Pulpal Blood Flow Measurement with Ultrasound Doppler Imaging

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Abstract

Introduction: This study compared the difference in pulpal blood flow between vital and root-filled teeth by using ultrasound Doppler imaging. **Methods:** To compare the difference in pulpal blood flow between vital and root-filled teeth, 11 patients (mean age, 32.06 years; 3 male, 8 female) who had undergone root canal treatment on the anterior tooth of the maxilla or mandible and had a vital contralateral tooth were examined. Pulpal blood flow measurements were performed on the vital and root canal–treated teeth by using ultrasound Doppler imaging. The parameters examined were the maximum linear velocity (Vas), average linear velocity (Vam), minimum linear velocity (Vakd), pulsation index (PI), and circulation resistance (RI), which are indicators of the pulpal blood flow. The differences between the vital and root-filled teeth were examined by using a paired *t* test at the 95% confidence interval. **Results:** There were significant differences in the Vas, Vam, Vakd, and RI between the vital and root-filled teeth ($P < .05$). With the root-filled teeth, ultrasound Doppler imaging revealed a linear and non-pulsed waveform, whereas the vital teeth showed a pulsed waveform that is characteristic of an arteriole. **Conclusions:** Ultrasound Doppler imaging can detect pulpal blood flow in vital tooth through indicators such as Vas, Vam, Vakd, PI, and RI. *(J Endod 2010;36:419–422)*

Key Words

Pulpal blood flow, tooth vitality, ultrasound Doppler, vitality test

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The pulpal vitality is generally assessed clinically through sensitivity tests of the nerve fibers by using electrical or thermal stimulation. However, these methods only represent the nerve fiber transmission and not the vitality. A more accurate assessment of the pulpal vitality would be made if the functional blood supply could be determined. In traumatized teeth, false-negative and false-positive cases are frequently encountered (1).

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

Ultrasound has recently found applications in dentistry. Cotti et al (2) reported the differential diagnosis of periapical granulomas and cystic lesions, which were confirmed by histopathology examinations in all 11 cases. Rajendran and Sundaresan (3) also determined the efficacy of ultrasound Doppler imaging as a tool for monitoring the healing of periapical lesions treated by nonsurgical endodontics. This study showed that ultrasound Doppler imaging provides sufficient information with regard to the nature of bone healing and vascularity. By using ultrasound Doppler imaging, Lustig et al (4) clinically identified the main blood supply to the bony chin and measured its parameters, such as the vessel diameter, flow direction, and its volume. The results revealed the diameter of the artery and blood flow to be 0.18–1.8 mm and 0.7-3.7 mL/min, respectively.

Ultrasound Doppler imaging was used successfully to measure the blood flow of the tissues surrounding the tooth (2–4). However, there are few reports on the use of ultrasound Doppler imaging in the tooth itself. Examinations of the pulp cavity (5) and other fundamental research (6) have been carried out, and observations of marginal periodontal disease (7) and measurements of the remaining dentin thickness (8) have been reported. These studies were carried out on extracted teeth. However, no studies have measured the pulpal blood flow in living subjects. This study examined whether ultrasound Doppler imaging could differentiate the blood flow between vital and root-filled teeth.

Material and Methods

Subjects

Fifteen anterior teeth from 11 patients (mean age, 32.06 years; 3 male and 8 female) were included in this study. Patients with cardiovascular disease were excluded. The root canal treatments were performed on the maxillary or mandibular anterior teeth, with the contralateral teeth vitality intact. The contralateral vital teeth had no caries or trauma history, and the tooth vitality was confirmed by using a conventional thermal test and electric pulp test (Table 1).

This study was approved by the Ethics Committee of the dental hospital at Yonsei University (2-2008-0022).

Apparatus

An MM-D-K (Minimax, Moscow, Russia), an ultrasound Doppler imaging instrument, was used to measure the 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

TABLE 1. Gender, age, and tooth type of the subjects

Subjects	Gender	Age (y)	Vital tooth	Root-filled tooth
1	F	23	#7	#10
2	F	26	#8	#9
3	F	28	#10	#7
4	F	48	#9	#8
			#10	#7
5	M	8	#25	#24
6	F	36	#9	#8
7	F	22	#10	#7
8	F	26	#8	#9
			#7	#10
9	M	27	#9	#8
			#10	#7
10	M	36	#9	#8
			#10	#7
11	F	55	#8	#9

because it could detect blood flow as deep as 0.8 cm. All measurements were analyzed by using the Doppler signal spectrum analysis program.

Procedure

All experiments were carried out by a single experimenter to eliminate interobserver error. With ultrasound Doppler imaging, one experimenter measured the pulpal blood flow of 15 vital and 15 root-filled teeth from 11 patients. Before measuring the vital teeth with ultrasound Doppler imaging, it was confirmed that the tooth showed a positive reaction to the cold and electric pulp tests. The patient was allowed to rest for 10 minutes before the measurements to eliminate the effects of exercise. Each patient was placed in the supine position. After drying the tooth, the ultrasound gel was applied to the cervical area of the tooth and a probe was placed at a 60-degree angle with the labial surface (Fig. 1). By using a 20-MHz probe, the blood flow measurement was performed on the vital and root-filled tooth.

Ultrasound Doppler Imaging Parameters for Pulpal Blood Flow Measurement

The measurement parameters that are listed in Table 2 were examined.

Statistical Analysis

The raw data were analyzed statistically by using the SAS 9.1 Version (SAS Inc, Cary, NC) program. The differences between the vital and root-filled teeth were analyzed by using a paired t test at the 95% confidence interval.

Results

In the vital teeth group, the mean blood flow velocity in the maximum linear velocity during the systolic period (Vas), average linear velocity during the systolic period (Vam), and minimum linear velocity during the systolic period (Vakd) was 0.781 cm/s, 0.274 cm/s, and 0.295 cm/s, respectively. The mean pulsation index (PI) and circulation resistance (RI) values were 0.958 and 0.584, respectively. In the root-filled teeth group, the mean blood flow velocity in the Vas, Vam, and Vakd was 0.368 cm/s, 0.032 cm/s, and 0.072 cm/s, respectively. The mean PI and RI values were 1.168 and 0.683, respectively. In the root-filled teeth, ultrasound Doppler imaging revealed a linear, nonpulsed waveform, whereas the vital teeth showed a pulsed waveform and pulsating that are characteristic of an arteriole (Fig. 2).

Figure 1. Twenty-megahertz probe and the position of measurement.

There were significant differences in the Vas, Vam, Vakd, and RI between the vital and root-filled teeth ($P < .05$). There was no statistical difference in PI between the 2 groups (Fig. 3).

Discussion

There were several problems with ultrasound Doppler imaging when measuring the pulpal blood flow. These include a difficulty in transmitting sufficient ultrasonic energy into the pulp cavity and detecting small Doppler frequency shifts produced by the slow moving pulpal blood. These limitations have been overcome partially by the recent development of high-frequency (20–100 MHz) ultrasonic devices. Berson et al (9) reported that a 20-MHz frequency could be used to measure the velocity profiles (velocities <0.05 mm/s) in 100- to 300-μm diameter vessels. A 20-MHz probe, which can detect blood flow as deep as 0.8 cm from the tooth surface, was used in this study.

A comparison of the vital and root-filled teeth with ultrasound Doppler imaging revealed significant differences in Vas, Vam, Vakd, and RI between the vital and root-filled teeth. When calculating the ratio of the flow velocity, the level of Vas in the root-filled teeth was 47% of that observed in the vital group. Similarly, the levels of Vam and Vakd were 12% and 24%, respectively, of those observed in the vital teeth. The RI value in the root-filled teeth was 185% of that observed in the vital group. This is a similar result to that obtained from the experiment of Orgart et al (10), which measured the pulpal blood flow in 33 necrotic teeth by using laser Doppler flowmetry. In that experiment, the pulpal blood flow in the necrotic teeth was <10% of that observed in the vital teeth. However, a laser Doppler flowmetry study by Polat et al (11) reported 30% lower pulpal blood flow values from the root-filled teeth than from the vital teeth. It was concluded that in laser Doppler flowmetry, a major portion of the signal comes from tissues other

TABLE 2. Definition of the ultrasound Doppler imaging parameters

Parameters	Definition
Vas (cm/s)	Maximum linear velocity during systolic period
Vam (cm/s)	Average linear velocity during systolic period
Vakd (cm/s)	Minimum linear velocity during diastolic period
PI	Pulsation index: resilience of blood vessel (Maximum velocity – Minimum velocity)/ Average velocity
RI	Circulation resistance (Maximum velocity – Minimum velocity)/Maximum velocity

than the pulp. Hartmann et al (12) also reported that the major cause of a false-positive response of laser Doppler flowmetry is the signal from the periodontium, because the splint used to hold the probe did not completely block the signals from the other oral tissues such as the lips and tongue. To overcome these limitations of laser Doppler flowmetry, Sasano et al (13) proposed the use of high-powered transmitted laser light. An increase in laser power increased the level of blood flow detection from the thicker vital teeth, and no blood flow signal of a nonpulpal origin was monitored in the nonvital teeth.

In this experiment with ultrasound Doppler imaging, the origin of the signals could be differentiated with the aid of different Doppler graphic waveforms and sounds. In vital teeth, ultrasound Doppler imaging revealed a pulsed waveform and pulsating sound that are characteristic of an arteriole, whereas the root-filled teeth showed linear, nonpulsed waveform without pulsating sound (Fig. 2). The signals detected in the root-filled teeth might have arisen from the surrounding tissue. Hence, ultrasound Doppler imaging also detected the nonpulpal blood flow like laser Doppler flowmetry. However, ultrasound Doppler imaging could distinguish the origin of the signal (pulp or surrounding tissues of teeth) by using the waveform and ultrasound Doppler graphic sound. In addition, there is no need to make a splint in ultrasound Doppler imaging.

Other methods to evaluate the vascularity of pulp are pulse oximetry (14–16) and measurement of surface tooth temperature (17). In pulse oximetry, red and infrared LED light beam transmits the light into the pulp blood vessels through tooth structure. The pulsating change in blood volume of pulpal arterioles causes periodic change in the amount of red and infrared light absorbed by the vascular bed,

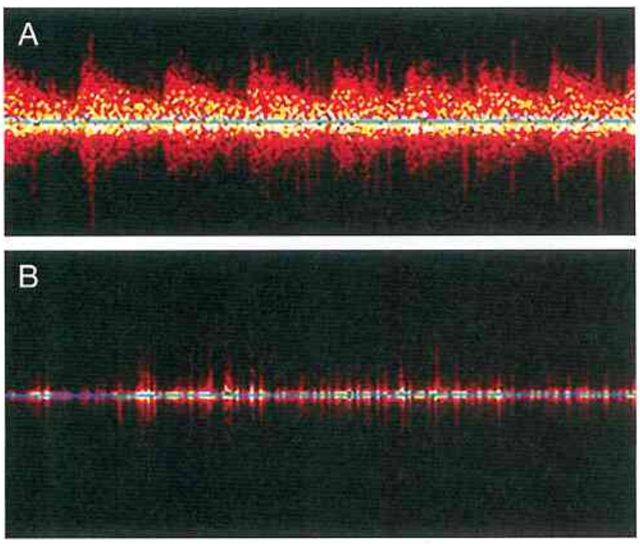

Figure 2. Examples of ultrasound Doppler imaging on a vital tooth (*A*) and root-filled tooth (*B*).

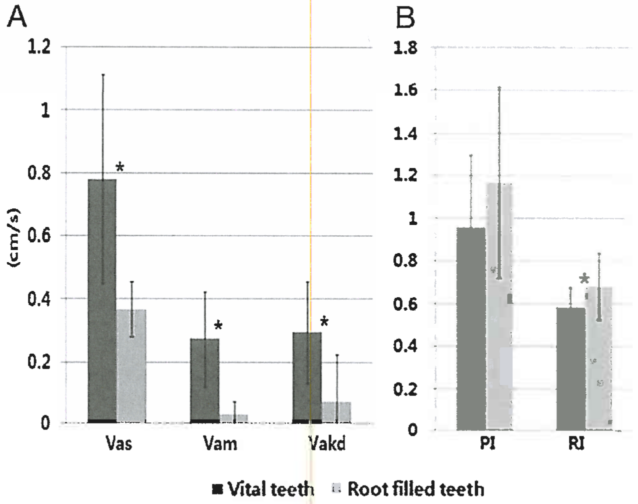

Figure 3. Vas, Vam, and Vakd (*A*), RI and PI (*B*) in the vital and root-filled group. *$P < .05$.

and this change is caught by the detector that is positioned opposite parallel side of light beam source. The relationship between the pulsating change in the absorption of red and infrared light is assessed by the oximeter to show the oxygen saturation level by using the oxygenated and deoxygenated hemoglobin content. It needs a special probe that can firmly stabilize the oximeter sensor in the tooth. The data are influenced by many intrinsic, extrinsic, and patient factors, such as increased acidity and metabolic rate, hypotension and hemoglobin disorders, probe movement, and overhead lamp (16). Tooth temperature measurement as a diagnostic procedure is still technique-sensitive, and many factors should be controlled. Patients should be asked to refrain from smoking, eating, and drinking for 60 minutes before the procedure, the room should be insulated and clean, and the room temperature should be maintained at 20°C. It is desirable to have patient lie down or sit with adequate support for the head, and the use of a rubber dam is also recommended (17).

The present application of ultrasound Doppler imaging to the teeth showed that the blood circulation in the pulp could be detected through the intact enamel and dentin. In addition, it appears possible to distinguish the vital teeth from root-filled teeth at the level of the blood flow parameters, waveform, and the sound of ultrasound Doppler imaging. These features of ultrasound Doppler imaging make it a promising tool for assessing the vitality of traumatically injured teeth.

Conclusions

Ultrasound Doppler imaging can detect pulpal blood flow in vital tooth through indicators such as Vas, Vam, Vakd, and RI.

Acknowledgments

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