FORCES AND TEMPERATURE MEASUREMENT DURING TEMPORAL BONE MILLING

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Introduction

Otologic surgery is performed using a hand-held milling tool to access anatomical areas of interest inside the temporal bone. This milling process generates heat, which diffuses in the living tissues and leads to potential thermal injuries. The facial nerve is especially at concern due to its location, near the standard surgical path for middle ear surgery. In fact, it has been shown that irreversible damages to nervous tissues occurred after one minute of exposition at a temperature of 41°C (1). However, monitoring the facial nerve temperature is difficult because of its complex anatomy and its difficulty of access inside the temporal bone. In the following study, we present a protocol allowing for simultaneous measurement of the facial nerve temperature and milling forces during an otologic surgery procedure on a cadaveric human temporal bone sample.

Methods

A cadaveric specimen of a left human temporal bone was obtained from a female donor aged approximately 80 years old and provided by the Laboratory of Anatomy of Nancy University Hospital, France. A thermocouple insertion protocol, previously validated on 3D printed synthetic samples (2) was applied, allowing for precise insertion of four 0.08 mm diameter, PFA-insulated thermocouples on the third portion of the facial nerve. The specimen was then manually milled by an expert surgeon with the use of irrigation (15cc/min flow rate) following middle ear surgery classical steps, with mastoidectomy and skeletonization of the facial nerve. Mastoidectomy was performed with a 4mm diameter tungsten carbide round burr, while skeletonization was performed using a 2mm diameter diamond burr. Surgical spindle rotation speed was manually controlled by the surgeon during the milling process and varied from 30,000 to 50,000 rotations per minute.

Milling was performed under a Zeiss operating microscope using a Medtronic Indigo High-Speed Otologic Drill motor with a straight handpiece, an IPC console and an IPC System Multi-function Foot pedal. The measurement of milling forces was made using a Kistler™ 9119AA1 dynamometric platform. Forces were amplified through a Kistler™ 5167A charge amplifier, and both thermocouples and platform signals were acquired through a NI CompactDAC™ using a dedicated computer with NI Labiew™ 2020 software.

Results

As illustrated by figure 1, all four thermocouples signals followed the same trend, indicating good positioning repeatability. Temperature increased regularly in spikes, with a maximum recorded variation of 5.8°C. Forces signals showed extensive vibrations, characteristic of manual milling, with good repeatability between the milling sequences. A decrease in force signals values was observed between mastoidectomy and skeletonization phases. The values oscillated from -4.7N to 11.2 N, with the same order of magnitude for all components (X and Y axes corresponding to the milling plane and Z to the milling depth).

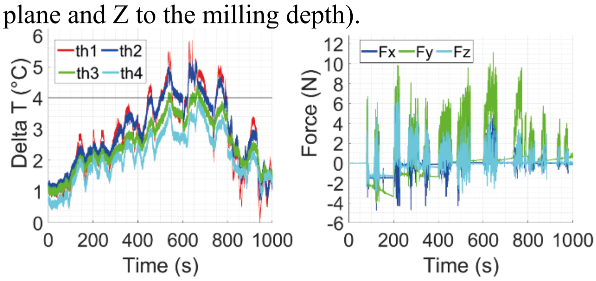

Figure 1: Temperature variation of the facial nerve and corresponding milling forces

Discussion

We were able to measure the forces and temperatures generated during surgical milling of human temporal bones. Measured temperature variation did exceed the thermal damage threshold for nerves despite the use of irrigation, showing the importance of studying the process parameters to mitigate the heat generated and avoid complications. Additionally, force signals put in evidence the influence of surgical phases on the level of forces applied, and consequently the influence of the surgical tools and milling parameters. Further testing is required to assess the repeatability of those measurements, and determine good practices in otologic surgery milling.

References

1. G. C. van Rhoon et al. , European Radiology, 23(8), 2215–2227, 2016
2. M. Boillat et al., Computer Methods in Biomechanics and Biomedical Engineering, S34-S35, 2022

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