Temperature rise in human tooth upon drilling by femtosecond pulses

H. Skenderović[1,2], M. Rakić[1], E. Klarić Sever[3], S. Vdović[1]

1. *Institute of Physics, Bijenička cesta 46, 10000 Zagreb, Croatia*

2. *Center of Excellence for Advanced Materials and Sensing Devices, Bijenička cesta 54, 10000 Zagreb, Croatia*

3. *School of Dental Medicine, University of Zagreb, Gundulićeva 5, 10000 Zagreb, Croatia*

Thanks to increased availability of ultrashort lasers pulses (ps and fs) there are numerous studies dealing with ultrashort laser interaction with hard dental tissue which could lead to replacement of mechanical drills. An alternative to mechanical drilling should have reasonable removal rate without damaging the neighbouring tissue, smallest possible increase in temperature, it should leave smooth surfaces to facilitate the direct adhesion of filling materials and no need for anaesthesia. The dental pulp is extremely sensitive to temperature variations, and an increase of more than 5.6 °C can already result in pulp necrosis in 15 % of cases[1]. Thus, it is mandatory to limit temperature effects for the clinical applicability of lasers.

In our research we employed fs pulses generated in a Ti:Saphire amplifier with pulse length of 120 fs at 800 nm and with 1 kHz pulse repetition to form cavity in a tooth sample. Simultaneously with formation of cavity we measured the temperature with thermocouple at the place where the dental pulp was and numerically modelled the heat transfer in order to assess safe parameters for future employment of fs laser for hard dental tissue preparation. Compared to previous work, we used lower repetition rates and slower scanning speeds.

The scanning speed was varied between 0.2 mm/s to 1 mm/s, and laser power was varied from 20 mW to 200 mw. SEM image of rectangular cavities made by scanning the sample is shown in Fig. 1. right panel. One can see extreme precision of the laser cut. The temperature evolution in the course of drilling a tooth sample is shown in Fig. 1. left panel, along with numerical simulation. In x direction laser scan path length was 500 μm (in 1 s), while y scan step was 40 μm. In total 25 lines with different y position were scanned in meandering way, resulting in the 500x1000 μm scan area.

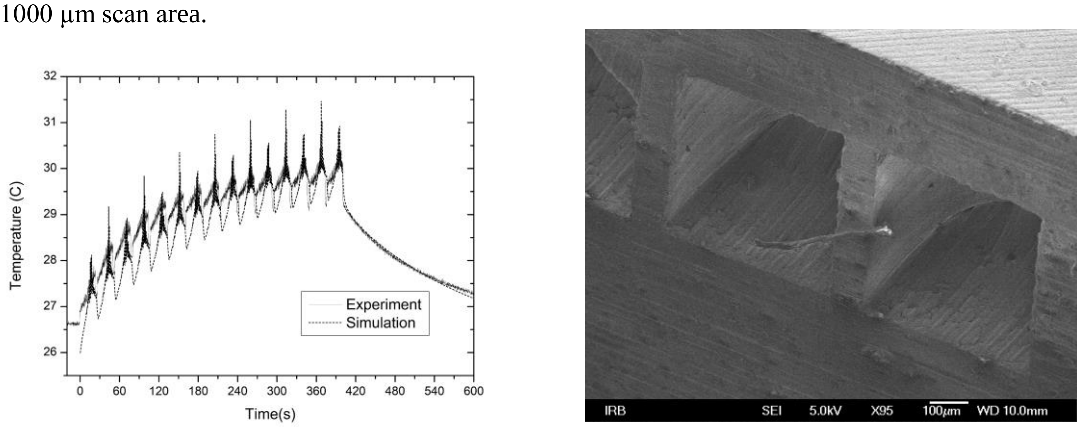

Fig. 2. Measured temperatures during fs laser operation with numerical simulation, left panel. SEM image of dental cavities formed by fs laser, right panel

We used finite element analysis to develop fully three-dimensional heat conduction model with associated boundary conditions. Values of the thermophysical properties are taken from literature. Fourier's heat conduction equations were used. We modeled the incident heat flux from the laser as a moving spatially distributed volumetric heat source where we used the known value for the optical penetration depth in dentine and Beer-Lambert law to model incident heat flux in the direction normal to the incident top surface. The source of heat loss from the top surface is via radiation to the surroundings, while the heat loss at other boundaries is determined by the heat transfer coefficient H which was the only adjustable parameter.

The laser beam is modeled as a continuous heat source with Gaussian profile of 40 μm diameter. The laser beam radius is equal to three standard deviations of the Gaussian function and it account for 99.7% of the total laser energy. The focal point is moved by using a product of triangular and piecewise waveform to define its position along x and y axis over time.

We used fs laser to produce cavities in teeth samples, measured the temperature rise and carried out numerical modelling. The conditions for safe operating are found and can be checked by altering dimensions, powers, and scanning speeds in our model. This work can contribute to assessment of the use of fs lasers in restorative dentistry.

References

[1] L. Zach and G. Cohen, "Pulp response to externally applied heat," Oral Surg. Oral Med. Oral Pathol. **19** 515 (1965).