Pilot ex vivo study of laser induced breakdown spectroscopy for hard and soft tissue differentiation as a feedback system for tissue-specific laser surgery

Hamed Abbasi

E-mail: hamed.abbasi@unibas.ch

Phone: +41612075461

Biomedical Laser and Optics Group, Department of Biomedical Engineering, University of Basel, Allschwil, Switzerland

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Introduction:

Smart surgical tools are devices that can help surgeons reduce possible medical errors and reducing medical errors are quite important [1]. Some of these lethal medical errors can occur during surgery; therefore, developing smart surgical tools that prevent medical errors is necessary. A laserosteotome would be one such smart surgical system that can help surgeons in cutting hard and soft tissues in a safe and efficient manner. This study is part of Minimally Invasive Robot-Assisted Computer-guided LaserosteotomE (MIRACLE) project which is devoted to the development of an integrated miniaturized system able to perform minimally invasive osteotomies (bone cuts) that are less stressful for the patients. In comparison with mechanical tools, it is proven that laser osteotomy has some significant advantages such as noncontact interaction, free-cut geometry, better healing, minimal invasiveness and higher accuracy [2, 3]. In doing so, it is hoped to reduce the length of stay in the hospital and to reduce the time spent in rehabilitation. The main purpose of this study is to develop an optical based sensor that provides feedback during laser surgery. This feedback mechanism will help the surgeon to specifically determine the tissue that being cut and stop the laser when the all desired tissues have been removed. In this way, it will provide high specificity in laser cutting which can prevent cutting important and critical tissues.

Materials and Methods:

While Er:YAG and CO_2 lasers in 3 and 10 micron are the most common laser for bone cut [4], but there are some recent good results of using 532 nm laser for this application [5]. In this study, a pulsed flash pump Nd:YAG laser in second harmonic which generates 532 nm beam with 5ns pulse duration was used for the ablating tissue samples. The laser was run at 107 mJ pulse energy. The generated plasma was collected using a 50um fiber optic connected to a UV-NIR light collector with F-number of 2, and the collected light was send to echelle spectrograph connected to an intensified CCD. Porcine fresh bone and muscle tissue were used as hard and soft tissue samples, respectively. Figures 1.1, 1.2 and 1.3 show the experimental setup, bone sample, and muscle sample, respectively.

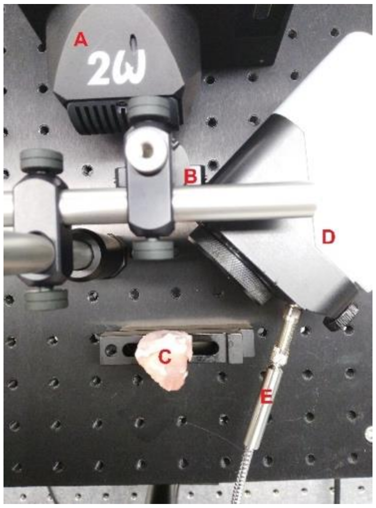

Fig. 1.1. Experimental setup, A: Laser, B: Focusing lens, C: Sample, D: Light collector, and E: Optical fiber.

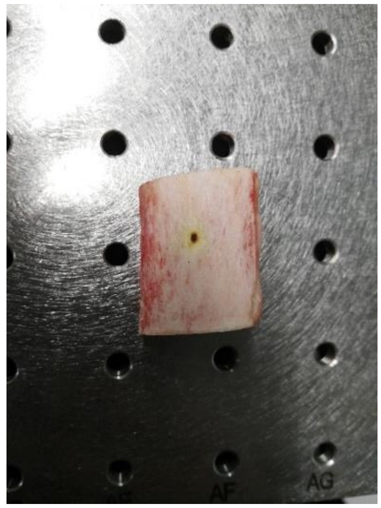

Fig. 1.2. Porcine fresh bone as a hard tissue sample.

Fig. 1.3. Porcine fresh muscle as a soft tissue sample.

Result and Discussion:

The peaks related to the elements found in the samples and were in good agreement with those described in the literature [6, 7]. Figures 2.1 and 2.2 show the recorded spectra of the bone sample, both from one measurement. They are depicted in two different part to show a better resolve between neighbor peaks, the horizontal axis is wavelength in nanometer, and the vertical axis is relative intensity.

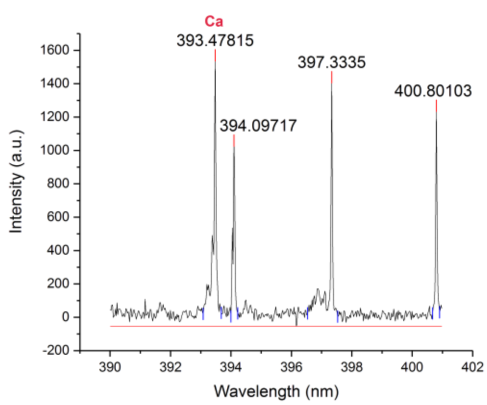

Fig. 2.1. Collected spectra from bone in 390-400 nm interval.

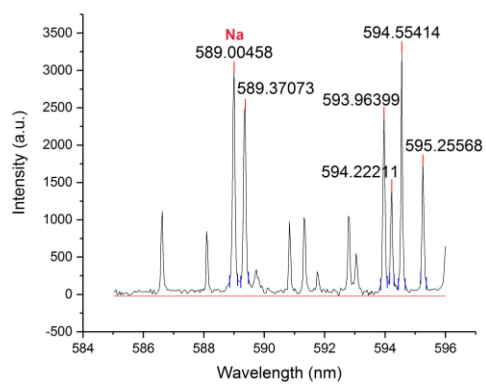

Fig. 2.2. Collected spectra from bone in 585-595 nm interval.

Figures 3.1 and 3.2 show the recorded spectra of the muscle sample, both from one measurement. They are depicted in two different part to show a better resolve between neighbor peaks, the horizontal axis is wavelength in nanometer and the vertical axis is relative intensity.

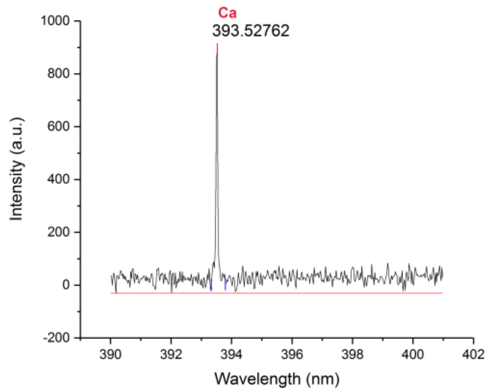

Fig. 3.1. Collected spectra from muscle in 390-400 nm interval.

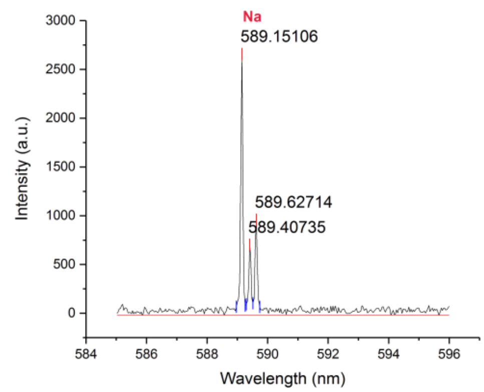

Fig. 3.2. Collected spectra from muscle in 585-595 nm interval.

The recorded spectra were analyzed based on the intensity ratios of the well-known peaks of the calcium and sodium lines which were visible in both tissue types. In the bone sample, the ratio of 393.5 nm Ca peak to 589 nm Na peak (first in doublet lines) was 0.52 while this ratio for muscle sample was 0.34. It is due to more Ca content is calcified hard tissue samples like bone.

Conclusion:

The obtained preliminary results show a successful differentiation between hard and soft tissues samples to use as a real-time feedback mechanism to improve the safety and sensitivity of clinical laser surgeries. However, the repeatability of the experiment should be evaluated, and the error bar should be calculated in the future study.

Acknowledgements:

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