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Detecting the rupture of the pterygoid plate using an instrumented hammer: an animal study

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1. Introduction

Osteotomies are surgical procedures during which the surgeon uses an osteotome to cut bone tissue. Despite their routine clinical use, they are often performed without any visual control. For example, in many maxillofacial surgeries, the surgeon must detach the pterygoid plates from the palatal bones using an osteotome, with significant risks described in detail in (Kang, Lin, & Marentette, 2009). Although X-ray-based surgical navigation systems have been proposed (Nijmeh, Goodger, Hawkes, Edwards, & McGurk, 2005), they are not commonly used because they are radiating and they increase the operating time. Surgeons still rely on their proprioception to determine when to stop impacting the osteotome, which is important to avoid complications such as dental damage and bleeding.
Our group has developed a technique consisting in using an instrumented hammer that can provide information on the mechanical properties of the tissue located around the osteotome tip (Hubert, Rosi, Bosc, & Haiat, 2020). The aim of the present study is to determine whether a hammer instrumented with a force sensor can be used to detect the crossing of the osteotome through the pterygoid plate.

2. Methods

2.1 Experiments

31 osteotomies were performed on 16 lamb skulls with a hammer (32-6906-26, Zepf, Tuttlingen, Germany) instrumented with a force sensor (208C04, PCB Piezotronics, Depew, NY, USA). The hammer and the osteotome were held manually. The force signal *s(t)* obtained for each impact was analyzed using a dedicated signal processing technique. This signal, shown in Figure 1, is composed of several peaks. The first peak corresponds to the impact of the hammer on the osteotome, the following peaks correspond to the rebound of the osteotome between the hammer and the material on which the osteotome lies (Hubert *et al.*, 2020). The indicator τ was then defined as the difference between the times of the second and first peaks of *s(t)*. The impulse ratio λ corresponds to the ratio between the first two peak integrals.

2.2 Data processing

Each impact was then assigned to a class corresponding to the material surrounding the tip of the osteotome. After each impact, an operator checks visually whether the osteotome has crossed the plate or not. The canonical variable c_1 and c_2 were determined following (Krzanowski, 1998) as linear combinations of the indicator τ, λ, $\Delta\tau$ and $\Delta\lambda$ given by the difference of τ and λ between an impact and the previous one, respectively.
An SVM-based algorithm for classification was then developed to automatically classify impact according to c_1 and c_2.
Since the aim of our device is to detect the impact corresponding to the osteotome crossing the bone plate, we

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had to minimize the impact classified as an impact in the bone while the osteotome has already crossed the bone plate. To do so, we chose to apply a cost matrix as defined in (Liu *et al.*, 2018), which considers different weight to the misclassification. To adjust the weight apply to the misclassification, we performed an optimization procedure based on the negative likelihood ratio (Yang, Parikh, Stavros, Otto, & Maislin, 2018).

3. Results and discussion

3.1 Experimental results

The indicator τ increases when the osteotome crosses the pterygoid plates and it is negatively correlated with the plate thickness. These results are consistent with those presented in (Hubert *et al.*, 2020).

3.2 Classification result

The performance of the prediction algorithm before and after the use of the cost matrix is summarized in Table 1. Although the accuracy of the algorithm decreases slightly when the cost matrix is applied (from 0.958 to 0.947), the cost matrix allows to reclassify 20 "Crossing" classifies as "Bone" which is the most critical case in the clinic.

Table 1. Performance of the prediction algorithm before and after the use of the cost matrix

Parameters	Without cost matrix	With cost matrix
Total Impact Number	1591	1591
Correct Prediction	1527	1507
"Crossing" classified as "Bone"	49	29
"Bone" classified as "Crossing"	15	55

Credit: Manon Bas dit Nugues

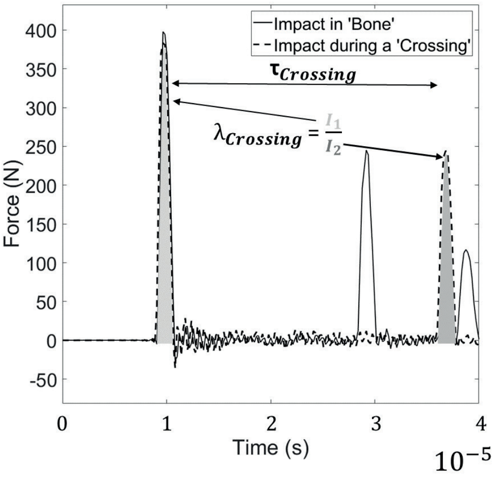

Figure 1. Example of a part of two signals *s(t)*, variation of the force as a function of time, for an impact in 'Bone' and an impact during a 'Crossing'

4. Conclusions

This study shows that the hammer presented herein was able to detect the crossing of the osteotome and that it is also sensitive to the thickness of the sample being osteotomized. It could therefore provide information to the surgeon during the operation, thereby avoiding unnecessary impacts leading to complications. These results pave the way for the development of an intra-operative decision support system in maxillofacial surgery.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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