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Biomechanical stability analysis of rigid intraoral fixation for bilateral sagittal split osteotomy

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Summary *Background:* Biomechanical stability in patients in whom mandibular prognathism was corrected with different fixation methods during bilateral sagittal split osteotomy (BSSO) surgery remains controversial and needs to be clarified.
Methods: A three-dimensional (3D) finite element (FE) model of the mandible was developed to simulate the biomechanical responses of osteo-synthesis screws and the stability of different screw-placement arrangements in BSSO. Six types of fixation methods for the osseous segments were simulated with two or three screws in different placement arrangements to avoid injury to the inferior alveolar nerve.
Results: A triangular configuration of the screw position across the nerve presented less stress loading than the linear configuration, and hence provided better stability as the preferred fixation method for BSSO of the mandible. When the screws were aligned in a linear setting, the stress values were 4 times higher, implying a less stable fixation. Neither two nor three screws applied at the superior border appeared to be better at exploiting the increased thickness of the cortical bone encountered in this region.
Conclusions: According to the 3D-FE analysis, the configuration with three screws inserted in a triangular shape across the inferior alveolar nerve (Type 4) demonstrates the best rigidity among six screw-placement configurations. Three 2.3-mm diameter bi-cortical screws were considered a sufficient fixation tool after BSSO of the mandible.

A high proportion of the normal population has been observed to have malocclusion, and 5–10% of them in Taiwan are due to mandibular prognathism.[1] Orthognathic surgery with bilateral sagittal split osteotomy (BSSO) with or without maxillary osteotomy is now widely used to

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correct mandibular prognathism. Rigid internal fixation of osteotomy segments is required to reduce relapse and to allow early mobilisation of the mandible following BSSO. Screws are used with different numbers and locations for rigid intraoral fixation.[2] Although screws are well-known and clinically accepted alternatives to bone plates for achieving stable osteo-synthesis or rigid intraoral fixation, the biomechanical stability and the stresses associated with various fixation modes have not been investigated previously and remain to be clarified.

Analysing traditional experimental approaches or clinical observations reported to date does not provide enough information to determine the biomechanics for BSSO. On the contrary, finite element (FE) method could provide mechanical responses and alter parameters in a more controllable manner, driving its common use as an analytical tool in biomechanical studies. The FE method is a mechanical analytical system widely applied in engineering and the aerospace industry and can also be used to solve complex problems in dentistry and orthopaedics.[3,4] In the FE method, the computational model is developed on the modular principle from many elements of finite size; thus, it is well adapted to the real structure. This procedure is termed 'discretisation'. In given conditions of clamping tension and stress, the deformations and strains of these elements can be calculated. The elements are linked together by nodes. On the basis of the linkage conditions of the elements to the nodes (the displacement and torsion of the nodes is the same in all directions), the deformation of the overall structure at every node and the variables derived from this, as well as the strains, can be calculated.[5] Baiamonte et al.[6] compared *in vitro* results of the strain on a loaded monkey mandible that had osseo-integrated titanium implants with the results obtained by means of the FE method; they concluded that the FE method is a feasible tool for mechanical strain calculation.

In the present study, the stability and biomechanical responses of six different screw-placement arrangements in BSSO were evaluated by 3D-FE analysis (FEA). The stress distributions around the screws and the bone were used as stability criteria to select the preferred fixation method for bilateral split osteotomy of the mandible.

Material and methods

A healthy male mandible was chosen for the FE model construction. The mandible was scanned in the neutral position using computed tomography (CT). Images were taken with intervals of 1 mm in the axial plane direction. The 3D mandible reconstruction was performed using commercially available software (Amira 3.1.1 Mercury Computer Systems, Germany). The parallel contours of the inner/outer cortical bone contours were then input into an FE package (ANSYS, v 8.0, Swanson Analysis Inc., Houston, PA, USA) to generate solid cancellous and cortical bone models.

The solid model of the mandible was excised using an idealised planar cut to simulate the BSSO method in ANSYS. The distal fragment was repositioned into a position set back by 10 mm. According to studies previously published by Shira,[7] Ardary et al.,[8] Foley et al.,[9] Kim et al.,[10], Obeid and Lindqvist,[11], Schwimmer et al.,[12] Shetty et al.,[13] Uckan[14] and Maurer et al.,[5] six types of fixation methods for the osseous segments were simulated with two or three screws in different screw-placement arrangements. Fixation in type 1 consists of a linear screw-placement configuration, in which two screws are placed above and parallel to the neurovascular bundle. Fixation in type 2 consists of a linear screw-placement configuration, in which three screws are inserted above and parallel to the neurovascular bundle. Fixation in type 3 consists of a triangular screw-placement configuration, in which three screws are inserted above the neurovascular bundle. Fixation in type 4 consists of a triangular screw-placement configuration, in which two screws are inserted above the neurovascular bundle and one below (lower screw is in line with front upper screw). Fixation in type 5 consists of a triangular screw-placement configuration in which two screws are inserted above the neurovascular bundle and one below (lower screw is in line with back upper screw). Fixation in type 6 consists of a linear screw-placement configuration, in which three screws are inserted above and perpendicular to the neurovascular bundle (Figure 1). The mechanical properties of the mandible bones and screw are listed in Table 1. The construction of the 3D-FEA model for three-screw triangular placement configuration is shown in Figure 2. In order to avoid quantitative differences in the FEAs, six screw-placement patterns were derived from the same solid model with a single mesh pattern. During solid model generation, the solid model was shaped with many independent volumes because the screws overlapped owing to the six screw-placement patterns. However, the form and size of these volumes allowed them to act as part of the bone or screw, depending on the material properties ascribed to them.

To verify the FEA results, a convergence test was used to guarantee that our numerical model reached the converged results and that no further mesh refinement was necessary. Based on the solid model of type I screw fixation, single mesh patterns of the FE models with smart element size levels 5, 6, 7 and 8 (as shown in Figure 3) were generated using quadratic tetrahedral elements (Solid 92) in ANSYS.

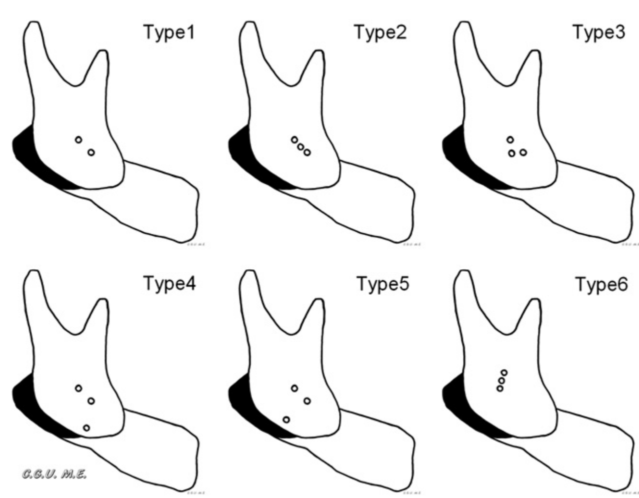

Figure 1 Six rigid, intraoral fixation screw-placement configurations. BSSO was performed and set back by 10 mm.