Decompressive craniectomy via a pterional approach leaves a large skull defect, with concomitant psychological and physiological adverse effects for patients, including headache, dizziness, and memory loss. Uncovered pulsating brain is often associated with weakness of limbs and aphasia, and cosmetic abnormalities of the head can also produce feelings of inferiority, anxiety, and even depression in these patients; these abnormalities are related to the “sinking skin flap” syndrome. Thus, through cranioplasty, patients not only receive a restored physical appearance, but may also regain self-confidence and dignity.

Repair materials may be under great tension when covering a large frontotemporoparietal skull defect. A cranioplasty should also include reshaping of the normal skull shape, including the temporal fossa and forehead. To achieve a satisfactory repair effect and reduce postoperative complications, good surgical skills and suitable repair materials are demanded. Various materials such as Plexiglas, bone cement, acrylic, and silicon rubber have been used to fill skull defects, but have mostly been abandoned due to their poor biocompatibility, high incidence of infection, and formation of subcutaneous fluid effusions. Autogenous bone is also less frequently used because of its limited availability and different degrees of postimplantation absorption. From a variety of different repair materials, titanium mesh has become a popular material for cranioplasty due to its good compatibility with human tissue, light weight, thinness, hardness, and ability to be easily shaped.

In recent years, digital computer techniques have been widely used for molding titanium mesh for cranioplasty. In this technique, head CT scan data, obtained from the contralateral side of the skull defect, is
used as a reference for accurate design of the size and physiological curvature of the repair materials, to create a prosthesis that matches the original appearance of the skull. However, many patients prefer to select a manually shaped titanium mesh for cranioplasty because of the lower expense (computer-aided shaping of titanium mesh is approximately twice as expensive as a manually shaped mesh). However, the advantages and disadvantages of each method have yet to be identified.

From March 2005 to June 2011 in the Department of Neurosurgery, Second Affiliated Hospital, Shantou University Medical College, 161 cases of large frontotemporoparietal skull defects underwent cranioplasty using titanium mesh. Eighty-three of these cases involved computer-aided shaping of the titanium mesh, whereas the remaining 78 cases used a manually shaped titanium mesh. In this study, the 2 repair methods are compared.

Methods

Experimental Design

The study sample consisted of 161 eligible patients from March 2005 to June 2011. All patients had recovered from a head injury with frontotemporoparietal skull defects. The cases were divided into 2 groups according to the repair materials used for cranioplasty. The first group (n = 78) used manually shaped titanium mesh, and the second group (n = 83) used computer-aided shaping to form the titanium mesh. One hundred thirty-one patients were male and 30 were female. The patients’ ages ranged from 16 to 71 years. The surgical techniques, materials, and operators were the same for both groups. Mean patient age, mean bone window size, sex, and mean duration after decompressive craniectomy were not significantly different between the 2 groups (Table 1).

Inclusion Criteria

All patients received decompressive craniectomy via a pterional approach 3 or more months prior to the cranioplasty. All scalp wounds following the craniectomy had healed well. At the time of cranioplasty there was no swelling, effusion, or hydrocephalus. The pressure of the brain in the bone window was not raised. All patients had signed an informed consent form with respect to the implant materials and the surgical procedure.

Repair Materials

The same 2D titanium mesh (OsteoMed Corp.) was used in both groups. The titanium mesh used in the first group of patients was processed manually in accordance with the shape of the bone window during the operation. The titanium mesh used in the second group of patients was individually designed by a digital computer preoperatively.

Digital Computer Shaping Method

Initially, a head CT scan with thin slices and no interstitial gap (slice thickness 2 mm) was performed. Then the scanned data were sent to the remodeling company, where the shape of the skull defect was reconstructed based on the CT data, and a corresponding mold was constructed. The titanium mesh was then compacted on this mold.

Surgical Method

First, general anesthesia, routine disinfection, and draping were performed. The scalp incision followed the original incision. In the first group (manual shaping), the scalp was raised from the underlying muscle. Scar tissue was separated from the edge of the bone window. The temporal muscle was not separated from underlying tissue and thus the temporal fossa was not exposed. Then the titanium mesh was manually shaped and placed so as to cover the edge of the bone window superficial to the temporal muscle and the dura mater, and was fixed in place with screws. The titanium mesh and the dura were then sutured together.

In the second group (computer-aided shaping), the temporalis muscle was separated carefully after raising the scalp. A residual thin layer of temporal muscle was left over the underlying cerebral tissue. The temporal fossa was fully exposed. Then the titanium mesh, shaped with the help of a computer, was placed between the layers of the divided temporalis muscle and fixed with screws. When the titanium mesh and the bone window were in correct relationship to one another, the dura and the titanium mesh were sutured in the same way.

Outcome Parameters

Operative time, number of screws, patient satisfaction, and postoperative complications were recorded in both groups. The Odom criteria were used to evaluate the overall postoperative satisfaction of patients. The patients who reported feeling excellent or good had outcomes that were considered “satisfactory,” and those who reported feeling fair or poor had outcomes that were considered “unsatisfactory.” The mean follow-up period was 5.3 months (range 1–12 months). Subcutaneous fluid col-

| Table 1: Comparison of baseline data in patients who underwent manual or computer-aided shaping of titanium mesh for cranioplasty* |
|---------------------------------|----------------|----------------|----------------|----------------|
| **Titanium Mesh Group** | **Age (yrs)** | **Bone Window Size (mm²)** | **Males/Females** | **Duration After Decompressive Craniectomy (days)** |
| 1 (manual)† | 32.6 ± 12.3 | 134.4 ± 15.1 | 62/16 | 148.4 ± 11.8 |
| 2 (computer) | 35.1 ± 13.4 | 129.6 ± 16.8 | 69/14 | 152.4 ± 14.2 |

* All data given as mean ± SD unless otherwise indicated.
† p > 0.05 for all variables compared with Group 2.
Titanium mesh for repairing large skull defects

After repair, there was no loosening of the titanium mesh in any patient. In the manually shaped group (Group 1), the titanium mesh and the edge of the bone window easily formed palpable lumps. Moreover, the physiological curvature of the original skull (Fig. 1) was not achieved. In the computer-aided group, the titanium mesh and bone window edge joined smoothly. The original physiological depressions in the skull and curvatures (especially the forehead and temporal fossa) had been satisfactorily restored. Complications found in both groups during hospitalization and follow-up included subcutaneous fluid collection, titanium mesh tilt, exposure of the titanium mesh, scalp infection, seizures, and temporal muscle pain (Table 2).

Compared with manual shaping, using computer-aided shaping of the titanium mesh fits the shape of the bone window well, postoperative titanium mesh tilt in the temporal region was rare in this study. In addition, subcutaneous fluid collection and compression of the temporal muscle by titanium mesh were also significantly decreased, reducing the chance of postoperative pain.

In our study, the cost of a large, manually shaped titanium mesh (11 × 13 cm²) was about 9812 Yuan ($1549 US), the price of a computer-shaped titanium mesh of the same size was 17,380 Yuan ($2744 US), and the cost of a titanium screw was 210 Yuan ($33 US). On average, 2 titanium screws can be saved in the computer-shaped group compared with the manually shaped group. Thus, a total of 7148 Yuan ($1129 US) would be saved when choosing manually shaped titanium mesh instead of the computer-shaped titanium mesh for cranioplasty. Due to this notable cost difference, patients who are sensitive to price tend to choose the less expensive manually shaped materials. However, in our current study, patients who had the manually shaped titanium mesh group, 49 of 78 noted excellent results, 16 good, 9 fair, and 4 poor results. In the computer-shaped group, 69 of 83 noted excellent results, 9 good, 3 fair, and 2 poor results.

### Discussion

The existence of natural physiological curvatures in the skull makes it difficult to manually shape the repair material for cranioplasty that is concordant with the shape of the skull. To fit a bone window, titanium mesh needs to be artificially squeezed and twisted. This manipulation may cause the edge of the titanium mesh to form a lump that affects the patient’s appearance. It may even cause other complications, such as postoperative subcutaneous fluid collection and irritation of the scalp, causing pain. We find that manual shaping of the titanium mesh prolonged the operative time due to repeated reshaping and grinding during the operation. The titanium mesh should be changed if it does not match the bone window. Adjacent titanium screws in the temporal region may be far apart due to the fact that the manually shaped titanium mesh lay outside the thick temporalis muscle. This can cause excessive tension in the titanium mesh, producing titanium mesh edge tilt, temporal muscle compression, and pain.

Compared with manually shaped titanium mesh, digital computer-aided shaping of the mesh achieves satisfactory restoration of the forehead and temporal fossa. This is important for cosmetic results and creates a symmetrical appearance (Fig. 2). Because computer-aided shaping of titanium mesh fits the shape of the bone window well, postoperative titanium mesh tilt in the temporal region was rare in this study. In addition, subcutaneous fluid collection and compression of the temporal muscle by titanium mesh were also significantly decreased, reducing the chance of postoperative pain.

**TABLE 2: Comparison of postoperative complications during hospitalization and follow-up between the 2 groups with titanium mesh**

<table>
<thead>
<tr>
<th>Titanium Mesh Group</th>
<th>Subcutaneous Fluid Collection</th>
<th>Titanium Mesh Tilt</th>
<th>Exposure of Titanium Mesh</th>
<th>Seizures</th>
<th>Epidural Hematoma</th>
<th>Temporal Muscle Pain</th>
<th>Scalp Infection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (manual)</td>
<td>14*</td>
<td>10*</td>
<td>5†</td>
<td>2†</td>
<td>4†</td>
<td>15*</td>
<td>2†</td>
</tr>
<tr>
<td>2 (computer)</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

* p < 0.05 compared with Group 2.
† p > 0.05 compared with Group 2.
selected the computer-shaped titanium mesh for cranioplasty had reduced potential complications and the resulting additional hospital costs. This group also experienced a shorter duration of surgery as well as a fewer number of screws used. Most importantly, patients’ postoperative satisfaction was significantly improved in the computer-aided group. All of the above factors partially offset the cost disadvantage of computer-shaped titanium mesh.

To reduce complications, intraoperative dural and temporal muscle separation should be careful and meticulous. Muscle thickness should be moderate, especially when incising the temporalis muscle. If the retained muscle is too thin, brain tissue may be exposed or even damaged. If the retained muscle is too thick, coverage by the titanium mesh would be difficult and would cause compression of the temporal muscles. During the process of separation of subcutaneous tissues, if the dura ruptures or a muscle rupture is found with consequent exposure of brain tissue, the defect should be sutured closed at once. When separating the temporal muscle, it is better to detach the temporalis muscle from the edge of the skull defect. After exposing the skull, temporal muscle separation should be performed transversely across the skull plane, keeping the temporal muscle and the skull basically in the same plane.

For the human body, the titanium mesh is a metallic foreign body. When implanted into the body it can increase the chance of infection and rejection. Once postoperative infection has occurred, the wound would be difficult to cure and the titanium mesh usually must be removed. However, previous results show that compared with other repair materials, titanium mesh has a minimal infection rate. In this study, the chance of exposure of titanium mesh due to postoperative infections in both groups of patients was similar. Exposure of the titanium mesh was mainly located in the parietal region with less soft-tissue cover. Sufferers were mostly elderly patients, which may be due to the thin scalp of the elderly. To reduce postoperative infections, the scalp cannot be separated too thinly and overstretched in surgical procedures, otherwise flap necrosis may occur. Before implanting the titanium mesh, the tissues around the edge of the bone window should be fully separated from the bone. The scalp may be damaged if titanium mesh is forcibly embedded in the skin. In addition, the rejection of titanium mesh by the patient’s body may also be associated with exposure of the mesh. In this study, there was 1 elderly patient whose wound was healing well at discharge, but 6 months later his scalp incision became ulcerated and the titanium mesh became exposed. The wound would not heal in spite of repeated thorough debridement and dressing change. Eventually it healed following removal of the titanium mesh (Fig. 3). In addition, if the tension of the titanium mesh is too great or the edge of the titanium mesh extrudes and irritates the scalp for a long period of time, scalp ulceration may gradually occur, leading to exposure of the titanium mesh.

### TABLE 3: Comparison of operative duration, number of titanium screws, and patient satisfaction with surgical results between the 2 groups

<table>
<thead>
<tr>
<th>Titanium Mesh Group</th>
<th>Mean Duration of Surgery (mins)</th>
<th>No. of Screws</th>
<th>Satisfaction of Patients (satisfactory/unsatisfactory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (manual)</td>
<td>122.2 ± 12.5*</td>
<td>10.7 ± 1.3*</td>
<td>65/13†</td>
</tr>
<tr>
<td>2 (computer)</td>
<td>103.7 ± 10.8</td>
<td>8.5 ± 1.1</td>
<td>78/5</td>
</tr>
</tbody>
</table>

* p < 0.01 compared with Group 2.
† p < 0.05 compared with Group 2.

![Fig. 2. Images obtained in a 23-year-old man who received computer-shaped titanium mesh.](image)

**A:** Axial CT scan showing that the brain tissue at the bone window region was significantly depressed before cranioplasty.  **B:** Brain tissue was restored to the original position 2 days after cranioplasty with computer-shaped titanium mesh. A small epidural hematoma was noted in the cavity formed by dura mater and the titanium mesh.  **C–F:** Three-dimensional CT scans showing a skull defect in the left frontotemporoparietal region (C and E). Repaired using a computer-shaped titanium mesh, the frontal and temporal skull shape received an ideal reconstruction (D and F).

![Fig. 3. Images obtained in an elderly patient whose wound was healing well at discharge, but whose scalp incision became ulcerated.](image)

**Left:** Six months after cranioplasty, the scalp at the top of the temporal region had been absorbed and became thinned. At the parietal region, the titanium mesh was exposed. The titanium mesh outline can even be seen through the thinning scalp.  **Right:** The titanium mesh (arrow) is exposed at the skin breakage, accompanied by some secretion. Eventually the incision healed following removal of the titanium mesh.
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In this study, 8 cases of postoperative epidural hematoma were found. The hematoma was large in 1 case but disappeared after subcutaneous injection of urokinase accompanied by sustained drainage (Fig. 4). Other hematomas were smaller and resolved spontaneously. Epidural hematoma often occurred in patients with preoperative marked depression of the brain at the region of the skull defect. After cranioplasty, a large gap was left between the dura mater and the titanium mesh, which was likely to cause blood retention. There is no good way to fully expand the bone window, but preoperative rehydration and the use of a head-down position during the operation can sometimes improve the situation. The craniectomy wound contains much scar tissue with rich neovascularization, leading to much intraoperative bleeding. To avoid a postoperative hematoma, intraoperative bleeding should be thoroughly controlled and the titanium mesh and dura should be sewn together during the operation. When the operation is finished, the wound should be bandaged tightly. Also, anticoagulants should be withdrawn during the perioperative period, so as not to increase the chance of blood loss during the operation.

Conclusions

Compared with manually shaped titanium mesh, cranioplasty using computer-shaped titanium mesh achieves satisfactory restoration of the head appearance, decreases postoperative complications and operative duration, reduces the number of screws used, and increases patient satisfaction with the surgery. We suggest using computer-aided shaping of titanium mesh instead of manually shaped titanium mesh for repairing large frontotemporal parietal skull defects.

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References


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