

Comparison of Electrical, Thermal, and Pulse Oximetry Methods for Assessing Pulp Vitality in Recently Traumatized Teeth

Velayutham Gopikrishna, MDS, Kusb Tinagupta, MDS, and Deivanayagam Kandaswamy, MDS

Abstract

Pulse oximeter is a well-established and noninvasive method for measuring vascular health by evaluating oxygen saturation. This study compared the efficacy of a custom-made pulse oximeter dental probe with the electric pulp testing and thermal testing for measuring pulp vitality status of recently traumatized permanent teeth. Readings for pulp vitality for 17 recently traumatized maxillary incisors were taken with custom-made pulse oximeter dental probe (group 1), electrical pulp tester (group 2), and thermal testing (group 3) over a 6-month period. The proportion of recently traumatized teeth showing a positive responsiveness in thermal/electric pulp tests increased from no teeth showing responsiveness on day 0 to 29.4% teeth on the 28th day, 82.35% of teeth at 2 months, and 94.11% teeth at 3 months. However, pulse oximeter gave positive vitality readings that remained constant over the study period from day 0 to 6 months in all patients. (*J Endod* 2007;33:531–535)

Key Words

Pulp vitality, pulse oximeter, pulse oximeter dental sensor holder, traumatized permanent teeth

From the Department of Conservative Dentistry and Endodontics, Meenakshi Ammal Dental College, Chennai, India.

Supported by the scientific research grant given by university of Meenakshi Academy of Higher Education and Research, Chennai, INDIA, vide grant no. MAHER/742/2006.

All the authors have financial interest in the research and hold a patent application on the device (Pulse Oximeter Dental Sensor Holder).

Address requests for reprints to Dr. Velayutham Gopikrishna, Department of Conservative Dentistry and Endodontics, Meenakshi Ammal Dental College, Alapakkam Main Road, Maduravoyal, Chennai 600 095, India. E-mail address: hi_gopikrishna@hotmail.com.

0099-2399/\$0 - see front matter

Copyright © 2007 by the American Association of Endodontists.

doi:10.1016/j.joen.2007.01.014

The assessment of pulp vitality is a crucial diagnostic procedure in the practice of endodontics and for treating traumatized teeth. Because the pulp tissue cannot be directly inspected, the endodontist has to use indirect methods to register sensitivity of pulpal nerves. These methods include thermal tests, electric pulp tests, test cavity, and anesthetic tests. The most commonly used tests in practice are thermal tests and electrical pulp tests. Radiographs, mobility, percussion, palpation, transillumination, and evaluating the discoloration of a tooth crown have also been used as clinical aids to distinguish between a normal or necrotic pulp (1).

A major shortcoming with the present pulp testing methods is that they indirectly monitor pulp vitality by measuring the neural responses and not vascular circulation. The pulpal blood vessels supply and mediate many of the processes of acute and chronic inflammation. Also, the blood supply aids the reparative potential of the pulpal tissues (2).

Therefore, the precise histologic status of the pulp cannot be determined on the basis of these tests alone. Recent attempts to develop a method for determination of pulpal circulation have involved the use of laser Doppler flowmetry, dual wavelength spectrophotometry, and pulse oximetry. Although the laser Doppler flowmeter has met with some success in medical applications, its use in dentistry has been hampered by the sizeable expense, lack of reproducibility, and sensitivity of the device to motion (3). Dual wavelength spectrophotometry has been examined in the laboratory setting so far and detects the presence of hemoglobin and not the circulation of blood (4).

The pulse oximeter is a noninvasive oxygen saturation monitoring device widely used in medical practice for recording blood oxygen saturation levels during the administration of intravenous anesthesia through the use of finger, foot, or ear probes. It was invented by Takuo Aoyagi, a biomedical engineer working for the Shimadzu Corporation in Kyoto, Japan, in the early 1970s (5). Pulse oximetry is a completely objective test, requiring no subjective response from the patient, that directly measures blood oxygen saturation levels.

The pulse oximeter sensor consists of two light-emitting diodes, one to transmit red light (640 nm) and the other to transmit infrared light (940 nm) and a photodetector on the opposite side of the vascular bed. The light-emitting diode transmits red infrared light through a vascular bed such as the finger or ear. Oxygenated hemoglobin and deoxygenated hemoglobin absorb different amounts of red infrared light. The pulsatile change in the blood volume causes periodic changes in the amount of red infrared light absorbed by the vascular bed before reaching the photodetector. The relationship between the pulsatile change in the absorption of red light and the pulsatile change in the absorption of infrared light is analyzed by the pulse oximeter to determine the saturation of arterial blood (5).

Earlier studies by Schnettler and Wallace (6) reported a correlation between pulp and systemic oxygen saturation readings using a modified ear pulse oximeter probe on a tooth. They recommended its use as a definitive pulp vitality tester. Kahan et al. (7) designed, built, and tested a reflectance tooth probe by using a Biox 3740 oximeter (Ohmeda, Louisville, CO). Pulse-wave readings from the teeth were found to be synchronous with the finger probe but not consistently. They concluded that the accuracy of the commercial instrument was disappointing, and in its present form it was not considered to have predictable diagnostic value (7).

Gopikrishna et al. (8) developed a custom-made pulse oximeter sensor holder for an existing Nellcor OxiMax Dura-Y D-YS multisite oxygen sensor (Tyco Healthcare Group LP, Pleasanton, CA) and showed the utility of the pulse oximeter dental probe in assessment of human pulp vitality. We further evaluated the sensitivity, specificity, positive predictive value, and negative predictive value of this device in comparison with thermal and electric pulp testing methods and concluded that pulse oximetry is an objective and accurate method of assessing pulp vitality (9).

Because pulp vitality is purely the function of vasculature health, a vital pulp with an intact vasculature may test nonvital if only the nerve fibers are injured. This situation is commonly encountered in recently traumatized teeth (10). On the other hand, pulp nerve fibers are more resistant to necrosis than the vascular tissue (11). Therefore, thermal and electric tests may give a false-positive response if only the pulp vasculature is damaged.

In cases of trauma, teeth often do not respond to conventional pulp testing methods immediately after injury. This temporary loss of response is caused by injury, inflammation, pressure, or tension on the nerve fibers in the apical area because of trauma (12). Usually 1 to 8 weeks can lapse before a normal pulpal response can be elicited. However, greater observation periods may be required (13). According to Ozcelik et al. (14), early neuronal degeneration in cases of trauma is manifested as intramyelin edema, axonal swelling, and partial loss of myelin sheaths. Bhaskar and Rappaport (15) reported their clinical observation on 25 anterior teeth that had been traumatized and did not respond to conventional vitality tests. When the teeth were opened into pulp chambers, all revealed vital pulps. They concluded that conventional vitality tests are in reality sensitivity tests and have questionable predictive value of the vitality of pulp tissue. For this reason, they recommended that endodontic therapy should be delayed on traumatized teeth, and the affected pulp tissue should be considered vital unless apical radiolucencies or sinus tracts develop. A more accurate assessment of pulp vitality would be made by determining the presence of a functioning blood supply, thus allowing the healing potential to be evaluated at an earlier stage. Moreover, delay in diagnosis can lead to severe complications such as inflammatory root resorption (16). Therefore, it is important to determine the status of pulp in such cases to evaluate the necessity for root canal treatment.

Hence, the aim of this clinical study was to compare the efficacy of a custom-made pulse oximeter dental probe with the electric pulp testing and thermal testing for measuring pulp vitality status of recently traumatized permanent teeth.

Materials and Methods

The test group comprised of patients who reported to our department with a history of trauma in relation to the maxillary anterior teeth within a period of 48 hours of injury.

The inclusion criteria included the following (Table 1): (1) patients with horizontal fractures involving enamel and/or dentin without pulpal, (2) exposure in any one of the maxillary incisors, (3) patient complaints of pain and/or tender in any one of the maxillary incisors, and (4) signs of grade 1 mobility in any one of the maxillary incisors. Exclusion criteria used for this study was as follows: (1) patients with incomplete root formation; (2) carious, restored, or periodontally involved test teeth; (3) teeth with more than grade I mobility; (4) patients giving a history of taking anti-inflammatory drugs prior to the vitality testing; and (5) teeth with severe luxation injuries.

Seventeen patients (test group) were selected after taking into consideration the previously mentioned inclusion and exclusion criteria. All 17 teeth were evaluated with the custom-made pulse oximeter dental probe (group 1), electrical pulp tester (group 2), and thermal testing (group 3) on the day the patient reported (day 0), day 2, day 4, day 7, day 14, day 21, day 28, after 2 months, 3 months, and 6 months. All the three pulp vitality tests were used on the same subjects in order to assess and compare their efficacy.

Positive control comprised of 30 undergraduate students of our college with vital anterior teeth with no caries, fracture, or discoloration, healthy periodontal status, no radiographic periapical changes, and complete formation of root apex. Thirty patients with endodontically treated teeth were taken as negative control.

Three blinded operators assessed the vitality status of the test teeth each using one of the pulp vitality testing devices. The order of testing was first with electric pulp test followed by pulse oximeter and then by the cold test with a time lag of 30 minutes between each test.

For the electric test, the Parkell pulp vitality tester (Parkell Electronics Division, Farmingdale, NY) was used. The contralateral tooth was used as the control. Teeth to be tested were dried and isolated. The probe of the electric pulp tester was placed on the labial surface of the contralateral tooth that was taken as the control. The intensity of the electric current was slowly increased with the help of a numerical dial present on the electric pulp tester. The rate of intensity increase was standardized to one numerical increase per 5 seconds. The numerical reading at which the patient elicited a response was considered as the control value. The same procedure was repeated on the test tooth. The

TABLE 1. Distribution of 17 test patients according to age, sex and type of injury

Patient	Age (years)	Sex (male/female)	Type of Injury/*26
1	21	Male	Enamel-dentin fracture (uncomplicated crown fracture)/N502.51
2	23	Male	Enamel-dentin fracture (uncomplicated crown fracture)/N502.51
3	25	Male	Enamel-dentin fracture (uncomplicated crown fracture)/N502.51
4	18	Male	Enamel-dentin fracture (uncomplicated crown fracture)/N502.51
5	17	Male	Enamel-dentin fracture (uncomplicated crown fracture)/N502.51
6	15	Female	Enamel-dentin fracture (uncomplicated crown fracture)/N502.51
7	26	Male	Enamel-dentin fracture (uncomplicated crown fracture)/N502.51
8	25	Male	Enamel-dentin fracture (uncomplicated crown fracture)/N502.51
9	24	Male	Enamel-dentin fracture (uncomplicated crown fracture)/N502.51
10	24	Female	Enamel-dentin fracture (uncomplicated crown fracture)/N502.51
11	19	Female	Concussion/N 503.20
12	19	Male	Concussion/N 503.20
13	16	Male	Concussion/N 503.20
14	17	Male	Concussion/N 503.20
15	18	Male	Concussion/N 503.20
16	21	Male	Concussion/N 503.20
17	18	Female	Subluxation (loosening)/N 503.20

*Code number according to the International Classification of Diseases, modified by Andreasen and Andreasen (26).

test tooth was considered to be vital if the patient gave response similar to that of contralateral control tooth. However, if the patient elicited no response even at maximum intensity of electrical pulp tester (numerical reading 10), then the test tooth was considered nonvital. Two readings were taken for each tooth with an interval of 5 minutes and the average recorded.

For pulse oximeter testing, Nellcor's fifth-generation OxiMax 550 pulse oximeter (Tyco Healthcare Group LP) was used, which can detect motion and incorrect placement of sensors. The "sensor message" feature of the OxiMax system examines the information available from the sensor and uses a proprietary algorithm to evaluate parameters programmed into the memory chip of the particular sensor being used and current signal characteristics coming from the patient (17). A Nellcor OxiMax™ Dura-Y D-YS multisite oxygen sensor (Tyco Healthcare Group LP) was selected for use because the dimensions of this sensor were smaller than the mesio-distal dimensions of human permanent dentition. A pulse oximeter sensor holder (patent pending) for the previously mentioned sensor was designed and custom made to ensure accurate placement and adaptation of the sensor on human permanent teeth for assessment of pulp vitality. This assembly of the existing pulse oximeter sensor adapted to the custom-made sensor holder is termed as the Pulse Oximeter Dental Probe (PODP).

The PODP was placed on the teeth to be tested (Fig. 1). The probe was placed in such a way that the light would travel from the facial to the lingual surfaces through the middle of the crown. The values were recorded after 30 seconds of monitoring each tooth. The pulse oximeter values for a particular tooth were interpreted as a positive response if it was within the range of 75% to 85% oxygen saturation. Any value below 75% was taken as a negative response. The normal range for oxygen saturation values was determined by another study completed by our group comparing this customized pulse oximeter dental probe with finger saturation values (8). That study showed two major properties of this device: (1) the oxygen saturation values for human permanent teeth using customized pulse oximeter dental probe were in the range of 75% to 85% and (2) the oxygen saturation values for teeth (75%–85%) were lower as compared with fingers (98%), which may be because of diffraction of the infrared light by the enamel prisms and dentin, which may cause decrease in measured values of oxygen saturation.

The thermal test studied was the cold test (1,1,1,2 Tetrafluoroethane, Endo ice refrigerant spray; Coltène/Whaledent Inc, Mahwah, NJ). The cold test consisted of soaking a cotton pellet with 1,1,1,2 Tetrafluoroethane and placing it on the middle third of the facial surface



Figure 1. Pulse oximeter dental probe placed on patient's tooth.

TABLE 2. Comparison of thermal versus electric pulp tests

Time Interval	Thermal Test (Teeth Showing Vitality)		Electric Pulp Test (Teeth Showing Vitality)		p Value
	No.	%	No.	%	
Day 0	0	0	0	0	—
Day 2	0	0	0	0	—
Day 4	0	0	0	0	—
Day 7	0	0	0	0	—
Day 14	0	0	0	0	—
Day 21	0	0	0	0	—
Day 28	5	29.4	5	29.4	1.00
2 months	14	82.35	14	82.35	1.00
3 months	16	94.11	16	94.11	1.00
6 months	16	94.11	16	94.11	1.00

of the teeth to be tested. A tooth was rated as having no response to cold if the patient felt no sensation after two 15-second applications at 2-minute intervals. The McNemar test was used to determine the statistical difference between thermal test, electric pulp test, and pulse oximeter testing at different time intervals.

Results

All the 30 endodontically treated teeth gave "no response" with thermal and electric pulp tests and "0" response with pulse oximeter. The thirty normal teeth tested as positive controls gave normal vital response with cold and electric pulp tests and a value of 75% to 85% oxygen saturation with pulse oximeter. In the test group, comparison of thermal versus electric pulp tests is shown in Table 2. The comparison of thermal/electric pulp tests versus pulse oximeter testing is shown in Table 3.

There was no significant difference between thermal and electric pulp tests from day 0 to 6 months with a p value of 1.0. However, the proportion of traumatized teeth showing vitality in both thermal and electric pulp tests increased from no teeth showing vitality on day 0 to 29.4% on the 28th day, 82.35% at 2 months, and 94.11% at 3 months. However, pulse oximeter gave vitality readings that remained constant over the study period from day 0 to 6 months in all patients.

There was significant difference between thermal/electric pulp tests and pulse oximeter from day 0 until the 28th day with a p value of <0.0001 until day 21 and <0.0005 on day 28. But there was no significant difference between thermal/electric pulp tests and pulse oximeter at 2, 3, and 6 months with a p value of 0.25 at 2 months, 1.00 at 3 months, and 1.00 at 6 months.

Discussion

For pulse oximeter testing, a Nellcor OxiMax™ Dura-Y D-YS multisite oxygen sensor was selected because the dimensions of this sensor were suitable to be employed on human teeth. The sensor measured 4 mm in length and 5 mm in breadth. To reliably place these sensors parallel to each other onto a tooth, a dental pulse oximeter holder was designed and fabricated in such a way that it provided a stable relationship between the sensor elements and the tooth. This allowed the maintenance of a constant path length for the light emanating from the light-emitting diode sensor and received by photoreceptor sensor, thus enabling accurate readings (9). The arms of the dental pulse oximeter holder had two projections on either side with a hole in the center to facilitate easy placement of PODP on the tooth with the existing rubber dam forceps already used in dentistry.

Traumatized teeth were selected in order to compare the efficacy of pulse oximeter with thermal and electric pulp tests because trauma-

TABLE 3. Comparison of thermal/electric pulp tests versus pulse oximeter testing

Time Interval	Thermal/Electric Pulp Test (Teeth Showing Vitality)		Pulse Oximeter (Teeth Showing Vitality)		p Value
	No.	%	No.	%	
Day 0	0	0	17	100	<0.0001
Day 2	0	0	17	100	<0.0001
Day 4	0	0	17	100	<0.0001
Day 7	0	0	17	100	<0.0001
Day 14	0	0	17	100	<0.0001
Day 21	0	0	17	100	<0.0001
Day 28	5	29.4	17	100	<0.0005
2 months	14	82.35	17	100	0.25
3 months	16	94.11	17	100	1.00
6 months	16	94.11	17	100	1.00

tized teeth do not accurately respond to conventional pulp testing methods even if the pulp is vital because of temporary paresthesia of nerves in the first few weeks. However, if teeth have intact vasculature, it is expected that they will give normal values of oxygen saturation with the pulse oximeter. The management of traumatized teeth is usually delayed until clinical symptoms develop for the clinician to ascertain the status of pulp before deciding the treatment plan. However, during this period, a diseased pulp might go into complications like inflammatory root resorption (16). Thus, an objective diagnostic tool like pulse oximeter during this critical period will be of substantial diagnostic value in the practice of endodontics.

Cold test using 1,1,1,2-Tetrafluoroethane was used because the cold tests have proved to be more reliable than heat tests. Petersson et al. (18) evaluated the ability of thermal and electrical tests to register pulp vitality. The results indicated that the probability that a nonsensitive reaction represented a necrotic pulp was 89% with the cold test, 48% with the heat test, and 88% with the electric test. The probability that a sensitive reaction represented a vital pulp was 90% with the cold test, 83% with the heat test, and 84% with the electrical test. Thus, the accuracy was 86% for cold test, 71% for heat test, and 81% for electrical test. Moreover, according to Peters et al. (19), it is much rarer to have a false positive to cold than electrical. The ability to cause a response via tissue breakdown is lost much sooner for cold than electrical. Thus, cold stimulation is not possible via fluids or necrotic material. In cases of gangrene, heat produces thermal expansion of fluids in the pulp space, which in turn exerts pressure on inflamed periodontal tissues (20).

In this study, in 16 of 17 cases of recently traumatized teeth, vitality testing with thermal and electric pulp tests returned to normal within 3 months of trauma whereas pulse oximeter showed normal values of vitality in these cases starting from the first day to over 6 months. One case with subluxation injury (Table 1) did not show any response to thermal and electric pulp tests even after 6 months, whereas the pulse oximeter showed normal response throughout the test period. This reestablishes the fact that the paresthesia of nerve fibers in traumatized teeth often return to normal responsiveness as postinjury time progresses.

The proportion of traumatized teeth showing vitality with thermal/electric pulp tests increased from no teeth showing vitality on day 0 to 5 teeth showing vitality on the 28th day, 14 teeth at 2 months, 16 teeth at 3 months, and remained the same at 6 months. However, the proportion of vital teeth remained same from day 0 to 6 months with pulse oximeter testing wherein all the test teeth showed an objective vital response over the 6-month period without any change.

All the cases in this study were either enamel fractures, enamel-dentin fractures, concussion, or subluxation injuries with no severe

luxation injuries. All the cases in the test group were vital throughout the test period as proved by the pulse oximeter. However, at the end of the observation period, thermal and electric pulp tests indicated vitality in 94% of the cases and only 6% showed pulpal necrosis. These results with thermal and electric pulp tests are in concurrence with previous studies performed on traumatized teeth (21–23) in which the risk of pulp necrosis was found to range from 0% to 3.5% in cases of enamel infarctions and 0.2% to 1% in cases of enamel fracture. In cases of enamel-dentin fractures without pulpal involvement, the risk of pulp necrosis was found to range from 1% to 6% (23, 24). The greatest frequency of pulp necrosis is encountered among intrusions followed by lateral luxation and extrusion, whereas the least frequent occurrence of pulp necrosis is after concussion and subluxation (25). According to Andreasen and Vestergaard (25) the frequency of pulp necrosis in permanent dentition after concussion and subluxation ranges from 3% to 6% and for extrusive, lateral, and intrusive luxation from 26% to 85%. The pulp may become partly or totally severed and sometimes crushed at the apical foramen or at the level of root fracture during luxation injuries, causing loss of neurovascular supply. Further long-term studies on the accuracy of pulse oximeter in severe luxation injuries would be of clinical significance.

Conclusion

This study shows that pulse oximeter is an effective, objective method of evaluating pulp vitality. It is especially applicable to recently traumatized permanent teeth in which temporary paresthesia of nerves reduces the effectiveness and reliability of thermal and electric pulp testing methods. Consistent pulse oximeter readings in this study confirm that pulp circulation and blood oxygen saturation can be detected by the pulse oximeter. Treatment plans for traumatized teeth can be decided immediately when the patient reports by accurate assessment of vitality by pulse oximeter instead of waiting for thermal and electric pulp tests to give response.

Acknowledgments

The authors thank Mr. Ilangovan, head of CAD-CAM center of Central Institute of Plastic Engineering and Technology, Chennai, India, for his support in the fabrication of custom made Pulse Oximeter Dental Sensor Holder and Mr. A.K. Mathai, Indian Council of Medical Reseach, for statistical analysis.

References

- Ikeda H, Suda H. Subjective sensation and objective neural discharges recorded from clinically nonvital and intact teeth. *J Endod* 1998;24:552–6.
- Watson ADM, Pitt Ford TR, McDonald F. Blood flow changes in the dental pulp during limited exercise measured by laser Doppler Flowmetry. *Int Endod J* 1992;25:82–7.

3. Ramsay DS, Artun J, Martinen SS. Reliability of pulpal blood flow measurements using laser Doppler flowmetry. *J Dent Res* 1991;70:1427–30.
4. Nilsson R, Trope M, Zhang CD, Chance B. Dual wavelength spectrophotometry as a diagnostic test of the pulp chamber contents. *Oral Surg Oral Med Oral Pathol* 1992;74:508–14.
5. Salyer JW. Neonatal and pediatric pulse oximetry. *Respir Care* 2003;48:386–97.
6. Schnettler JM, Wallace JA. Pulse oximeter as a diagnostic tool of pulp vitality. *J Endod* 1991;17:488–90.
7. Kahan RS, Gulabivala K, Snook M, Setchell DJ. Evaluation of a pulse oximeter and customized probe for pulp vitality testing. *J Endod* 1996;22:105–9.
8. Gopikrishna V, Kandaswamy D, Tinagupta K. Assessment of the efficacy of an indigenously developed pulse oximeter dental sensor holder for pulp vitality testing—an in vivo study. *Indian J Dent Res* 2006;17:111–3.
9. Gopikrishna V, Kandaswamy D, Tinagupta K. Evaluation of efficacy of a new custom made pulse oximeter dental probe in comparison with the electrical and thermal tests for assessing pulp vitality. *J Endod* 2007;33:411–4.
10. Munshi AK, Hedge AM, Radhakrishnan S. Pulse oximetry: a diagnostic instrument in pulpal vitality testing. *J Clin Pediatr Dent* 2002;26:141–5.
11. Fun Z, Trowbridge H, Bender IB, Rickoff B, Sorin S. Assessment of reliability of electrical and thermal pulp testing agents. *J Endod* 1986;12:301–5.
12. Andreasen FM, Andreasen JO. Luxation injuries. In: Andreasen FM, Andreasen JO, eds. *Textbook and Color Atlas of Traumatic Injuries to the Teeth*. 3rd ed. Copenhagen: Munksgaard; 1994:353–4.
13. Andreasen FM, Andreasen JO. Crown fractures. In: Andreasen FM, Andreasen JO, eds. *Textbook and Color Atlas of Traumatic Injuries to the Teeth*. 3rd ed. Copenhagen: Munksgaard; 1994:245.
14. Ozcelik B, Kuraner T, Kendir B, Asan E. Histopathological evaluation of the dental pulps in crown fractured teeth. *J Endod* 2000;26:271–3.
15. Bhaskar SN, Rappaport HN. Dental vitality tests and pulp status. *J Am Dent Assoc* 1973;86:409–11.
16. Tronstad L. Root resorption—etiology, terminology and clinical manifestations. *Endod Dent Traumatol* 1988;4:241–52.
17. A technology overview of the Nellcor OxiMax Pulse Oximeter System: 1–8. Available at: www.nellcor.com. Accessed June 7, 2006.
18. Petersson K, Soderstrom C, Kiani-Anaraki M, Levy G. Evaluation of the ability of thermal and electrical tests to register pulp vitality. *Endod Dent Traumatol* 1999;15:127–31.
19. Peters DD, Baumgartner JC, Lorton L. Adult pulp diagnosis. I. Evaluation of the positive and negative responses to cold and electrical pulp tests. *J Endod* 1994;20:506–11.
20. Mumford JM. Thermal and electrical stimulation of teeth in the diagnosis of pulpal and periapical disease. *Proc R Soc Med* 1967;60:197–200.
21. Ravn JJ. Follow-up study of permanent incisors with enamel cracks as a result of an acute trauma. *Scand J Dent Res* 1981;89:117–23.
22. Ravn JJ. Follow-up study of permanent incisors with enamel fractures as a result of an acute trauma. *Scand J Dent Res* 1981;89:355–65.
23. Stalhane, Hedegard B. Traumatised permanent teeth in children aged 7–15 years. Part II. *Swed Dent J* 1975;68:157–69.
24. Zadik D, Chosack A, Eidelman E. The prognosis of traumatized permanent anterior teeth with fracture of enamel and dentin. *Oral Surg Oral Med Oral Pathol* 1979;47:173–5.
25. Andreasen FM, Vestergaard PB. Prognosis of luxated permanent teeth – the development of pulp necrosis. *Endod Dent Traumatol* 1985;1:207–20.
26. Andreasen JO, Andreasen FM. Classification, etiology and epidemiology. In: Andreasen FM, Andreasen JO, eds. *Textbook and Color Atlas of Traumatic Injuries to the Teeth*. 3rd ed. Copenhagen: Munksgaard; 1994:151–5.