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The lamp effect of laser Doppler flowmetry on teeth

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SUMMARY The aim of this study is to analyse the intra and extracoronal scattering of laser light. Twelve vital teeth from 12 volunteer individuals (aged 22–29 years) were used. The camera removing the charge coupled device's infrared cut filter was used for imaging the laser Doppler flowmetry light during pulpal blood flow measurement. When the obtained photos were analysed, it was seen that the laser beam caused the tooth to shine like a lamp and it also illuminated the tissues inside the mouth (tongue, lips, adjacent teeth, etc.). As a result, it was shown that when the necessary cautions were not taken, the laser could scatter all around the tissues surrounding the tooth. Because of the conductive characteristic of the fibre and the optical characteristics of the tooth, we think that the beam is inevitably scattered onto the tissues outside the pulp and together with the isolation of the gingiva, crown should be isolated, as well.

KEYWORDS: laser Doppler flowmetry, laser light scattering, pulpal blood flow, lamp effect

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Introduction

The laser Doppler flowmeter (LDF) evaluates dynamic changes in blood flow through non-invasive measurement methods, by detecting blood cell movement in a small volume of tissue (about 1 mm^3) (1, 2). The flow in individual microvessels, the number of vessels with active flow, and vessel diameter cannot be analysed (3), but total flow can be monitored throughout the tissue. Its use in human teeth was first described by Gazelius *et al.* (4). The technique uses a laser light beam that is directed into the tooth. Light that contacts a moving object is Doppler-shifted, and a portion of that light is backscattered out of the tooth and returned to the photodetector, and a signal is produced. As red blood cells represent the vast majority of moving objects within the tooth, measurement of the Doppler-shifted backscattered light serves as an index of pulpal blood flow (1, 2).

It is reported that the LDF technique is valuable for measuring human pulpal blood flow to determine pulp vitality (5–8). However, the reliability of the pulpal blood measurement has recently begun to be questioned. Vongsavan and Matthews (9) stated that blood flow in periodontal and other adjacent tissues outside the tooth may contribute to the records obtained from the crown of a tooth *in vivo*. They revealed that under all conditions the major part of the signal recorded from an intact pig tooth was from the pulp (an average of between 85 and 93% depending on the conditions) (10). However, the recent studies suggest that 45–82% of the blood flow recorded from human teeth may not be from the pulp (11–15).

The aim of this study is to analyse the intra and extracoronal scattering of laser light.

Materials and methods

The experiment was carried out on 12 healthy upper right central incisors in 12 individuals (aged 22–29 years, mean $25{\cdot}1 \pm 0{\cdot}69$ years). The study was performed at Cumhuriyet University, School of Dentistry Hospital. The protocol was approved by the Ethics Committee of Cumhuriyet University, School of Dentistry.

To stabilize the probe, a laboratory-made autopolymerizing clear acrylic resin (Panacryl)* splint

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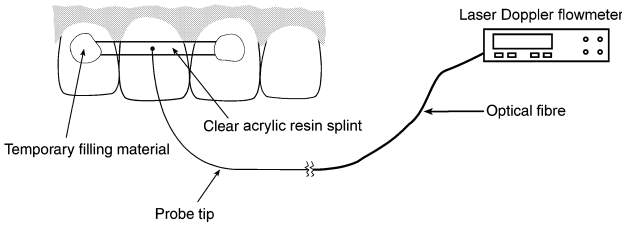


Fig. 1. Schematic representation of test device.

Table 1. Camera settings

Exposure time (Auto)	0·033 s
ISO speed (Auto)	Max. 800
Exposure bias value	0
Aperture	f2·0
Flash mode	Off
Focal length	9·7 mm
Pixel X dimension	640
Pixel Y dimension	480
Image mode	JPEG(fine)
Macro mode	On

positioned the probe labially on the cervical third of the tooth crown. Probe tip was in full contact with the tooth. Splint was fixed on the vestibule sides of the adjacent teeth with temporary filling material (Coltosol Paste)[†] (Fig. 1).

A Periflux 4001 Master Laser Doppler Flowmeter (Periflux 4001)[‡] was used in this study. The LDF emitted light with a 780 nm wavelength. Bandwidth was 20 Hz–20 kHz and sampling frequency was 32 Hz. Master probe (418-1)[§] and microtip (MT B500-0 L170)[§] were used. Calibration (zeroing was done automatically at calibration) was made with the 'PF 1200 Calibration Device'[‡] before study.

Camera (DSC-F717 Cyber-shot® Digital Stil Camera)[¶] was used to take a photograph of laser light. Camera's infrared light source was fastened with tape (included black plastic). In this manner camera's own light sources were eliminated. Camera was adjusted to 'night shot' mode (to make infrared imaging, removing the charge coupled device's infrared cut filter). Other settings of the camera were shown in the Table 1.

The study was performed in a dark room. The previously prepared acrylic splint was fixed on the right upper central tooth. The LDF probe was set in its place in the splint. Lips were retracted by Sternberg lip retractor**. Then a photograph was taken from tooth. Later, by means of a mirror, another photo was taken from the palatinal aspect of the tooth. Photos were taken approximately 12 cm away from the tooth.

Oilpaper with millimetric grid was used to image illumination circle in pulpal depth. Fibre optic probe tip was placed about 3 mm away from the oilpaper and a photograph was taken.

Results

According to both the vestibule (Fig. 2a) and palatinal photos (Fig. 2b), in all cases the laser beam was observed to scatter outside the crown of the tooth. High density illumination was recorded in the vestibule mucosa of the tooth on which laser was applied. Moreover, adjacent teeth, lips, tongue and even the tip of the nose were also illuminated. It was observed that the amount of illumination on the tongue and the opposite dentition decreased while the distance between them and the tooth being measured increased.

The radius of the illuminated circle within the crown was approximately 6 mm (at the distance representing pulpal depth) (Fig. 3).

Discussion

Vongsavan and Matthews (10) found that covering (this coverage prevented the beam scattering out of the tooth to the other oral tissues) the crowns of measured teeth and surrounding soft tissues with aluminium foil increased the perfusion unit signals from the tooth pulp. The use of aluminium folio not only prevents beams from scattering out of the crown but also reflect back into the tooth (prevent loss of signal). This help to increase the amount of beam reaching pulp and possibly periodontal ligament (perhaps alveolar bone), which may increase the value of pulpal blood flow measurement.

Akpınar *et al.* (16) showed that periodontal paste decreases the pulpal blood flow measurement value by 63% in intact human teeth. Hartman *et al.* (11) and Soo-ampon *et al.* (13) showed that the rubber dam reduced significantly the mean blood flow reading from the intact human teeth by 69 and 73% respectively.

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[‡]Perimed AB, Stockholm, Sweden.
[§]Perimed, Järfälla, Sweden.
[¶]Sony Electronics Inc., San Diego, CA, USA.
**Normed, Tuttlingen, Germany.

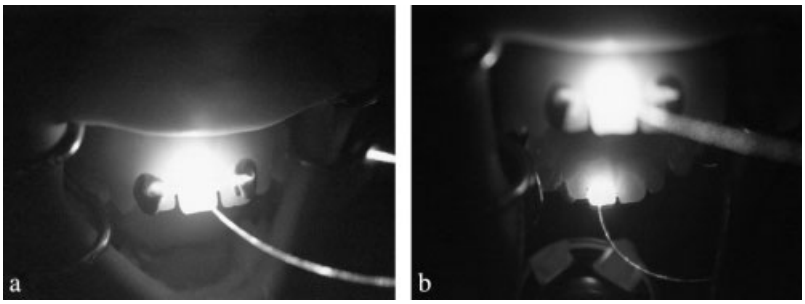


Fig. 2. Vestibule (a) and palatinal (b) light scattering in 780 nm wavelengths in a sample.

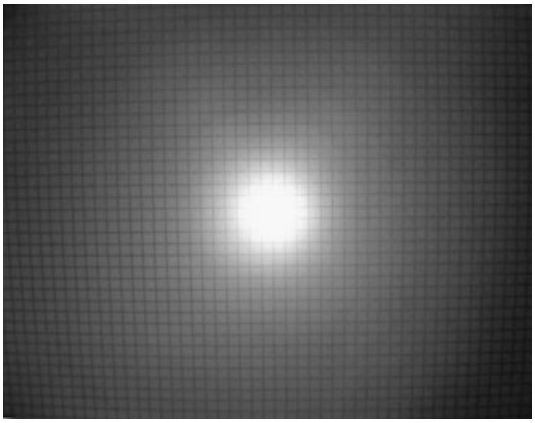


Fig. 3. Illuminated circle 3 mm away from laser Doppler flowmeter probe (representing pulpal depth).

Studying pig teeth, Vongsavan and Matthews (10) claim that the effect of tissues other than the pulp is very small (7–14·9%). It may be that the discrepancy between these results is caused by species differences in the optical properties of the dentine and enamel, and pulpal bulk. Although, LDF device used in human studies (11, 13, 16) had 780 nm wavelengths infrared light, we perceived that these studies do not correlate with each other directly. However, in rubber dam application the reason for being much more decrease in pulpal blood flow measurement degree may be related with the screen off oral tissues such as tongue and lip. Hartmann *et al.* (11) showed that insertion of a cotton roll between the lip and tooth slightly decreased the signal; it can be assumed that distant tissues like the lip may also participate in the recorded flow. Ultimately as Hartman *et al.* (11) and Roebuck *et al.* (17) stated in pulpal blood flow measurements primary contamination is because of periodontium, also it may be said that oral tissues such as tongue and lip are less influential. In previous studies (11, 17) it is predicted that in pulpal blood flow measurements laser light can reach to the oral tissues such as lip and tongue and it may effect to the measurement. In this study we were able show that laser light focussed to the tooth can reach to the surrounding oral tissues.

In the photos, there was no other light source; therefore, each illuminated area is the one illuminated by the laser beam. However, this does not mean that the beam, reaching each area, gets back contributing to the signal. In our study, especially the periodontium in the vestibule side of the tooth was observed to be densely illuminated. This finding is parallel to Akpınar *et al*. (16) study, where they showed that vestibule gingiva clearly contributed more to the signal compared with palatinal gingiva.

The reason for using Sony Camera in the present study is that it has an infrared filter that is preferentially removed (with Night Shot property). Thus, with this camera it has become possible for us to image the laser wavelength that we used. By having this property, its own infrared light sources work automatically, as well. We have eliminated these light sources in order to image only the infrared laser that we used.

It has been observed that with 780 nm wavelength beam, almost all the tissues in the mouth can be illuminated. However, the interesting thing is that the tissues outside the mouth, like the tip of the nose, can also be illuminated. Even when the camera is ~12 cm away, the illumination is possible (this can be seen in photos on the palatal aspect of tooth). The tooth on which LDF laser has been applied shines like a lamp and enlightens the surrounding areas in its own wavelength (780 nm). Therefore, this event has been named as 'lamp effect'.

Light pulses move easily down the fibre-optic line because of a principle known as total internal reflection. This principle of total internal reflection states that when the angle of incidence exceeds a critical value, light cannot get out of the glass; instead, the light

bounces back in. In theory, for a straight fibre whose end faces are perpendicular to its axis, a small collimated beam of rays entering the fibre at 25° off axis will exit the fibre at same degrees off axis. In practice, multiple internal reflections, fibre length, micro-bending (small external surface features) and manufacturing defects will spread collimated rays out to fill an annulus of a cone whose total angle is twice that of the input angle (18–21).

Because of this angle, the radius of the illuminated circle increases while getting away from the probe. The area (representing pulp depth) which was illuminated 3 mm away from the probe used in our study had a radius of 6 mm. It is impossible to estimate how much of the pulp will remain in this area, and how much scattering the enamel and dentine will cause. Fried *et al.* (22) show that dentine scatters strongly in the visible and near infrared wavelength and absorbs weakly. The same study reveals that enamel weakly scatters light between 543 nm and 1·06 μm wavelengths and absorption is negligible. In pulpal blood flow measurements, it is not possible to estimate the contribution of pulpal and outer pulpal tissues to the signal. The radius of the fibre used will also affect the radius of the illuminated circle and change the amount of scattering. If we think that acceptance cones of receiver fibres are narrower than transmitters, how much of the beams can be collected and used is a question. Especially when there is a decay or filling, laser beam scatters towards very different directions. Therefore, especially in these situations, it is difficult to predict where the scattering will be dense.

Polat *et al.* (23) showed that in extracted teeth laser beam can reach 4 mm depth of the root densely, and up to 13 mm depth less densely. They showed that, in some teeth, the laser beam may reach even to apex. These earlier results of ours are in line with our present findings showing that intra and extracoronal scattering may be much more than predictions.

Conclusion

To conclude, apart from the pulp, laser beam applied to the tooth can reach vestibule mucosa, palatinal mucosa, adjacent teeth, lips, tongue and outside the mouth. This indicates that when crown is not isolated, the unwanted tissues may contribute to the signal. We think that while measuring pulpal blood flow, together with the gingiva it is also necessary to isolate the crown.

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