

OPTIMIZING LASER ABLATION PARAMETERS AND SETUP FOR ROBOT-ASSISTED BONE CUTTING AND DRILLING

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The advantages of laser in surgery such as contact-free processing, arbitrary cutting geometries, and high precision are apt to increase its clinical relevance. Due to challenges including missing depth feedback during ablation and heterogeneous laser tissue interactions no widespread clinical use for hard tissue ablation could be established, yet. In the presented experimental setup an optical coherence tomograph (OCT) ($\lambda = 930 \text{ nm}$) for online process monitoring was added to pulsed Er:YAG cutting laser ($\lambda = 2940 \text{ nm}$)¹ [1]. The OCT's high spatial resolution of about $10 \mu\text{m}$ and its ability to penetrate a few millimetres into tissue qualify this imaging technique for in situ process control [2, 3]. After a detailed description of the setup, this abstract presents results of parameterization experiments for gentle hard tissue ablation without necrosis.

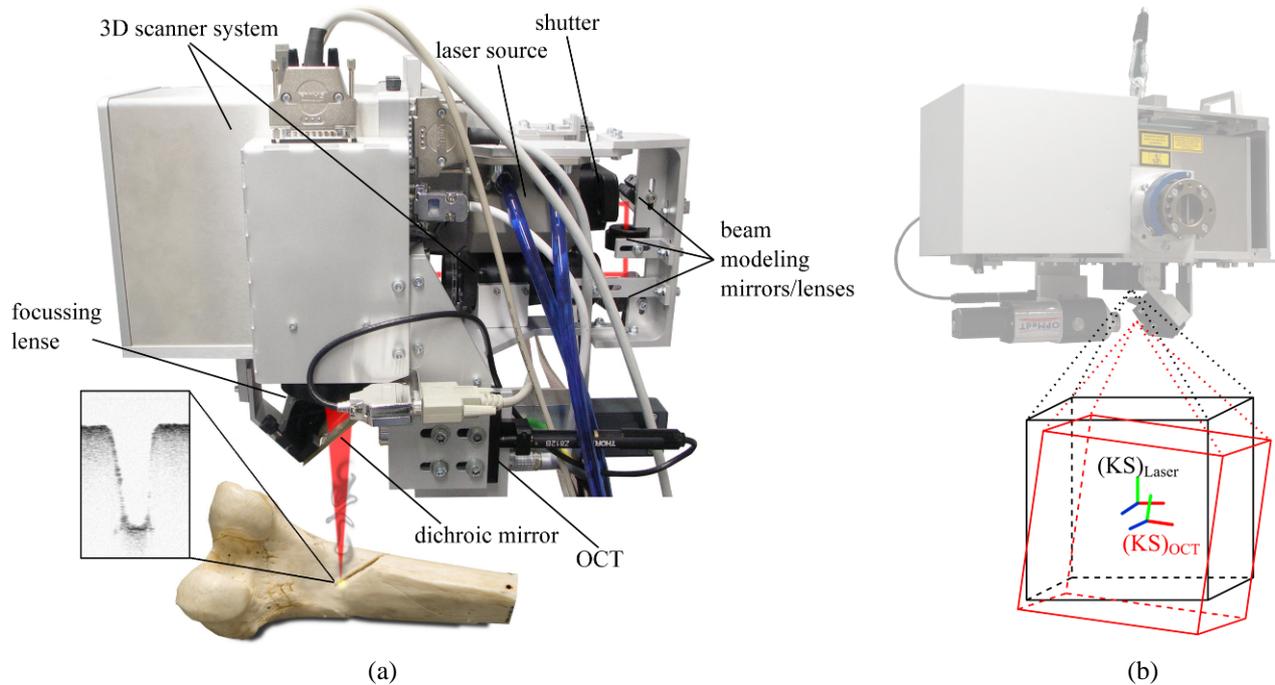


Figure 1: (a) beam propagation within the setup and exemplary ablation with OCT imaging; (b) tilted coordinate systems of Er:YAG laser and OCT

For online imaging of the current incision depth OCT and Er:YAG laser beam are combined by a dichroic mirror (see fig. 1 (a)). Previously, lenses and mirrors are used to model and improve the cutting laser's beam quality as well as its focus spot. A 3D scanner system (2D scanner and dynamic focussing unit) in combination with a focussing lense create an ablation volume of $(10 \times 10 \times 10) \text{ mm}^3$. This volume ideally overlaps the OCT volume and, thereby, guarantees visibility and measurement of the ablated geometry. Due to inaccuracies in the orientation of the mirrors and beam axes a registration of the spatial correlations of OCT and Er:YAG laser is necessary (see fig. 1 (b)). Therefore, a laser grid is ablated in different heights within the OCT volume. In order to calculate the rigid transformation matrix between both coordinate systems,

¹ DPM 15 Laser Module (Pantec Engineering/3m.i.k.r.o.n™)

intersecting planes can be found within the measured laser spots defining position and orientation of the laser coordinate system in the OCT volume. This relationship is constant during the following experiments and high accuracy values can be achieved.

Freshly cut porcine bone was used for the experiments evaluating the parameter space for necrosis-free ablation. Due to the wavelength of the Er:YAG laser that is best absorbed by water molecules the wetness of the tissue is important for success. A fine water spray was used that showed no droplets on the bone surface and did not accumulate in dents. It is sprayed iteratively between each laser sweep with a rate of only about 65 μl per 50-ms-blow. The ablation process is surveyed by an infrared camera in order to analyse thermal effects (see fig. 2 (a)). Although temperatures as high as 120 $^{\circ}\text{C}$ occur at the position of the laser focus, the cooling effects after the spot has passed reduce the temperature under the critical mark of 40 $^{\circ}\text{C}$ in less than 200 ms.

Besides constraining the heat development for the safe cutting of bone close to risk structures it is important to define sets of laser parameters (pump duration, repetition rate, scanning speed) for maximal and minimal ablation rates as well. The deepest incisions of about 350 μm per scanning cycle are reached with 200 μs , 100 Hz, 5 mm/s resulting in 2.4 W. Once a critical tissue strength is reached a slower ablation is necessary to protect underlying nerves. With the parameters (100 μs , 100 Hz, 5 mm/s resulting in 1.2 W) for minimal bone ablation (< 100 μm) it is possible to cut cortical bone as well as periosteum with the same settings without necrosis (see fig. 2 (b)). Therefore, an additional preparation step is obsolete.

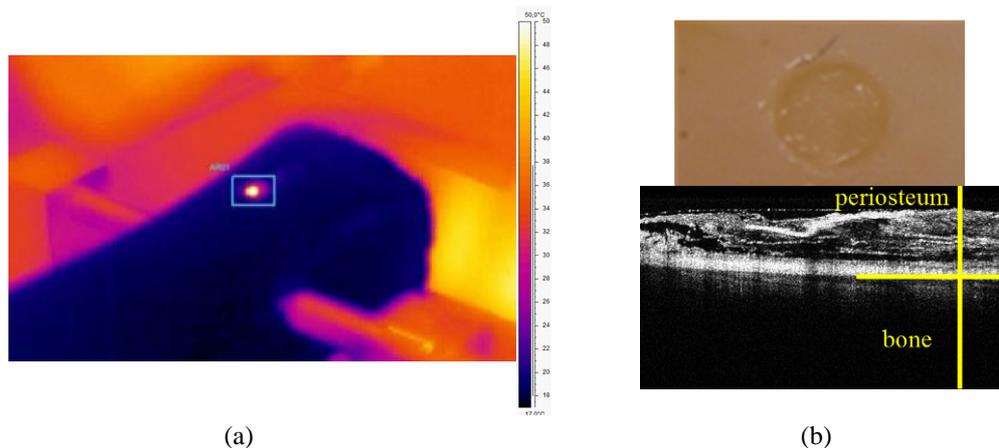


Figure 2: (a) thermo camera image of ablation area on porcine bone; (b) ablated periosteum and OCT image of transition between periosteum and bone

References

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