Noninvasive control of dental calculus removal: qualification of two fluorescence methods

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Abstract
The main condition of periodontitis prevention is the full calculus removal from the teeth surface. This procedure should be fulfilled without harming adjacent unaffected tooth tissues. Nevertheless the problem of sensitive and precise estimating of tooth-calculus interface exists and potential risk of hard tissue damage remains. In this work it was shown that fluorescence diagnostics during calculus removal can be successfully used for precise noninvasive detection of calculus-tooth interface. In so doing the simple implementation of this method free from the necessity of spectrometer using can be employed. Such a simple implementation of calculus detection set-up can be aggregated with the devices of calculus removing.

1. Introduction
The periodontitis is one of the most frequent dental diseases. Its development is accompanied with the calculus growth on the teeth surface. Dental calculus contains microorganisms, which vital activity results in the destruction of the periodontal ligament and even loss of the teeth. Calculus removal is the main condition of periodontitis prevention. Its full removal is the principal aim of the treatment. On the other hand such a medical procedure must not result in tooth tissue harming. The problem is accentuated in the case of subgingival calculus removal as it covers the dental root in periodontal chamber \cite{1-2}. The desire of complete calculus removal leads to fatal hard tissue damage because the procedure of calculus removal must be stopped precisely at calculus–tooth interface. Residual calculus detection by tactile, visual, radiograph, ultrasonic, optical coherence tomography, light scattering, IR and THz imaging are not always precise, convenient and cheap \cite{2–7}.

In view of its potential for dental diagnostics, fluorescence spectroscopy in optical range has been the object of research for the last years \cite{8-23}. Such a diagnostics is sensitive and noninvasive. However the opportunities of calculus–tooth interface detection using fluorescence technique have not been investigated yet. The aim of this work is to determine the optimal spectral bands of excitation and registration of the fluorescence necessary for precise detection of calculus–tooth interface. We also aim to optimize the simple implementation of the method free from necessity of spectrometer using.
2. Materials and methods

10 human teeth extracted due to the reason of periodontitis of considerable degree were submitted to the in vitro experiments. The patients were from 40 to 50 years old. The fluorescence was stimulated by cw He-Ne (633 nm) laser and LED (369 nm) irradiation. The power density of irradiation did not exceed 100 mW/cm². The fibre-optic spectrometer LESA-5 on the basis of diffraction grating and linear array detector was used for the spectral analysis of fluorescence. The laser and LED beams were transported through a fibre bundle to the tip of the handpiece within a central fibre. Six surrounding fibres were arranged around this central fibre what allowed the fluorescent light emitted from the irradiated spot to be collected. The fibre tip was situated close to the investigated locus on the tooth surface. Probing area was equal to 200 μm. The wide-band cut-off glass filters KS-18 and ZhS-10 were used to suppress diffused exciting light and surrounding light.

The simple implementation of calculus detection set-up free from necessity of spectrometer using was proposed in [24]. The investigated tooth was illuminated by laser or LED directly or with the help of a fibre. Emitted signal from irradiated spot was collected by the fibre with the tip close to the investigated locus on the tooth surface and detected by photomultiplier. The measurements were fulfilled in direct-current and alternating-current regimes. In the second case exciting light was modulated by the obturator at the frequency of 500 Hz and the emitted signal was recorded in the frequency band 50 Hz. In such kind of implementation the correct choice of type and thickness of wide-band cut-off glass filter in front of a photomultiplier is important as the diffused exciting light must be completely suppressed, while the Stokes components of fluorescence pass a filter without essential losses.

The device SMA-30 was used for layer by layer dental calculus removal using rotating sapphire fraizes. Calculus thickness was determined with the help of optical coherence tomography with longitudinal spatial resolution at a level of 10 μm [25].

3. Results

As it was shown recently [24] the maximum difference between fluorescence intensity from dental calculus and tooth root takes place in two spectral ranges: 620 – 645 nm and 340 – 370 nm. This fact can be used as a basis for calculus–tooth interface detection.
Spectra of fluorescence excited at wavelengths of 369 nm and 633 nm are shown in Fig. 1. It is seen from Fig. 1, that the fluorescence intensity of calculus exceeds its value for dental tissue at the excitation by red light, while at the ultraviolet excitation this situation is opposite because of different optical properties of fluorophores and structures of irradiated objects in these spectral domains. Typical tomogram of tooth with calculus, one part of which was removed by sapphire fraize, is presented in Fig. 2.

Experimental dependencies of fluorescence intensity as a function of dental calculus thickness are shown in Fig. 3. The simple implementation of calculus detection set-up free from necessity of spectrometer was used for these measurements. In comparison with spectral measurements on the basis of spectrometer LESA-5 in this case the difference between the fluorescence signals from calculus and from the root is more essential as these signals are detected using wide-band filters but not narrow band (10 nm) of spectrometer.

For convenience the fluorescence intensity from the calculus with initial thickness $d_0 = 120 \mu m$ is designated by a number 1 for both excitation wavelengths. As can be seen, intensity of fluorescence excited at wavelength of 633 nm decreases approximately on one and a half order. In this case the calculus fluorescence is the principal contribution to fluorescence signal. Reduction of this signal is well described by exponent $\exp[-440(d_0 - d)]$, considering the decrease of exciting and fluorescence light in calculus [26]. The behavior of fluorescence intensity excited at wavelength of 369 nm differs from the one described above. In such a case the fluorescence intensity increases four orders. As a result the difference between the fluorescence intensities excited at wavelength of 633 nm and of 369 nm in the vicinity of calculus-tooth interface is more than five orders.

At the calculus thickness $60 \mu m$ and more the detected signal is determined by both the calculus fluorescence and the root fluorescence. At $d < 60 \mu m$ the fluorescence from the root predominates. Therefore the detected signal quickly increases while approaching calculus-tooth interface.

Thus, the fluorescence excitation in ultraviolet has the obvious advantage in comparison with the excitation by red light. Indeed, the fluorescence intensity excited at wavelengths of 369 nm is more than five orders the fluorescence intensity excited at wavelengths of 633 nm in the vicinity of calculus-tooth interface. A gain in fluorescence signal near interface can be used for the development of the system controlling the calculus removing operation. By estimate, using 10% change of fluorescent signal could guarantee positioning near $d = 0$ with the error at a level 2 $\mu m$. Such a quality of calculus removing has never been achieved.
4. Conclusion

It is shown that the fluorescence excited at near ultraviolet is the most suitable to precise calculus-tooth interface detection. The simple set-up free from the necessity of spectrometer using can be successfully used for these measurements. This set-up can aggregate with the devices of dental calculus removing. It should also be noted that compact, economical and low cost LED can be used for the fluorescence excitation.

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Fig. 1. Spectra of the fluorescence excited at wavelengths of 369 nm (a) and 633 nm (b): 1 – calculus, 2 – root, 3 – transmittances of ZhS-10 (a) and KS-18 (b) wide-band cut-off filters.
Fig. 2. Typical OCT image of the tooth with fractionally removed (right-hand site of image) calculus. Vertical dimension of the image is equal to 1 mm.

Fig. 3. Experimental behaviour of fluorescence intensity excited at wavelengths of 633 nm (1) and 369 nm (2) as a function of layer by layer removed calculus.