Biomechanical Evaluation of Magnesium-Based Resorbable Metallic Screw System in a Bilateral Sagittal Split Ramus Osteotomy Model Using Three-Dimensional Finite Element Analysis

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Purpose: The aim of this study was to evaluate the stress distribution of a magnesium (Mg)-based resorbable screw system in a bilateral sagittal split ramus osteotomy (BSSO) and to compare its biomechanical stability with those of titanium (Ti)-based and polymer (IN)-based systems.

Materials and Methods: A 3-dimensional BSSO model (10-mm advancement and setback) was constructed with Mimics. Bicortical screw fixation using Ti, IN, and Mg screws was performed with 4 different geometries of fixation. With an occlusal load of 132 N on the lower first molar, the von Mises stress (VMS) distribution was calculated using ANSYS.

Results: The VMS distribution of Mg was more similar to that of Ti than to that of IN. In all cases, the highest VMS was concentrated on the screw at the most posterior and superior area. Stress was distributed mainly around the screw holes (cancellous bone) and the retromolar area (cortical bone). In the advancement surgery, fixation with 5 Mg screws (5A-Mg, 99.810 MPa at cortical bone) showed biomechanical stability, whereas fixation with the same number of IN screws did not (5A-IN, 109.021 MPa at cortical bone). In the setback surgery, although the maximum VMSs at cortical bone for Mg, IN, and Ti were lower than 108 MPa (yield strength of cortical bone), Mg screws showed more favorable results than IN screws because the maximum VMSs of Mg at cancellous bone were lower than those of IN.

Conclusion: The Mg-based resorbable screw system is a promising alternative to the IN-based system.

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Titanium (Ti)-based osteosynthesis systems have remained the gold standard for facial bone surgery for many years; however, they have problems, such as the spread of Ti particles into the surrounding tissues,[1] the disturbance of bone remodeling by the "stress-shielding" effect,[2] and the intracranial translocation of the implant in pediatric patients.[3] Since polylactic acid was introduced for surgical implants[4] and its first application for fracture reduction was reported,[5] various kinds of polymer-based resorbable screw systems have been introduced as substitutes for Ti-based systems. Initially, mechanical properties inferior to those of Ti

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were the major limitations for clinical applications of polymer-based resorbable screw systems, but these have gradually been overcome with the development of self-reinforcing techniques.[6] During the past 2 decades, polymer-based systems have gained increasing popularity among surgeons. Although many researchers have reported that current biodegradable osteosynthesis systems can provide clinically reliable stability in facial bone surgery,[7,8] some results are questionable, owing to the insufficiency of well-designed randomized controlled trials, in terms of biocompatibility and strength.[9-11] With additional drawbacks, such as the inconvenience of use in thin bones owing to an additional tapping procedure, higher cost, and unsatisfactory stability in high load-bearing areas, polymer-based biodegradable osteosynthesis systems are still not accepted as alternatives to Ti systems.

Since the first clinical use of magnesium (Mg) as a ligature wire for bleeding vessels was described in 1878 by the physician Edward C. Huse,[12] Mg has been investigated as a biodegradable metallic implant. Mg has several unique and interesting properties. First, Mg is safe and biocompatible because it is the second most abundant intracellular cation in the human body; it is indispensable to adenosine-5′-triphosphate metabolism and is involved in the function of more than 300 enzymes.[13] Second, it is known to promote the adhesion of osteoblastic cells.[14] Third, its mechanical properties are superior to those of biodegradable polymers and are close to those of natural bone. However, although some osteosynthetic applications of Mg had been documented in the early 1900s,[15,16] its biomedical application has been discouraged for a long time owing to its poor corrosion resistance in an aqueous environment and to the tissue-damaging potential of the concomitant hydrogen gas.[17] In recent years, encouraging results showing control over the corrosive behavior of Mg[18,19] and favorable in vitro characteristics of Mg-based orthopedic screws have been reported.[20] However, little evidence of their biomechanical reliability in clinical situations exists.

In this study, a 3-dimensional finite element analysis (FEA) was used to evaluate the stress distribution in a mandibular orthognathic surgery model with an Mg-based resorbable screw system and compare the results with those of polymer-based and Ti-based screw systems. The authors evaluated the biomechanical stabilities of 3 screw systems and tried to predict an appropriate or minimal strength for clinical application, a requirement for developing an Mg-based fixation device.

Materials and Methods

A 3-dimensional virtual mandibular model was constructed using Mimics 12.1 (Materialise Ltd, Ann Arbor, MI) with computed tomographic Digital Imaging and Communications in Medicine (DICOM) data (0.5-mm slice thickness). In this model, the outer layer (one fourth the diameter) was defined as cortical bone, and the inner cancellous core occupied half the diameter of the mandible. The 2 mandibular condyles were rigidly fixed in the glenoid fossa, and no condylar movement was allowed.

A bilateral sagittal split ramus osteotomy (BSSO) was performed. The horizontal osteotomy line was parallel to the mandibular occlusal plane above the lingula, and the vertical osteotomy line was parallel to the axis of the lower second molar, located under the interdental gingiva between the lower first and second molars. The distal segment was advanced or setback with a length of 10 mm, and the screws were fixed bicortically.

Three different screw systems were used to fix the segments: Ti screws, Inion CPS screws (IN; Inion, Ltd, Tampere, Finland; 17% D-lactide, 78.5% L-lactide, and 4.5% trimethylene carbonate), and Mg screws. The diameter of each screw was set to 2.0 mm for Ti, 2.2 mm for Mg, and 2.5 mm for IN. All screws were 12 mm in length. To minimize the sharing effect of stress from bony contact, a gap of 0.5 mm was set between the proximal and distal segments of the mandible.

For an accurate localization of fixation points, the x axis was defined as an extension of the mandibular occlusal plane, and the reference point was defined as the intersection of the x axis and the anterior border of the ascending mandibular ramus. The y axis was defined as the line perpendicular to the occlusal plane and passing through the reference point. The fixation points and their locations were defined as follows (Fig 1A):

- Point 1: 10 mm below the reference point: (0, −10)
- Point 2: 5 mm backward and 8 mm upward from point 1: (−5, −2)
- Point 3: 5 mm forward and 8 mm downward from point 1: (5, −18)
- Point 4: 15 mm downward from point 1: (0, −25)
- Point 5: 15 mm backward from point 1: (−15, −10)

For assessing the effect of the number and locations of fixation screws, the geometries of fixation were assigned according to the modified protocol of Choi et al[21] (Fig 1B), where 2 or 3 screws are placed on the upper load-sharing area of the external oblique ridge and 0, 1, or 2 screws are placed on the lower load-bearing area (Table 1).

After a biting force of 132 N had been loaded onto the lower first molar,[22] the patterns of stress distributions around the screws and the cortical and cancellous bones were calculated as von Mises stress (VMS) using ANSYS 10.0 (ANSYS, Inc, Canonsburg, PA). The VMS is a scalar value that represents the