Biocompatibility and Efficiency of Biodegradable Magnesium-Based Plates and Screws in the Facial Fracture Model of Beagles

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Purpose: A biodegradable magnesium alloy system has been developed as a substitute for conventional plates and screws made of titanium or absorbable polymer. However, previous studies were limited to small animal experiments using screws or wires. In the present study, we preliminarily evaluated the biocompatibility and effectiveness of human standard-size biodegradable magnesium-based plates and screws in facial fractures of beagles.

Materials and Methods: Fracture lines were created bilaterally in the zygomatic arches of 6 beagles. They were fixed in situ with plates and screws made of magnesium alloy mixed with calcium and zinc (experimental group) or absorbable polymer (control group). Laboratory testing, radiologic imaging, histologic analysis, and mechanical testing were performed 4 weeks postoperatively.

Results: Inflammatory reactions were not significantly increased in any animal. Mechanical testing showed greater ultimate load and structural stiffness in the experimental group. In the histologic analysis, the void area and bone regeneration area were increased in the experimental, and the implant area and soft tissue area were increased in the control group. Radiologically, 3-dimensional micro-computed tomography showed no differences in the bone gap area between the 2 groups. A temporary increase in hydrogen gas around the magnesium implants regressed spontaneously and did not affect bone healing significantly.

Conclusions: Magnesium-based biodegradable plates and screws showed good biocompatibility and offered considerable stability for fixating facial bone fractures in the early bone-healing process. These results show the possibilities for the future development of magnesium alloy plates and screws for craniomaxillofacial fixation in humans.

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Titanium plates and screws are the reference standard for rigid fixation of craniomaxillofacial bone fractures. They are biologically inert and strong enough to provide rigid fixation during bone healing. However, permanent fixation devices are associated with bone growth impediments in children, interference with medical imaging, and complications such as palpability, extrusion, infection, and foreign body reactions.[1,2]

To overcome metallic plating system concerns, polymer-based osteosynthesis devices, such as poly-L-lactic acid plates and screws, were introduced.[3,4] They degrade spontaneously after stabilizing the fracture segments until bone healing; therefore, they eliminate the necessity of a secondary plate removal operation. However, questions remain about their physical strength and ability to endure high load-bearing indications. Molding the plates is cumbersome, and they are invisible on radiologic imaging studies, which impedes postoperative surveillance. They reside internally for a considerable period until complete degradation, which causes a subsequent tissue response owing to the acidic degradation of poly-L-lactic acid.[5-7]

A magnesium-based biodegradable metal alloy was developed to avoid secondary plate-removal procedures and provide strength in the early stage of bone healing. Compared with polymer plates, magnesium plates are stronger and do not degrade into an acidic byproduct. Magnesium alloy provides greater tensile strength, bending strength, and torsional strength compared with absorbable polymer, from which its superior bending characteristics were derived.[8-11] Postoperative surveillance is feasible through radiologic imaging. Furthermore, magnesium alloy stimulates new bone formation.[8] The hydrogen gas produced during rapid magnesium degradation in vivo has limited its clinical use.[12,13] However, material engineering advances have allowed us to control the corrosion speed and amount of hydrogen gas released by changing the ratio of the alloy's ingredients.

Studies of biodegradable magnesium alloy have been performed for decades regarding cytocompatibility, bone deposition and growth, and corrosion control.[8,14-16] However, most were conducted in small animals using screws or wires, which contain relatively little magnesium. Studies of plates and screws performed in large animals used nonfracture models. We investigated the safety and efficacy of biodegradable magnesium alloy plates and screws in a beagle model of a zygomatic arch fracture.

Materials and Methods

The institutional animal care and use committee approved all the procedures, which were performed in accordance with their guidelines (approval no. 15-0094-S1A0). Six male 24-week-old beagles were used. The dogs were housed in a light- and temperature-controlled environment and given food and water. The bilateral zygomatic arches were randomly assigned to the experimental and control groups. The plates and screws in the experimental group were made of biodegradable magnesium alloy mixed with calcium and zinc. The control group received a polymeric mixture of poly-L-lactic acid, poly-DL-lactic acid, polyglycolide, and trimethylene carbonate (INION, Tampere, Finland). The length, width, and thickness of the plates was $24.50 \times 5.00 \times 1.35$ mm in the experimental group and $25.00 \times 7.20 \times 1.40$ mm in the control group. The outer diameter of the screws was 1.7 mm in the experimental group and 2.0 mm in the control group. The procedures were performed identically in both groups. The beagles were sedated with an intramuscular injection of 10 mg/kg tiletamine-zolazepam (Virbac, Carros, France) and 5 mg/kg xylazine hydroxychloride (Bayer, Leverkusen, Germany), followed by a subcutaneous injection of 1% lidocaine (Huons, Seongnam, Korea) in the operative field. Through direct incision, the periosteum was peeled from the zygomatic arch to release the temporal and masseter muscles completely. Double osteotomies were performed 3 cm apart using an oscillating saw (AlloTech, Namyangju, Korea). Once a complete fracture had occurred, the central fragment was placed in situ to fixate it with 4-hole plates and screws on the anterior and posterior osteotomy lines. Four screws were fastened bicortically through each plate. The surgical wound was closed in layers after massive irrigation. A temporary drain was placed at the surgical site to prevent postoperative hematoma and removed the next day. We did not perform any procedure that prevented postoperative mastication such as intermaxillary fixation or placement of a mouth harness. The beagles were permitted a soft diet for 1 week postoperatively and then returned to a normal diet. Cefazolin (20 mg/kg; Chongkundang, Seoul, Korea) and meloxicam (0.4 mL/kg; Boehringer Ingelheim, Ingelheim am Rhein, Germany) were administered intramuscularly for 5 days to prevent wound infection and alleviate pain, respectively. The surgical wound was cleansed with povidone iodine for 5 days postoperatively. The beagles were sacrificed 4 weeks postoperatively to assess magnesium alloy plate and screw biocompatibility. The anterior bone–implant complex was used for mechanical testing; the posterior complex was used for histologic analysis.

LABORATORY TESTING

Biochemistry, a complete blood count, and blood coagulation panels were investigated preoperatively and before sacrifice to elucidate any harmful effects of the magnesium alloy.