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Investigation of stress distribution in the temporomandibular joint during maxillofacial surgery

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Introduction

Distraction osteogenesis (DOG) is a surgical process that is used to reconstruct skeletal deformities and to lengthen bones. It consists in fracturing the bone into two segments (corticotomy) which are then gradually moved apart using a distraction device (around 1mm/day). This allows new bone and surrounding soft tissues to form in the gap. When the targeted length is reached, a consolidation phase follows in which the bone is allowed to keep healing. Originally used in orthopedics, early results in humans indicated that the process can be applied in maxillofacial surgery to treat transverse mandibular bone deficiency. However, bone movements must be carefully planned before a device is implanted, especially in the area of the temporomandibular joint (TMJ) which may be at the origin of chronic pain. This work aimed at investigating the stress distribution in the TMJ using a high resolution 3D finite element model of the masticatory system in order to support (or contradict) the clinical theory that symphyseal distraction generates a low risk of long-term TMJ dysfunction or condylar resorption.

Materials and methods

Some models of TMJ exist in literature but most of them are oversimplified (no teeth, coarse mesh …) or consider symmetrical movements of the mandible and do not account for the natural asymmetry of both joints. In this study, a three-dimensional head model [Fig. 1] of a thirty-year-old healthy (with asymptomatic joints) and fully dentate male patient was built starting from classical medical images [1,2]: the skull, the compact and cancellous parts of the mandible and the mandibular and maxillary teeth were obtained from CT scan images, whereas left and right articular discs and connective tissues (capsule and temporomandibular ligament) were located from MRI images. Medical images were processed using a 3D visualization and analysis software (AMIRA®). Resulting 3D geometries were imported into our FE analysis software FORGE®. Material properties were mostly taken from the literature and assigned to each body. When available data were too scattered (i.e. for mandible cortical bone), data were obtained using inverse analysis techniques [3]. A friction law was used to account for contact between the different bodies. Force vectors were applied to the model to account for the bilateral masticatory muscles (masseter, temporalis and medial pterygoïd). The magnitude of each muscle force was assigned according to its total physiological cross section (PCS) and the scaling factors.

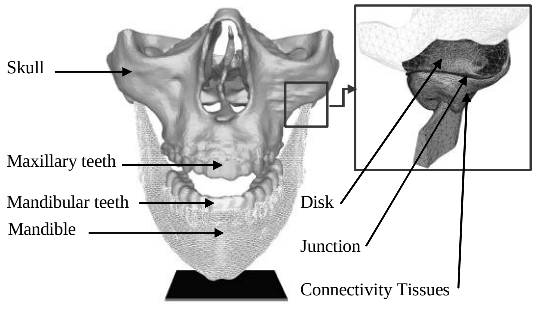

Fig. 1 : FE model before DOG

The osteotomy was modeled by cutting the mandible mesh in the mandibular midline area. The expansion was simulated using two forces normal to the cutting planes and applied to the two

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segments (this model is representative of a 10 mm displacement obtained with a bone borne expansion device). The bone callus was manually added in between and modelled as a strengthened region characterized by the Young's modulus of a consolidated bone.

Results and discussion

The von Mises stresses distribution in both joint discs before and after distraction was evaluated successively at 8, 6, 4, and 2 mm inter-incisal distances (IID) during jaw closure [Fig. 2].
In both cases:

- the stress patterns were asymmetric and increased continuously during jaw closing;
- a peak of stress was observed in the medial, lateral bands in both discs, and at every level.

The maximum stress intensity was slightly higher in the articular discs after distraction (14.80 MPa) than before (13.24 MPa) at 2 mm of jaw closure [Fig. 3].

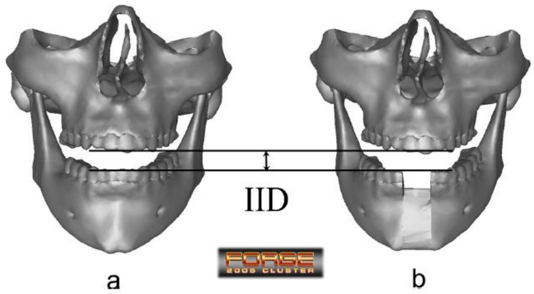

Fig. 2 : Inter-incisal distance (IID): (a) before and (b) after DOG

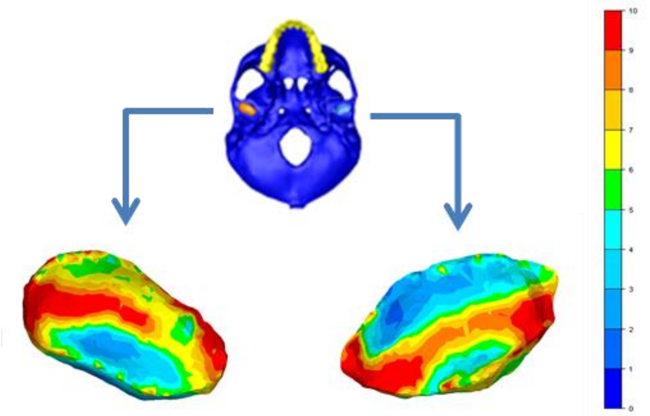
Fig. 3 : von Mises stress (MPa) in right and left articular discs (IID = 2 mm)

To be even more accurate, our model should take into account the periodontium tissue (located between the teeth and the mandible) because of its important mechanical role. However, this tissue is invisible using standard medical imaging techniques and requires microtomography systems which are not applicable to living patients. Nevertheless the results suggest that anatomical changes in TMJ structures are unlikely to predispose to long-term tissue fatigue and should avoid permanent clinical TMJ symptoms. Rate and frequency of distraction are probably more important than the amount of distraction.

References

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