understanding stressful circumstances in dental practice is crucial to effectively manage them and ensure optimal outcomes for both practitioners and patients. Future investigations should encompass a wider spectrum of endodontic treatments and their associated physiological demands, ultimately informing evidence-based stress management approaches in clinical dentistry.

Limitations

Several important limitations of this study should be acknowledged. First, the sample size was relatively small (n = 12 endodontists), which limits the statistical power and generalizability of the findings. Second, HR is an indirect and inherently nonspecific physiological parameter; elevated HR may result from factors other than procedural stress, including physical activity, caffeine or stimulant intake, fatigue, time of day, sleep quality, and general autonomic variability. As such, HR should not be interpreted as a direct measure of psychological stress, but rather as a physiological signal that may be associated with stress under controlled conditions. Third, motion-related artifacts may affect the accuracy of photoplethysmography-based HR measurements from the Apple Watch, particularly during manual procedural tasks. Fourth, patient-level variables—such as pain levels, anxiety, and specific clinical diagnoses—were not fully accounted for in the analysis and may represent important confounders of the observed HR changes. Fifth, pulp and periapical diagnoses (e.g., symptomatic irreversible pulpitis, pulp necrosis, symptomatic vs. asymptomatic apical periodontitis) were recorded but not analyzed as independent variables in the current study. As different diagnoses may substantially influence both patient behavior and operator stress levels, future studies should incorporate pulp and periapical status as a structured covariate in the analytical framework. Sixth, no correction for multiple comparisons was applied, given the exploratory nature of this study. Future research should address these limitations by enrolling larger and more diverse samples, incorporating additional validated biomarkers of stress (e.g., salivary cortisol, heart rate variability), controlling for a broader range of confounders, and employing validated

clinical ECG devices alongside wearable technology to further establish the accuracy of smartwatch-based HR monitoring in clinical dental settings.

5. Conclusions

Using Apple Watch technology, our study revealed significant HR variations during different endodontic treatment stages, suggesting fluctuating physiological responses that may reflect occupational stress levels. While a general trend of decreasing HR was observed as procedures progressed, significant pairwise HR increases were recorded at specific transitions: most notably at the onset of patient examination (transition from patient presentation to examination) and during rubber dam placement, consistent with these stages representing peaks of procedural demand, particularly in complex cases. These preliminary findings suggest that wearable technology may offer a practical and non-invasive tool for monitoring physiological responses during endodontic procedures; however, given the indirect nature of HR as a stress marker and the limitations of the current study, these results should be interpreted cautiously. Larger, controlled studies incorporating additional validated stress biomarkers are needed before definitive conclusions can be drawn.

Author Contributions: Conceptualization: E.S. and T.I.; Methodology: E.S. and T.I.; Software: R.D. and H.T.; Validation: T.I.; Formal analysis: R.D., H.T. and K.S.; Investigation: R.D. and H.T.; Data curation: R.D., H.T. and Z.N.; Writing—original draft: E.S.; Writing—review and editing: T.I.; Visualization: T.I.; Supervision: E.S., R.E. and T.I.; Project administration: S.H., R.E. and K.S. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was approved by the Institutional Review Board of the University of Illinois Chicago (Approval No. STUDY2026-0077) on 9 February 2026. The study was conducted in accordance with the Declaration of Helsinki.

Informed Consent Statement: Informed consent was obtained from all participants in accordance with the approved IRB protocol (STUDY2026-0077). IRB-stamped consent forms were used for both endodontist and patient participants.

Data Availability Statement: Data supporting reported results can be made available upon reasonable request.

Conflicts of Interest: Apple Inc. provided the Apple Watch devices used in this research. Apple Inc. was not involved in the study design, data collection, analysis, or interpretation, the writing of this article, or the decision to submit it for publication. The authors declare no other conflicts of interest.

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