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Doppler ultrasound to detect pulpal blood flow changes during local anaesthesia

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Abstract

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Aim To examine whether Doppler ultrasound can detect changes in pulpal blood flow after infiltration anaesthesia.

Methodology Changes in pulpal blood flow in maxillary central incisor teeth of 18 patients (mean age 26.7 years, 13 men, five women) after infiltration anaesthesia were examined. Before infiltration anaesthesia, the pulpal blood flow was measured using Doppler ultrasound. A local anaesthetic solution containing 2% lidocaine with 1 : 80 000 epinephrine was injected into the submucosa above the experimental tooth. The Doppler ultrasound test was carried out at 5, 10, 20, 30, 45 and 60 min after infiltration. The parameters were Vas (maximum linear velocity, cm s^{-1}), Vam (average linear velocity, cm s^{-1}) and Vakd (minimum linear velocity, cm s^{-1}), which are indicators of the level of blood flow. The mixed procedure at the 95% confidence interval was used to examine the changes in pulpal blood flow after the injection.

Results The linear velocity profiles (Vas, Vam, and Vakd) decreased sharply 5 min after anaesthesia and then reduced continuously for 30 min. The maximum degree of blood flow reduction in Vas, Vam and Vakd was 58%, 83% and 82%, respectively. After 30 min, the linear velocities increased gradually. The Vam returned to the pre-anaesthesia state at 60 minutes but the Vas and Vakd did not recover completely.

Conclusions Doppler ultrasound can detect changes in pulpal blood flow after infiltration anaesthesia. In the future, Doppler ultrasound can be used as a tool for measuring pulpal blood flow.

Keywords: Doppler ultrasound, infiltration anaesthesia, pulp vitality, pulpal blood flow.

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Introduction

Several methods have been used to examine pulpal blood flow. One of the methods involves the use of laser Doppler flowmetry, in which the frequency shifts when the laser beam is reflected by the moving red blood cells. Using laser Doppler flowmetry and maxillary central incisor teeth, Pitt Ford *et al.* (1993) examined the effect of dental local anaesthetic solutions containing lidocaine either with or without 1 : 80 000 epinephrine. Their results showed that the 1 : 80 000 epinephrine group demonstrated a significant decrease (31%) in pulpal blood flow in every subject. However, it was reported that laser Doppler flowmetry showed a false-positive response originating from the surrounding tissues other than the pulp (Hartmann *et al.* 1996). Another method to evaluate the vascularity of pulp is pulse oximetry (Gopikrishna *et al.* 2007a,b, Jafarzadeh & Rosenberg 2009). In pulse oximetry, red and infrared LED light beams are transmitted through tooth structure. The pulsating change in the blood volume of pulpal arterioles causes periodic change in the amount of red and infrared light absorbed by the vascular bed, and this change is caught by the detector that is positioned opposite to the light source. The relationship between the pulsating change in the absorption of red and infrared light is assessed by the oximeter to show the oxygen

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saturation level by the oxygenated and deoxygenated haemoglobin contents.

Ultrasound is a form of mechanical energy that is transmitted to biological tissues as an acoustic pressure wave at frequencies above the limits of human hearing. Doppler ultrasound is used in many medical disciplines as a noninvasive and radiation-free technique to assess the blood flow in microvascular systems.

Doppler ultrasound has been used successfully to measure the blood flow of the tissues surrounding the tooth (Cotti *et al.* 2003, Lustig *et al.* 2003, Rajendran & Sundaresan 2007). However, there are few reports on the use of Doppler ultrasound in pulpal blood flow measurements, because it is difficult to transmit sufficient ultrasound energy into the pulp cavity through the hard dental tissue and detect the small Doppler frequency shifts produced by slow-moving pulpal blood. These limitations were partially overcome by the recent developments of high-frequency (20–100 MHz) ultrasonic devices. Berson *et al.* (1999) reported that the velocity profiles (velocities < 0.05 mm s^{-1}) could be measured at 20 MHz, even in 100- to 300-μm-diameter vessels. In a previous study, Doppler ultrasound was used to differentiate between vital and root filled teeth (Yoon *et al.* 2010). They reported significant differences in pulpal blood flow measurements between the two groups. In vital teeth, ultrasound Doppler imaging revealed a pulsed waveform and a pulsating sound that are characteristic of an arteriole, whereas the root filled teeth showed linear, nonpulsed waveform without a pulsating sound.

It was demonstrated by laser Doppler flowmetry that dental anaesthetic solutions containing epinephrine reduced the pulpal blood flow (Pitt Ford *et al.* 1993, Odor *et al.* 1994a,b, Premdas & Pitt Ford 1995, Chng *et al.* 1996, Ahn & Pogrel 1998). To confirm the sensitivity of Doppler ultrasound, it is essential to determine whether Doppler ultrasound could detect the changes in pulpal blood flow after anaesthesia. This study examined whether Doppler ultrasound could detect the changes in pulpal blood flow after infiltration anaesthesia (2% lidocaine with 1 : 80 000 epinephrine).

Materials and methods

Subjects

Eighteen healthy volunteers (mean age 26.7 years, 13 men and five women) with no cardiovascular diseases were enrolled in this study. The following criteria for the maxillary central incisors were used to select the patients: (i) no restoration, (ii) no dental caries, (iii) no history of dental trauma, (iv) no history of orthodontic treatment and (v) a positive reaction to a cold test (0 °C ice stick) and the electric pulp test. This study was approved by the Ethics Committee of the dental hospital of Yonsei University (2-2008-0022).

Apparatus

The MM-D-K (Minimax, Moscow, Russia), a Doppler ultrasound machine, was used to measure pulpal blood flow. The MM-D-K measures the blood flow of the arterioles and venules with diameters <300 μm. A 20-MHz probe was chosen because it can detect blood flow as deep as 0.8 cm from the external surface of the tooth. Ultrasound gel (Pro-gel II; Dayo medical, Seoul, Korea) was used as a coupling agent, and the probe was located on the cervical area of the tooth (Fig. 1). On the tip of the probe, there is a 5-mm-diameter sensor that transmits ultrasound energy into the tooth through ultrasound gel.

Procedure

A single experimenter obtained all measurements from the maxillary central incisors of the 18 volunteers.

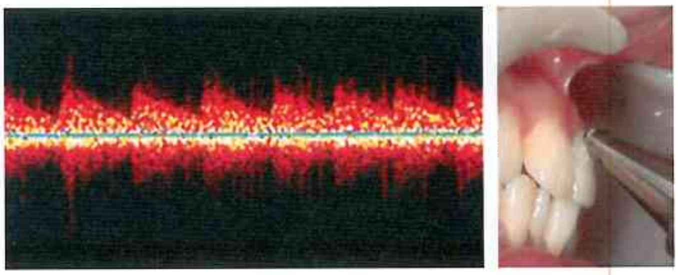

Figure 1 Typical Ultrasound Doppler graphy waveform in vital tooth (left) and the position of the measurement with a 20 MHz probe (right).

Figure 2 Template for repositioning probe.

Before the experiment, a template was made with 0.5-mm-thick Copyplast® (Dentarum, Ispringen, Germany) for reproducible repositioning of the probe on the tooth surface. The location of the probe was marked on the template by making a hole in the cervical area of the tooth (Fig. 2). After re-confirming a positive reaction to a cold test (0 °C ice stick) and the electric pulp test, ultrasound gel was applied to the exposed tooth surface. The pulpal blood flow before anaesthesia was then measured. For anaesthetic pulpal blood flow, infiltration was performed on the apical labial mucosa of the same tooth using 2% lidocaine with 1 : 80 000 epinephrine (1.8 mL). Subsequently, pulpal anaesthesia was confirmed by a negative pulpal response to a cold test (0 °C ice stick) and electric pulp test, and Doppler ultrasound measurement was taken after 5, 10, 20, 30, 45 and 60 min.

Doppler ultrasound parameters for the pulpal blood flow measurement

The measurement parameters were as follows: maximum linear velocity during the systolic period (Vas, cm s^{-1}), average linear velocity during the systolic period (Vam, cm s^{-1}) and minimum linear velocity during the diastolic period (Vakd, cm s^{-1}). Because little is known about which parameter (Vas, Vam and Vakd) is most affected by anaesthesia, all three velocities were recorded. All measurements were analysed using the Doppler signal spectrum analysis programme.

Data processing and statistical analysis

After calculating the mean value and standard deviation of each parameter, the ratio of pre-anaesthesia (0 min) to each time (5, 10, 20, 30, 45 and 60 min) was obtained. The mixed procedure at the 95% confidence interval was used to evaluate the changes in the pulpal blood flow after the injection. The data consisted of repeated measurements at 0, 5, 10, 20, 30, 45 and 60 min from the same person, and these repeated measurements were correlated with each other. Therefore, the mixed procedure fitted the analysis strategy of this study. The raw data were analysed statistically using the SAS® 9.1 Ver. program (SAS Inc., North Carolina, USA).

Results

Pulpal blood flow measurement

The linear velocity profiles (Vas, Vam and Vakd) decreased sharply 5 min after anaesthesia and then decreased continuously until 30 min. After 30 min, the Vas, Vam and Vakd increased gradually (Table 1).

The percentage of change of pulpal blood flow after infiltration anaesthesia

The ratio of pre-anaesthesia (0 min) to each time (5, 10, 20, 30, 45 and 60 min) was calculated. Figure 3 shows the tendency of pulp blood flow changes after infiltration anaesthesia. The linear velocity values in Vas, Vam and Vakd decreased sharply 5 min after anaesthesia and then decreased continuously until 30 min. The maximum degree of blood flow reduction in the Vas, Vam and Vakd was 58%, 83% and 82%, respectively. After 30 min, the linear velocities increased gradually.

Statistical analysis

The results of the mixed procedure indicate whether each parameter had recovered to the pre-anaesthetic state. The Vam returned to the pre-anaesthesia state at 60 min, but the Vas and Vakd did not.

Table 1 Mean and standard deviation of each parameter for the 18 teeth (cm s^{-1})

	Mean ± SD		
Time (min)	Vas (cm s^{-1})	Vam (cm s^{-1})	Vakd (cm s^{-1})
0	0.98 ± 0.30	0.49 ± 0.30	0.45 ± 0.29
5	0.52 ± 0.34	0.17 ± 0.27	0.14 ± 0.25
10	0.46 ± 0.33	0.13 ± 0.29	0.12 ± 0.23
20	0.42 ± 0.19	0.12 ± 0.20	0.12 ± 0.19
30	0.49 ± 0.28	0.13 ± 0.20	0.14 ± 0.20
45	0.61 ± 0.43	0.15 ± 0.20	0.22 ± 0.32
60	0.72 ± 0.54	0.34 ± 0.42	0.34 ± 0.43

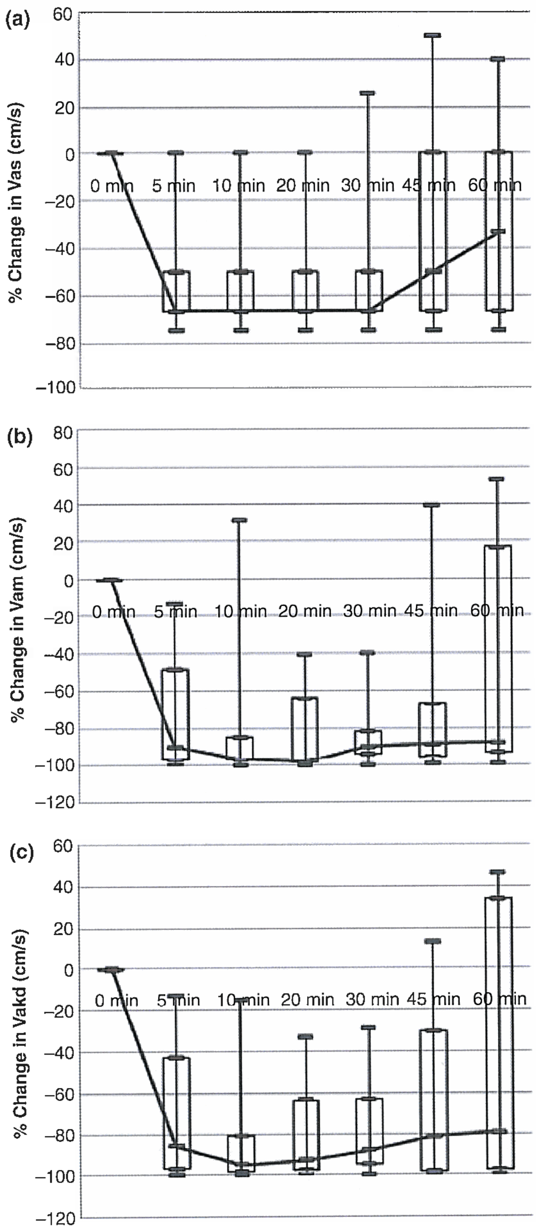

Figure 3 (a) Changes in Vas (Maximum linear velocity, cm s^{-1}). (b) Changes in Vam (Average linear velocity, cm s^{-1}). (c) Changes in Vakd (Minimum linear velocity, cm s^{-1}). [Correction added after online publication 11 November 2011: Images for Figure 3a and 3c swapped around.]

Discussion

This study examined whether Doppler ultrasound could detect changes in pulpal blood flow after the infiltration of 2% lidocaine containing 1 : 80 000 epinephrine on sound maxillary central incisor teeth. The linear velocity profiles (Vas, Vam and Vakd) decreased sharply 5 min after anaesthesia and then decreased continuously until 30 min. The maximum degree of blood flow reduction in the Vas, Vam and Vakd was 58%, 83% and 82%, respectively. The Vam returned to pre-anaesthesia state at 60 min, but the Vas and Vakd did not. The sharp decrease in pulpal blood flow after anaesthesia was attributed to the action of adrenaline on the alpha receptors in the blood vessels, which might have caused vasoconstriction. These results are comparable with a previous laser Doppler flowmetry study, where a significantly reduced pulpal blood flow was measured after injecting 2% lidocaine with 1 : 80 000 epinephrine (Premdas & Pitt Ford 1995). In that study of maxillary premolars, where a 2-mL buccal injection was administered, the pulpal blood flow reduction was 47% and the duration of blood flow reduction was 27 min. Chng *et al.* (1996) examined the effects of prilocaine local anaesthetic solutions on the pulpal blood flow in the maxillary canine with laser Doppler flowmetry. When 3% prilocaine with a 1 : 100 000 epinephrine solution was administered, the pulpal blood flow decreased to one-third the level of the pre-injection state. Although each study showed different degrees of decrease and recovery times from anaesthesia, all studies report a sharp decrease in pulpal blood flow immediately after anaesthesia followed by a gradual return to the pre-anaesthetic state. Therefore, Doppler ultrasound appears to be useful for detecting changes in pulpal blood flow.

Interestingly, the variations in the measurements tended to increase with time. This means that the recovery of the pulpal blood flow showed larger variations compared with the onset of pulpal blood flow reduction.

Many factors may affect pulpal blood flow including the position of the patients and their physiological condition. The cardiac output of patients can have a large effect because the pulpal blood flow is a terminal circulation. To eliminate the effect of systemic circulation, patients with cardiovascular disease were excluded and a sufficient rest period was taken before the experiment. However, other factors such as gender and age of the patients as well as tension from injection could affect the results. It is also possible that the anatomy of the area influenced the extent of blood flow reduction.

In this study, Doppler ultrasound revealed large variations between patients. The main cause of the variations might be that the penetration depths of the ultrasound wave were not constant in each tooth because the thickness of dentine and enamel was not constant. The company that developed the MM-D-K Doppler ultrasound machine recommends the probe to be located on the cervical area of the tooth at a 60° angle with the labial surface. This recommendation seems to be reasonable because the thickness of dental hard tissue is thinnest in the cervical area and the 60° angle with the labial surface aims towards to pulp canal space. The best results were obtained when the probe was located on the cervical area of the tooth, but the angle of the probe varied between patients. Therefore, when determining pulpal blood flow in a certain tooth, the value of its healthy contralateral tooth needs to be considered.

Despite these limitations, the Doppler ultrasound parameters revealed changes in pulpal blood flow after anaesthesia with time, which suggests that Doppler ultrasound may be of value when testing pulp status. In particular, in dental trauma, it is important to determine the extent of injury as well as the status of the healing process or healing complications in the follow-up period. However, most procedures, such as thermal tests and electronic pulp testing, assess the nerve supply to the pulp. A vascular detecting system, such as Doppler ultrasound, may be more sensitive than EPT and thermal testing because neural regeneration in a traumatized pulp is slower than vascular regeneration.

Conclusions

Doppler ultrasound can detect changes in pulpal blood flow following infiltration anaesthesia.

Acknowledgements

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