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Research Paper
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Finite element evaluation of three methods of stable fixation of condyle base fractures

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Abstract. The surgical treatment of mandibular condyle fractures currently offers several possibilities for stable internal fixation. In this study, a finite element model evaluation was performed of three different methods for osteosynthesis of low subcondylar fractures: (1) two four-hole straight plates, (2) one seven-hole lambda plate, and (3) one four-hole trapezoidal plate. The finite element model evaluation considered a load applied to the first molar on the contralateral side to the fracture. Results showed that, although the three methods are capable of withstanding functional loading, the lambda plate displayed a more homogeneous stress distribution for both osteosynthesis material and bone and may be a better method when single-plate fixation is the option.

Keywords: finite element analysis; mandibular condyle; mechanical processes.

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Condyle fractures are one of the most controversial maxillofacial injuries regarding diagnosis, classification, and treatment.[1,2] One of the most used classifications considers the anatomical level of the fracture: condylar head, neck, and base.[3,4]

In growing patients, these fractures may impair the growth of the craniofacial skeleton and result in mandibular deficiency, asymmetry, or ankylosis.[5,6] In adult patients, condylar head and high subcondylar fractures have greater potential for functional adaptation of the condyle without restoration of the anatomy than displaced base fractures with loss of ramus height.[7] Thus, high fractures with little bone available for fixation are usually treated non-surgically, whereas low displaced fractures are frequently treated surgically by reduction and stable internal fixation.[8]

In the condylar region, functional loads result in compressive stress patterns along the posterior border of the ramus and tensile stress patterns along the anterior border of the ramus and in the zone situated below the sigmoid notch.[9] Osteosynthesis of condylar fractures must properly stabilize both areas, allowing early function with minimum stress.[10] Failure of osteosynthesis, such as plate fractures or loosening of screws has been reported,[7,11–14] leading to a better understanding of the biomechanics of condylar osteosynthesis and of how fixation methods behave in the condylar area.[15–18]

Mechanical dynamic essays have led to advances in our understanding of the stress that occurs at the condylar process and to the osteosynthesis materials applied to that area, providing information that can be used in other types of analysis. Finite element analysis is a technique by which a physical prototype can be studied by creating a precise mathematical model.[19] It is considered an efficient method for the evaluation of the biomechanical behaviour of the mandible.[20,21] Mathematical models do not allow absolute clinical inferences but can offer a detailed description of the distribution and relationship between forces and tensions within biological variability.[22]

This study aimed to evaluate the biomechanical behaviour of three methods of plate osteosynthesis of condyle base fractures, in relation to load transferring and tension distribution over the fixation materials and bone, through finite element analysis.

Materials and methods

Construction of the mandibular model

A three-dimensional finite element model (FEM) of a human mandible without anomalies was generated from DICOM files of data collected by the Centre for Information Technology (CTI; Renato Archer Information Technology Centre, Campinas, SP, Brazil). The data were derived from a dry mandible from which computed tomography (CT) images were obtained. The software InVesalius (version 2.1; CTI, Ministry of Science and Technology, Campinas, SP, Brazil) was used for image processing and the creation of an STL model, which was later converted to CAD (computer aid-designed) geometry with the software Rhinoceros (version 4.0, Robert McNeel and Associates, Seattle, WA, USA) and exported for FEM analysis with the software ANSYS Workbench (version 14.0; Canonsburg, PA, USA). For the study, a condylar base fracture was simulated on the left side of the mandibular model. It was classified in accordance with the recommendations of the Strasbourg Osteosynthesis Research Group (SORG). According to this classification, condyle fractures are defined as diacapitular fractures (through the head of the condyle), condylar neck fractures, and condylar basis fractures.[3,4]

The element type used for this FEM was 'tetrahedral with 10 nodes' (Tet10). A manual control was carried out, where structures close to the plates and screws had smaller element sizes so that they could better demonstrate the stress gradient.

Construction of the osteosynthesis models

Three different digital models of commercially available titanium plates were provided by the manufacturer (Synthes, Basel, Switzerland) as STL models, which followed the same processing method as described for the construction of the mandibular FEM model. Virtual screws were created according to the manufacturer's specifications. The virtual plates and screws were used to simulate the osteosynthesis of the condylar fracture created on the mandibular model. Plate models were 1 mm thick and stabilized with 6 mm × 2 mm screws on the condyle segment and 8 mm × 2 mm screws on the mandibular ramus, following principles of functionally stable internal fixation,[23] to control tensile and compression functional stresses that develop on the bone and osteosynthesis material.[18] Plates and screws are made of commercially pure titanium. Screws from the particular manufacturer that provided the plate models are made of a titanium alloy (Ti–6Al–7Nb). Regarding the screws, although the exact shape and thread design were not considered, an external diameter of 2 mm was used. This corresponds to the diameter of a 2-mm real screw including the threads. The bone structure was differentiated between cortical and trabecular, in which the cortical structure has an average thickness of 2 mm. No pre-tension was applied.

Types of osteosynthesis tested

Type 1 comprised two straight non-locking four-hole plates, one positioned along the posterior mandibular border and the other bellow the sigmoid notch in an oblique fashion, at the anterior border of the condylar process, with two screws on each side of the fracture (Fig. 1A).

Type 2 comprised one seven-hole lambda plate, which is a locking plate, positioned along the posterior border of the mandible with the oblique extension under the sigmoid notch and two screws in the condylar fragment and the remaining five distributed along the ramus (Fig. 1B).

Type 3 comprised one four-hole trapezoidal plate, also a locking plate, positioned with the wider base centred in the distal fragment and the narrow end in the proximal condylar fragment. Two screws were placed on each side of the fracture (Fig. 1C).

Properties of materials

For the FEM analysis, the models were considered homogeneous, isotropic, and linear elastic: homogeneous due to the same mechanical properties in all their points; isotropic, because in all points the mechanical properties do not change

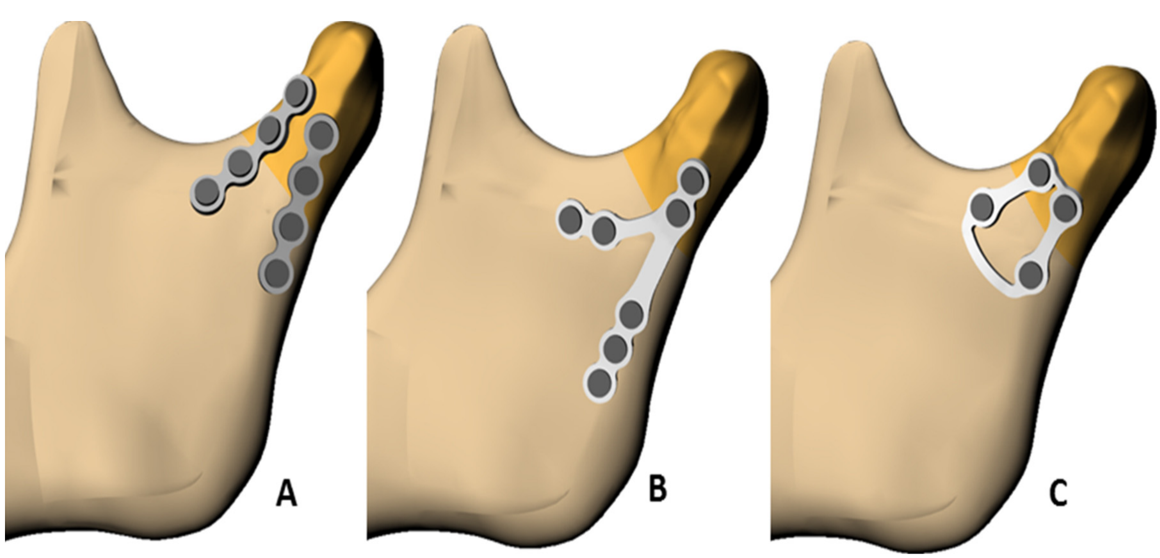

Fig. 1. Fixation methods: (A) two straight plates; (B) lambda plate; and (C) trapezoidal plate.