Clinical experience with bioresorbable plates for skull flap fixation

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Bioresorbable devices are particularly useful for skull bone reconstruction. Different systems are now commercially available. The aim of this trial was to compare the clinical outcomes of bone flap fixation using a new bioresorbable system (Bonamates®) and a traditional titanium plate/screw system. Patients diagnosed with a head injury, brain tumor, or cerebral vascular stroke and who received a craniotomy in our hospital in 2003 and 2004 were randomly allocated to 2 treatment groups for skull flap fixation (study group A: Bonamates®: n=4; control group B: titanium plate: n=4). Treatment outcomes and complication rates were compared between these 2 groups. In total, 8 patients (study groups A and B) were followed-up for at least 6 months after surgery. All patients in the study group A whose bone flap was fixed with bioresorbable plates/screws were reviewed postoperatively. Uneventful healing occurred during the entire follow-up period for all 4 patients (100%) in group A but for only 3 of 4 patients (75%) in group B. None of the patients developed postoperative complications (i.e., infection, soft tissue dehiscence, bone flap sink, or implant-related tissue reactions). After the operation, all patients in group B had severe artifacts on the imaging study (especially the computed tomographic scan), but none was seen in group A. For patients who received radiotherapy (1 from each group), the one fixed with the titanium plate had some dosimetry considerations and complications, but the one using Bonamates® fixation had none. There were no significant differences between the bioresorbable device and titanium fixation with respect to fracture healing, bone flap sink, or postoperative complications. But the fusion rate appeared to be higher in the Bonamates® group. If patients are going to receive radiotherapy (especially brain tumor patients), the Bonamates® system seems to be an ideal choice for bone flap fixation. (J Dent Sci, 1(4): 187-194, 2006)

Key words: bioresorbable, bone plate, skull flap fixation.

The introduction of open reduction internal fixation (ORIF) during the 1990s utilizing titanium mini- and microplates achieved favorable functional and esthetic results. Immediate and firm stabilization as well as reduced incidences of neurological injuries was found when miniplate fixation was used to repair zygomatic complex fractures compared to other methods. According to a retrospective review by Rondahl, patients treated with rigid fixation systems showed fewer late postoperative deformities compared to those treated with wire fixation or simple reduction. Despite the many favorable advantages of titanium plating systems, their long-term effects on pediatric facial growth and development are still unclear. There are occasions when metal implants have to be removed, for example, due to palpability, patient sensitivity, imaging interference, or infection. In addition, metal can be too stiff for optimal healing in some surgical applications. Stress shielding may result in bone atrophy and osteoporosis. More-
over, they become redundant once bony healing has occurred.

Bioresorbable fixation systems have been developed as a reasonable alternative in orthopedic surgery and craniofacial applications without adverse effects on bone healing. They offer stability in the initial phases of fracture healing, and once this function is served, are metabolized by physiological mechanisms. The advent of bioresorbable devices has eliminated the need for a second surgery and offers clinical advantages by causing less interference with craniofacial growth in children and with postoperative radiotherapy. Clinical studies have shown that they have successfully been used as a rigid internal fixation device in mandibular osteotomies and craniofacial surgery, and that normal growth patterns did not appear to be disturbed by the use of these bioresorbable fixation devices.

Typical bioresorbable devices are made up of copolymers of poly-L-lactide (PLLA), poly-DL-lactide (PDLA), or polyglycolic acid (PGA), because of the adverse reactions associated with pure PLLA, PGA, and their poly (glycolide co-lactide) acid (PLGA) copolymer. Various commercially available bioresorbable devices are summarized in Table 1. With improvements in processing and design, the Bonamates® system, composed of a copolymer of poly-5D/95L-lactide (designated PLA95 throughout this paper) has sufficient strength to stabilize bone fractures, thus facilitating more-versatile usage. Chen et al. indicated a good bone affinity observed with Bonamates® fixation material during the healing process. Similar observations were made by Ko et al., who claimed the advantage of a low-stress shielding effect and little risk of screw loosening. The bending strength of PLA95 plates increases up to the 8th week until fractured bones have had a chance to heal and subsequently decreases with time. These plates are also biocompatible and biodegradable, thus eliminating the need for a second operation. The Bonamates® series (PLA95 fixation plate/screws) was used in this study and applied for stabilization of fractures involving skull flap fixation. A non-blinded clinical evaluation of 8 cases (4 subjects each in the study and control groups) was conducted to compare the clinical outcomes of skull flap fixation using this bioresorbable system and a titanium system.

### MATERIALS AND METHODS

This study was conducted with the approval of the hospital's ethics committee. Informed consent was obtained from every patient who received the Bonamates® fixation system. Patients who required craniotomy surgery with a diagnosis of head trauma,

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<th>Table 1. Summary of commercially available bioresorbable fixation systems</th>
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<td><strong>System (Company)</strong></td>
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<tr>
<td>Lactosorb®, W.L. Lorenz</td>
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<td>Macropore®, Medtronic</td>
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<td>Bionx®, Bionx Implants</td>
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<td>Resorbable Fixation System®, Synthes Maxillofacial</td>
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<td>DeltaSystem®, Stryker-Leibinger</td>
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<tr>
<td>Inion CPS™ Bioabsorbable Fixation System, Inion</td>
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<td>Bonamates®, Biotech-One</td>
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PLLA, poly-L-lactic acid; PGA, polyglycolic acid; PDLA, poly-DL-lactic acid; TMC, trimethylene carbonate.
cardiovascular accident (stroke), or brain tumor presenting at our department in 2003 and 2004 were randomly allocated to 1 of 2 different groups (group A, Bonamates®: n=4; group B, titanium: n=4). Inclusion criteria were as follows: 1) patients aged over 12 years; 2) patients with no blood disorders or diseases related to immune deficiency; and 3) patients who were willing to cooperate during the postoperative recall. After the surgery, patients were regularly followed-up on a schedule of 72 h, 1 week, 1 month, 3 months, and 6 months to evaluate the operative wound condition, contour of the bone flap, allergic or rejection reaction to the material, and other complications. A computed tomographic (CT) scan was taken regularly at 1, 3, and 6 months after the surgery for evaluation of the bone flap sink, fusion condition, screw fracture or loosening, artifacts induced by the fixation plate, and other complications. The procedures were carried out by 2 neurosurgeons experienced in handling bioresorbable and titanium fixation systems.

Bioresorbable devices

The bioresorbable devices used were composed of a poly-5D/95L-lactide (PLA95) copolymer (or expressed as poly-L/DL-lactide (90/10)) to elucidate the ratio of raw materials (Bonamates®; BioTech One, Taipei, Taiwan). Various geometrical shapes and thicknesses of the bone plates and screws are manufactured via an injection molding technique to minimize human contact. Four- and 6-hole straight I-type bone plates with a thickness of 1.5mm and screws with a thread diameter of 2.5mm and a core diameter of 2.0mm were used (Figure 1). Bonamates® bone plates can be shaped intraoperatively to adapt to the operation sites by heating them in an autoclavable water bath containing 70°C sterile water. Screws were inserted by initial drilling followed by hand-held tapping.

Surgical procedures

All procedures were performed under general anesthesia with endotracheal intubation. Brain surgery was performed in a regular manner. The bone flap was opened using a high-speed burr (Anspach™, Palm Beach Gardens, Florida). After all of the neurosurgical procedures had been completed, the bony flap was replaced, and this flap was fixed with either a titanium plate and screws or a Bonamates® bioresorbable plate and screw system. The fixation plate and screws were applied at a 5–10-cm interval (Figure 2), so the larger the bone flap was, the more plates and screws that were required to fix the bony flap.

All patients were given intravenous antibiotic prophylaxis (1g/day cephazolin, 4x) for 3 days after surgery. The operative wound condition of patients was reviewed and examined during admission and at 72 h, 1 week, and 4 weeks after the surgery, and they were asked to report for postoperative assessments at 3 and 6 months after skull bone fixation. For

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**Figure 1.** BonaPlates, PD series, 1.5-mm thickness with 2.5-mm diameter holes, Bonamates®, BioTech One.

**Figure 2.** Patient fixed with Bonamates® system. The bioresorbable plates and screws are semitransparent, so cannot very clearly be identified in this figure. Arrows indicate the locations of the Bonamates® devices. Every device was applied with a 5–10-cm interval. After application, the fixed bone flap had an excellent contour.
follow-up of the bone flap condition, we used CT scans to identify the fusion and complication conditions in addition to a clinical examination. Imaging studies were arranged at 1, 3, and 6 (Figures 3–5) months after surgery. For comparison of results, we evaluated a consecutive series of 8 patients who had enrolled in this trial (4 subjects in each of groups A and B).

Statistical analysis

Data were analyzed using only descriptive statistics due to the limited sample size of the study.

RESULTS

The mean ages (± standard deviation (SD)) of all patients in the 2 groups (A and B) were 36.5 ± 15.2 (range, 21–75) years. The male-to-female ratio was 5:3. Four patients in the bioreorbable study groups (group A: n = 4) had their skull bone flaps fixed with only bioreorbable plates and screws. Four patients in group B exclusively received titanium plates and screws fixation. In the bioreorbable study group, uneventful healing during the entire follow-up period was observed in all patients (100%), whereas that was true for only 3 patients (75%) in group B. The last patient in group B suffered slower healing, compared with the other patients. Postoperative complications (such as infection, soft tissue dehiscence, and implant-related tissue reactions) were not encountered in any of these 8 patients. A bone flap sink also did not occur in any of these patients.

In group A, patients receiving Bonamates® internal fixation had no artifacts on the CT and MRI imaging studies. As the result, there was no need to adjust the dosimetry when 1 patient underwent subsequent radiotherapy after the fixation surgery. Six months after the operation, the scalp elevation produced by the Bonamates® internal fixator appeared flat and smooth, even though the Bonamates® material had not yet completely degraded at that point in time. The smoothness of the contour of the scalp and skull was satisfactory to both the surgeons and the patients’
families.

All patients in group B receiving the titanium plate and screw system experienced severe artifacts or distortion when they received follow-up CT and MRI scans (Figure 6). These artifacts made the postoperative follow-up difficult. Because of the original diagnosis of a brain tumor, the radiation dose of 1 of the patients who subsequently received radiotherapy had to be adjusted to avoid direct projection of the radiation beam onto the titanium system. Six months after surgery, there was still some degree of elevation of the scalp exhibited by all of the patients in group B due to the existence of the metallic plates and screws around the surgical area, while no such situation was observed in group A.

The successful fusion rates were 100% in the Bonamates® group and 75% in the titanium group. No statistical analysis could be applied due to the small sizes of the study groups. But theoretically the component of the Bonamates® fixator should promote bone fusion, so the fusion rate in the Bonamates® groups still appeared higher than that of the titanium group. There were no statistically significant differences in postoperative complications between the 2 study groups.

DISCUSSION

Bioresorbable materials are known to be ideal for the fixation of bone flap replacement after brain surgery. The main advantage is in avoiding a second operation to remove the fixation device. If not removed, metallic implants may become painful and irritating, and produce a foreign body sensation. In addition to being palpable and visible, metallic fixation systems are sensitive to temperature and pose difficulties with postoperative follow-up imaging studies, such as CT or MRI scanning. Bioresorbable devices are also a better choice for pediatric neurosurgery because they do not interfere with normal bone growth.

In these trials, 4 patients who participated in the bioresorbable study group benefited from the bioresorbable materials. However, bioresorbable devices cannot be used in cases of severe traumatic brain injury with a comminuted skull fracture or in the presence of small bone fragments. No statistically significant difference was found in the number of postoperative complications between the bioresorbable study group and the titanium counterpart.

One of the limitations of this study was that the ability to compare results among the samples may...
have been compromised by the limited patient number. This made it difficult to interpret the results through proper statistical analyses.

In 1998, some authors reported their experience with a bioresorbable fixation system in a series of patients with craniofacial bone fractures. In the first year after the operation, no patient reported any implant-related complications, including infection, erythema of the overlying skin, fracture instability, relapse, or radiographic evidence of osteolysis. Complete absorption of the device was also demonstrated within 13 months on average after the primary surgery. Other authors also reported excellent results after using bioresorbable fixation plates and screws for fixation of the skull bone.

Implant-related tissue reactions were the most common complication (50%) occurring in the bioresorbable patient groups. The major symptoms were recurrent pain and swelling around the implant sites throughout the process of degradation which can continue for as long as 2 years. However, no such observation was found in our trial within 6 months after surgery.

The first bioresorbable materials used for the fixation of craniofacial bone fractures were poly-L-lactide (PLLA) plates and screws. However, several years after fixation, some patients experienced foreign body reactions in the operative field, causing notable swelling which required a further operation to remove the hardware. So, pure PLLA and PGA are no longer used because of these adverse reactions. The majority of commercially available bioresorbable fixation systems now consist of amorphous co-polymers. In addition, many authors still believe that implant-related tissue reactions may occur long after implantation. The in vivo degradation of this material is similar to that of lactic acid: it enters the TCA (tricarboxylic acid) cycle, and CO₂ and H₂O are excreted at the end of the metabolic process. PLLA alone is incapable of supporting a fracture in a fully loaded area, but is suitable for use with cranio-maxillofacial bones which bear less stress. The polymer implant maintains its strength during the healing process, while slowly breaking down in the body through hydrolysis.

The bioresorbable plate-and-screw systems used in this study contained 90% PLLA. The main degradation mechanism of PLLA biomaterials is through hydrolysis. Tissue reactions are thought to be a result of an inability to absorb the degradation products resulting from rapid hydrolysis. In contrast to PLLA, polyglycolic acid undergoes more-rapid hydrolysis and therefore causes greater inflammatory reactions. The morphology of polymers is also believed to be a factor contributing to tissue reactions. Polymers dominated by indigestible crystalline components are known to elicit more tissue reactions than those with more-easily resorbed amorphous components. Other factors that may influence the resorption of these materials, and hence tissue reactions, are the size and shape of the implants, their molecular weight, the site of implantation, and the purity of the implanted material. In the present trial, a relatively new bioresorbable material composed of 2 polymers incited a relatively mild tissue reaction. This may have been due to the PLLA/PDLA ratio of this copolymer.

It has been reported that bioresorbable fixation devices offer similar capabilities to that of titanium ones when used for bone fixation in orthognathic surgery. A previous study also showed that both bioresorbable and titanium plates and screws can provide sufficient strength to permit mandibular (lower jaw) bone healing, and that the resorption process of the bioresorbable osteosynthesis material did not cause any acute or chronic inflammatory reaction or foreign body reaction during the study period. Moreover, bioresorbable plates are not known to cause an increase in clinical morbidity.

**CONCLUSIONS**

There were no significant differences in fracture healing and postoperative complications between bioresorbable fixation devices and their titanium counterparts. For cosmetic reasons, use of this bioresorbable fixation system is ideal for skull bone replacement, because a much-smoother contour of the skull can be achieved as the biodegradable material is hydrolyzed and metabolized within a couple of months of implantation. For patients who need further radiotherapy postoperatively, this bioresorbable fixation system is an ideal device for bone flap fixation.

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