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Sensitivity and specificity of pulp sensibility tests following traumatic dental injuries in permanent teeth: A one-year clinical study

Armita Rouhani[1], Hamed Karimi [1], Reza Shahmohammadi[2], Samuel Dorn[3], Hamid Jafarzadeh[1,3,4,5]*

Abstract

Objective: This study aimed to evaluate pulpal responses to sensibility tests after traumatic dental injuries and determine the sensitivity and specificity of these tests over time.

Methods: Twenty-one patients with 51 traumatized teeth were included. After excluding 12 teeth during follow-ups, 39 teeth remained for final assessment. Pulp sensibility responses (electric pulp test (EPT), cold test, and heat test) were recorded at the initial visit and two weeks, one month, two months, and 12 months post-injury. The sensitivity and specificity of the tests were calculated using the response of traumatized teeth in the 12-month follow-up as the reference standard.

Results: Lateral luxation was the most common injury. Among the 25 teeth with an initial negative response to sensibility tests, 4 concussions, 8 subluxations, 3 lateral luxation, 1 root fracture, and 1 uncomplicated crown fracture cases regained pulpal sensibility within one year. None of the immature teeth developed pulpal necrosis, whereas 7 out of 26 mature teeth did, primarily in lateral luxation cases. The specificity of the EPT increased from 0.47 on the first visit to 0.77 at two months and 0.83 at one year, with cold and heat tests showing similar trends. The sensitivity of cold and heat tests reached 1.0 at two months.

Conclusions: Sensibility tests improved over time in traumatized teeth, with 17 out of 25 initially non-responsive teeth recovering within a year. No immature teeth developed necrosis. The specificity of all sensibility tests reached 0.83 in 12 months, and cold/heat test sensitivity reached 1.0 at two months.

Keywords: Dental pulp test, Sensitivity and specificity, Tooth fracture, Tooth injuries, Tooth luxation, Trauma

Introduction

Dentoalveolar trauma is an urgent condition that is often accompanied by fear, pain, and esthetic concerns. Most of these injuries occur in 7–10-year-old children. The most frequent etiologic factors for dental trauma are collisions with people or objects, motor vehicle accidents, sports-related incidents, and physical violence (1). Beyond the immediate physical damage, dental trauma may lead to difficulties in speech, malocclusion, and psychological distress (2). Therefore, the prompt diagnosis and management of dentoalveolar trauma is of utmost importance.

Determining pulpal health is a critical aspect of clinical examination in patients with dental trauma. The routine methods for pulp testing are electric pulp testing and cold and heat stimulation (3, 4). However, sensibility tests assess only the neural response rather than the pulp vitality (5, 6). This might lead to false-positive and false-negative results, especially in traumatized teeth (7-9). Pulp vitality tests like pulse oximetry and laser Doppler flowmetry aim at assessing blood circulation within the pulp; therefore, they provide a more direct indication of pulp vitality after traumatic injuries (10). Nevertheless, the clinical application of pulp vitality tests remains limited, as they are expensive, time-consuming, and technique-sensitive (11, 12).

Following trauma, temporary paresthesia is common due to inflammation and pressure on the apical nerve bundles (10). Previous studies have shown that altered neurological responses may require nine months to recover fully (7, 13). Consequently, many have

[1] Department of Endodontics, Faculty of Dentistry, Mashhad University of Medical Sciences, Mashhad, Iran.
[2] School of Dentistry, McGill University, Montreal, Quebec, Canada.
[3] Department of Endodontics, School of Dentistry, West Virginia University, Morgantown, WV, USA.
[4] Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada.
[5] Dental Trauma Center, Academic Center for Education, Culture and Research, Mashhad, Iran.

*Corresponding Author: Hamid Jafarzadeh
Email: hamid_j365@yahoo.com & hj00016@mix.wvu.edu

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advocated a "watch-and-wait" approach, wherein root canal treatment is postponed unless definitive signs of necrosis (i.e., crown discoloration) emerge (14, 15).

Despite their limitations, pulpal sensibility tests remain the most frequently used tools for evaluating pulp vitality. The results from these tests act as an indirect indicator for pulp viability and serve as a baseline for future comparisons. This study aimed to evaluate pulpal responses to sensibility tests (thermal and electrical) and determine the sensitivity and specificity of each test at various time intervals following traumatic dental injuries.

Materials and methods

Study design and population

This single-center prospective clinical study included 21 patients who attended the dental trauma clinic at the Academic Center of Education, Culture, and Research (ACECR) in Mashhad, Iran. The patients were healthy and did not take any medications. Overall, 51 traumatized maxillary and mandibular anterior teeth showing any of the following traumatic injuries were included: crown infraction, uncomplicated crown fracture, crown-root fracture without pulp exposure, root fracture, concussion, subluxation, extrusive luxation, and lateral luxation. The exclusion criteria were a history of prior dental trauma, the presence of carious lesions, or clinical signs indicating pulp necrosis (e.g., sinus tract).

Data Collection

Before examination, each patient or his/her guardian completed a trauma assessment form. This form included the patient's general information (i.e., name, history of systemic diseases, date of referral, age, sex, and contact details), as well as specific trauma-related data, including tooth number, time and etiology of injury, time of attendance in the clinic, and type of trauma based on the International Association of Dental Traumatology (IADT) classification (16).

Etiologic factors were categorized into three groups: vehicle accidents, falls, and physical violence (i.e., fighting). Apex configuration was classified as either mature or immature. The attendance time was divided into four categories: immediately or within 24-48 hours, one week, or one month post-injury.

Clinical approach

The following clinical data regarding the pulpal status were collected at the initial visit and during subsequent appointments: tooth color, pulp sensibility responses, tenderness to percussion, and the existence of swelling or a sinus tract.

Sensibility tests (i.e., electric pulp test (EPT), cold and heat tests) were performed on all maxillary and mandibular anterior teeth, including traumatized and uninjured control teeth. After isolation with a cotton roll and air-drying, all the traumatized and control teeth were tested by a single operator using three methods with a one-minute interval between the tests (17, 18). Each test was performed twice, and a positive response was recorded if sensation was detected in either or both trials. A negative response was confirmed if no sensation was reported in both trials. The tests were done in the following order: EPT, cold test, and heat test.

An analog pulp tester (Parkell Inc., Edgewood, NY, USA) was used to conduct the electric test. The probe tip was lubricated with toothpaste and applied to the incisal edge or middle third of the buccal surface. The current gradually increased until the patient reported a tingling sensation or mild pain, indicating a positive response.

The cold test was performed using a refrigerant spray (FriscoSpray, Ad-arztbedarf GmbH, Frechen, Germany) which was sprayed on a cotton pellet and placed on the incisal edge or middle third of the buccal surface of the tooth. A heated ball-shaped burnisher was applied to the same tooth area as the cold test to perform the heat test. Thermal tests were conducted for up to 5 seconds, recording a positive response if the patient experienced mild pain.

Periapical (PA) radiographs were taken from the traumatized teeth at the initial and follow-up visits using a dental x-ray unit (Planmeca, Helsinki, Finland), with the following parameters: 8 mA, 70 kVp, and E-speed films (AGFA, Osaka, Japan). Two additional PAs with different vertical angulations were obtained in the case of suspected root fractures. The following radiographic findings were recorded in the patient’s form:

Root development stage, presence and type of root resorption, periapical lesions, and pulp canal calcifications. Based on the clinical and radiographic findings, a treatment plan and follow-up protocol were formulated by an experienced endodontist.

Follow-up sessions

Follow-up visits included repeated clinical and radiographic examinations and pulp sensibility testing.

Teeth were diagnosed necrotic if they exhibited sinus tract formation, coronal discoloration, radiographic evidence of periapical bone resorption or inflammatory external root resorption, or consistent negative

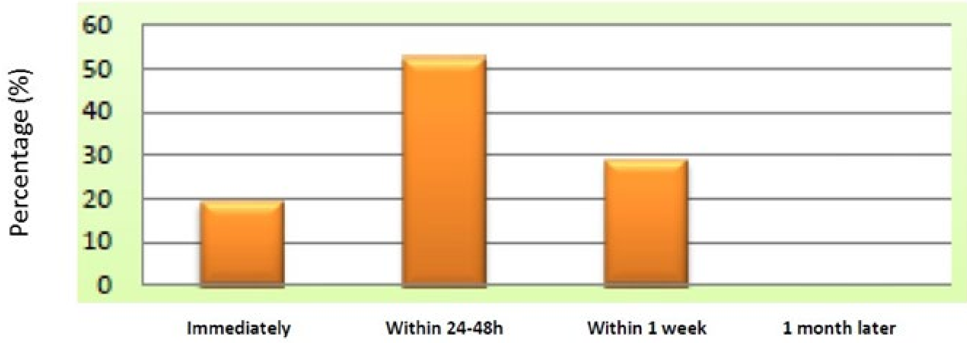

Figure 1. Patients' time of attendance following trauma

response to sensibility tests. Follow-up sessions were arranged in the following sequence: 2 weeks, 1 month, 2 months, and 12 months.

Statistical analysis

Sensibility test results were analyzed using SPSS Statistics for Windows (version 11.5; SPSS Inc., Chicago, IL, USA). The sensitivity and specificity of each test were calculated. Clinical observations and radiographic assessments of each tooth at the 12-month follow-up served as the reference standard to confirm the pulp diagnosis.

Results

A total of 21 patients (76% males, 24% females) with 51 traumatized teeth were included in this study. The mean age of patients was 17.82±11.54 years, ranging from 7 to 44 years. Maxillary teeth were affected more frequently than mandibular teeth (63% vs. 37%). Most patients (n=11) sought treatment within 24-48 hours post-trauma (Figure 1). Lateral luxation was the most common type of traumatic injury (Figure 2).

Of the 51 teeth initially included, 12 (24%) were excluded due to early root canal treatment (n=10) or missed follow-ups (n=2), leaving 39 teeth for final assessment (Table 1). The assessed teeth comprised 17 maxillary central incisors, 8 mandibular central incisors, 6 maxillary lateral incisors, 7 mandibular lateral incisors, and 1 mandibular canine, with maxillary teeth comprising 58.9% of the sample (Table 1). Thirteen teeth (33.3%) were immature, whereas 26 (66.7%) had mature roots. The primary etiologic factors were falling. (47.6%), vehicle accidents (28.6%), and physical violence (23.8%). The distribution of trauma types was as follows: subluxation (n=15), lateral luxation (n=13),

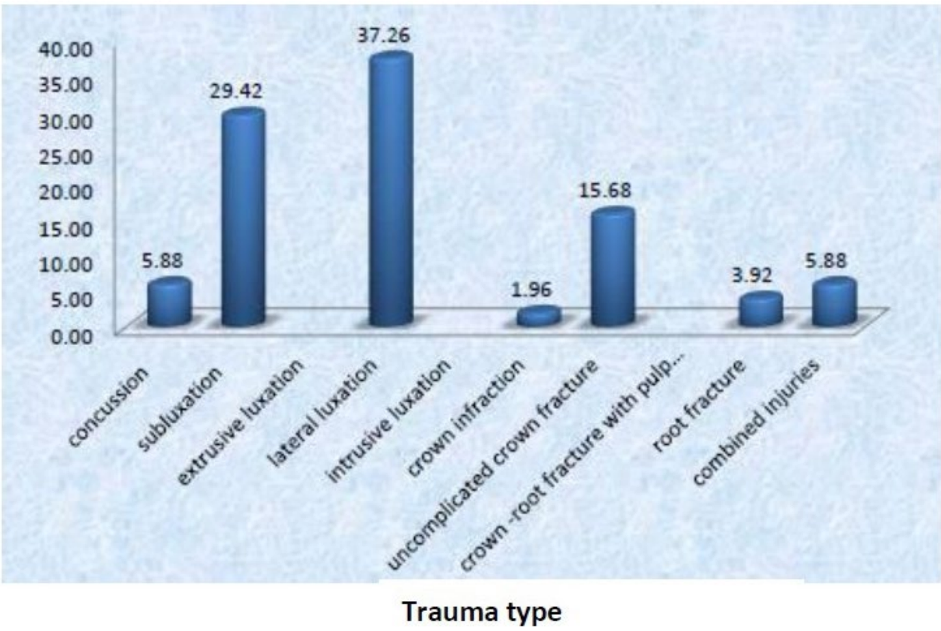

Figure 2. Frequency of each trauma type

Table 1. Final distribution of teeth based on apical maturation, type of trauma, and vitality status

Sample No.	Tooth No.	Age	Apical maturation	Type of injury	Initial response to sensibility tests	Final status	Final intervention
1	11	7	Immature	Concussion	Negative	Normal pulp	None
2	21	8	Immature	Concussion	Negative	Normal pulp	None
3	22	28	Mature	Concussion	Negative	Normal pulp	None
4	21	28	Mature	Concussion & UCF	Negative	Normal pulp	None
5	21	14	Mature	Subluxation	Negative	Irreversible pulpitis	RCT
6	12	14	Mature	Subluxation	Negative	Irreversible pulpitis	RCT
7	41	36	Mature	Subluxation	Positive	Normal pulp	None
8	32	30	Mature	Subluxation	Positive	Irreversible pulpitis	RCT
9	22	14	Mature	Subluxation	Negative	Normal pulp	None
10	21	13	Mature	Subluxation	Positive	Normal pulp	None
11	11	8	Immature	Subluxation	Negative	Normal pulp	None
12	41	8	Immature	Subluxation	Positive	Normal pulp	None
13	42	8	Immature	Subluxation	Negative	Normal pulp	None
14	31	8	Immature	Subluxation	Negative	Normal pulp	None
15	32	8	Immature	Subluxation	Negative	Normal pulp	None
16	32	22	Mature	Subluxation	Negative	Normal pulp	None
17	33	22	Mature	Subluxation	Negative	Normal pulp	None
18	41	22	Mature	Subluxation	Negative	Normal pulp	None
19	42	22	Mature	Subluxation	Positive	Normal pulp	None
20	11	36	Mature	Lateral luxation	Negative	Pulp necrosis	RCT
21	21	30	Mature	Lateral luxation	Negative	Pulp necrosis	RCT
22	11	8	Immature	Lateral luxation	Negative	Normal pulp	None
23	22	8	Immature	Lateral luxation	Negative	Normal pulp	None
24	12	8	Immature	Lateral luxation	Negative	Normal pulp	None
25	21	16	Mature	Lateral luxation	Negative	Pulp necrosis	RCT
26	41	9	Mature	Lateral luxation	Positive	Normal pulp	None
27	31	9	Mature	Lateral luxation	Positive	Normal pulp	None
28	42	9	Mature	Lateral luxation	Positive	Normal pulp	None
29	32	9	Mature	Lateral luxation	Positive	Normal pulp	None
30	11	44	Mature	Lateral luxation	Negative	Pulp necrosis	RCT
31	21	44	Mature	Lateral luxation	Negative	Pulp necrosis	RCT
32	12	44	Mature	Lateral luxation	Positive	Pulp necrosis	RCT
33	11	14	Mature	Root fracture	Negative	Pulp necrosis	RCT
34	21	25	Mature	Root fracture	Negative	Normal pulp	None
35	11	8	Immature	UCF	Positive	Irreversible pulpitis	RCT
36	21	7	Immature	UCF	Positive	Normal pulp	None
37	11	7	Immature	UCF	Negative	Normal pulp	None
38	41	20	Mature	UCF	Positive	Normal pulp	None
39	31	20	Mature	UCF	Positive	Normal pulp	None

UCF: Uncomplicated crown fracture; RCT: Root canal treatment

uncomplicated crown fracture (n=5), concussion (n=4), and root fracture (n=2).

Among the 25 teeth with an initial negative response to sensibility tests, 4 concussions, 8 subluxations, 3 lateral luxation, 1 root fracture, and 1 uncomplicated crown fracture cases regained pulpal sensibility within the first year. None of the immature teeth developed pulpal necrosis, while 7 out of 26 mature teeth did. Of these, 6 cases had lateral luxation injuries, and 1 had a root fracture. No cases of pulpal necrosis were observed in teeth with subluxation, concussion or uncomplicated crown fracture injuries.

The specificity of EPT was 0.47 at the first visit, increasing to 0.57 at two weeks, 0.64 at one month, 0.77 at two months, and 0.83 at 12 months. The specificity of the cold test followed a similar trend, rising from 0.56 at the initial visit to 0.83 at the 12-month follow-up. Likewise, the specificity of the heat test increased from

0.66 at the first visit to 0.83 at 12 months. The sensitivity of EPT, cold, and heat tests at the first appointment was 0.63, 0.75, and 0.88, respectively, reaching 0.5 (EPT), 1 (cold test), and 1 (heat test) at two months (Table 2).

Discussion

According to the outcomes of this study, an initial negative response to pulp sensibility tests did not necessarily result in pulpal necrosis. Among teeth with negative results, 17 out of 25 (68%) regained sensibility at the end of the first year. Numerous studies have discussed the time required for pulpal tissue to respond to sensibility tests post-trauma. Some studies indicated that adequate recovery of nerve bundles typically occurs within 4 to 6 weeks (19,20), while other studies reported recovery periods extending up to 1-2 years (19, 21, 22). Gopikrishna et al. (7) found that 94.1% of recently traumatized teeth regained responsiveness to thermal tests and EPT within three months. These data highlight the transient nature of pulpal non-responsiveness and emphasize the limitations of pulp sensibility tests in accurately detecting pulp vitality in the immediate post-trauma phase. Moreover, certain systemic conditions have been shown to influence sensibility test results (23). Therefore, many experts recommend a “watch-and-wait” approach to monitor for signs of necrosis before initiating endodontic intervention (8, 14, 15).

The specificity of EPT was initially lower than that of thermal tests, but it improved over time, reaching 0.77 at two months and 0.83 at 12 months. Similarly, the specificity of cold and heat tests increased over the follow-up periods. This suggests that sensibility tests become more reliable in assessing pulpal health after two months.

Previous studies have reported that EPT is generally more effective in identifying vital rather than necrotic pulp (7, 24, 25). Chen et al. (12) reported that EPT correctly identified healthy pulps in 98% of cases, a result potentially influenced by the exclusion of immature teeth. However, the present study included immature teeth, which may have contributed to the lower specificity values obtained in the findings.

Regarding sensitivity, thermal tests demonstrated a significant increase over time, reaching 1.0 at two months, whereas EPT did not attain this level of detection. As the sensitivity of thermal tests reached 1.0 at two months, no additional data were needed from that point onward, and thus the sensitivity test was not repeated at 12 months. The findings of this study contrast with those of another study (26), which reported that the sensitivity of heat, cold, and EPT increased substantially over two years, ultimately identifying EPT as the most accurate test. However, that study had the advantage of a larger sample size (121 teeth) and a more extended follow-up period, which may justify the differences in results.

Interestingly, the sensitivity of the heat test was highest during the first visit, which contrasts with existing evidence suggesting that heat tests typically exhibit low accuracy (27, 33). This discrepancy may arise from differences in study methodologies, including variations in patients' pain perception or the techniques used for administering the test. Previous studies commonly employed frictional heat generated by a rubber cup, which could be uncomfortable for traumatized patients (28, 33). In contrast, the present study used a heated burnisher, a method that is less distressing for traumatized patients. To better understand the sensitivity of heat tests at initial and follow-up visits, well-designed studies with larger sample sizes are necessary.

In the present study, none of the teeth with subluxation, concussion or uncomplicated crown fracture injuries developed pulpal necrosis, although three subluxation cases and one case of uncomplicated crown fracture required endodontic treatment due to irreversible pulpitis. Andreasen et al. (21) highlighted that the risk of pulpal necrosis is linked to the extent of

Table 2. Specificity and sensitivity of EPT, cold test, and heat test

Follow-up	Sensitivity			Specificity		
	EPT	Cold	Heat	EPT	Cold	Heat
1st visit	0.63	0.75	0.88	0.47	0.56	0.66
2 weeks	0.75	0.75	0.75	0.57	0.56	0.56
1 month	0.57	0.86	0.86	0.64	0.48	0.44
2 months	0.5	1	1	0.77	0.89	0.77
12 months	-	-	-	0.83	0.83	0.83

injury, with intrusion and lateral luxation carrying the highest risk. Moreover, the transition from a negative to a positive response was primarily observed in minor injuries without displacement (i.e., concussion and subluxation). In contrast, more extensive trauma, such as lateral luxation, frequently resulted in pulpal necrosis. The present study also found that teeth with subluxation and concussion injuries regained sensibility over time, while lateral luxation was more frequently associated with pulpal necrosis. Other studies reported similar findings (26, 27), indicating that temporary nerve bundle damage may be responsible for these changes in pulpal response. These consistent observations support the hypothesis that minor injuries permit neural recovery, while more severe trauma is more likely to result in irreversible pulp damage.

Regardless of trauma type, none of the immature teeth in this study developed pulpal necrosis, whereas 7 out of 26 mature teeth did. This could be attributed to the superior revascularization capacity of immature teeth. On the other hand, mature teeth have limited vascular regenerative potential, increasing their susceptibly to necrosis (21). Diangelis et al. (16) emphasized that teeth with open apices (>1.0 mm) have significant revascularization potential, and thus, should be closely monitored following trauma. A continued lack of response to sensibility tests beyond three months indicates pulpal necrosis (28). Research indicates that the risk of pulpal necrosis increases from 4.7% to 40% as patients age and their root apices mature (29), suggesting a potential link between age and necrosis risk. However, Bastos et al. (26) found no significant association between age and pulpal necrosis after traumatic dental injuries in permanent teeth. This discrepancy may be explained by the nature of their study, which primarily focused on minor injuries with minimal displacement.

No sensibility or vitality test has been proven to provide ideal results regarding sensitivity or specificity (12, 30). Practical challenges, such as cost, device size, and sensitivity to patient movement, pose significant barriers to the widespread adoption of vitality tests. According to the IADT guidelines, sensibility tests are practical tools for trauma evaluation and remain crucial during initial and follow-up assessments (16). However, their reliability depends on factors like patient compliance and the stage of tooth maturation (31), which can influence the outcomes.

There remains a critical need for enhanced diagnostic tools, particularly in the immediate post-trauma period, since complications such as inflammatory root resorption can occur within just two weeks of injury (32, 33). Technological advancements, like ultrasound Doppler flowmetry, have shown potential in addressing the complexities of trauma cases (34-39). It is important to note that sensibility tests require time to achieve reliability post-trauma, and in the interim, clinicians should recognize their time-dependent limitations. Where feasible, integrating vitality tests could offer a valuable adjunct to sensibility tests, aiding in determining pulpal health and informing patients about subsequent treatment strategies.

Future studies should focus on larger sample sizes to improve the generalizability of the findings. It would be beneficial to examine mature and immature roots as separate groups to assess whether the tooth development stage influences the accuracy of vitality tests. Additionally, it is suggested to assess the effect of incorporating vitality and sensibility tests on diagnosing pulpal health, particularly in the critical post-trauma period.

Conclusions

Under the study conditions:

1- A negative response to sensibility tests immediately after trauma does not necessarily indicate pulpal necrosis, as 68% of teeth regained responsiveness over time.
2- None of the immature teeth developed pulpal necrosis, possibly due to the greater regenerative potential.
3- The specificity of sensibility tests improved over time, with all tests reaching 0.83 at 12 months, while the sensitivity of cold and heat tests reached 1.0 at two months. Therefore, sensibility tests become more reliable over time, particularly beyond the two months.

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Conflict of interest

The authors deny any conflicts of interest related to this study.

Author contributions

A.R. and H.J. conceptualized the main idea, designed, supervised the study, and reviewed the manuscript. H.K. acquired data and did the tests. A.R. and R.S. conducted data analysis and wrote the original draft. S.D. reviewed the results and provided comments. All authors read and approved the final manuscript.

Ethical approval

The research protocol was approved by the ethics committee of Mashhad University of Medical Sciences. Sensitivity tests are a standard component of routine clinical assessment for traumatized teeth, and no additional diagnostic procedures were introduced. All patients provided informed consent before participation.

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