Application of navigation template to fixation of sacral fracture using three-dimensional reconstruction and reverse engineering technique

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Objective: To provide a new method in the fixation of sacral fracture by means of three-dimensional reconstruction and reverse engineering technique.

Methods: Pelvis image data were obtained from three-dimensional CT scan in patients with sacral fracture. The data were transferred into a computer workstation. The three-dimensional models of pelvis were reconstructed using Amira 3.1 software and saved in STL format. Then the three-dimensional fracture models were imported into Imageware 9.0 software. Different situations of reduction (total reduction, half-reduction and non-reduction) were simulated using Imageware 9.0 software. The best direction and location of extract iliosacral lag screws were defined using reverse engineering according to these three situations and navigation templates were designed according to the anatomic features of the postero-iliac part and the channel. The exact navigational template was made by rapid prototyping. Drill guides were sterilized and used intraoperatively to assist in surgical navigation and the placement of iliosacral lag screws.

Results: Accurate screw placement was confirmed with postoperative X-ray and CT scanning. The navigation template was found to be highly accurate.

Conclusion: The navigation template may be a useful method in minimal-invasive fixation of sacroiliac joint fracture.

Key words: Imaging, three-dimensional; Reconstructive surgical procedure; Sacral fracture

Sacroiliac fractures are rare in clinic. The stabilization of unstable pelvic fractures in critically injured patients is a necessary component of the early resuscitation protocol. Many techniques for fixation pin placement in the pelvis have been described,1 screw fixation is the common method in the treatment of these fractures. This technique consists of open reduction through a posterior approach and fixation with two screws inserted through the iliosacral joint into the sacral ala or the body of S1 vertebra. Later modifications include percutaneous screw insertion with the patient in the prone or supine position and computed tomography guided insertion. But in most cases, the locations of screws are not satisfactory. In order to provide a safe and precise guide for open insertion of iliosacral screws or transcutaneous fixation in cases of sacral fracture, we designed a new method in the fixation of sacral fracture by means of three-dimensional (3D) reconstruction, rapid prototyping and reverse engineering techniques.

METHODS

Materials
From June 2006 to September 2008, six cases of sacral fractures (five males and one female) were involved in the study. There was one case of type I, 3 type II and 2 type III according to Dennis classification. One case of Denis type III had neurological damage.

CT scanning
Six cases of sacral fracture underwent bilateral ex-
amination with a 64-row multi-slice spiral CT. The indexes were listed as follows: tube tension 120 kV, tube current 100 mA, collimation 0.5 mm, 512×512 matrix. Thin-layer images were obtained. Two-dimensional images in Dicom format were transformed into Amira 3.1 (TGS) software.

3D reconstruction

The 3D reconstruction via the Amira 3.1 (TGS) software consisted of tracing the contours of the bone structures to be reconstructed, adjustment by geometrical alignment of the contours of stacked points, modeling of the surfaces by meshing the framework of the points transformed into polygons and smoothing the contours of the object reconstructed from points, and 3D interactive visualization of the reconstructed structures. The 3D fracture models were saved as STL format, and then input Imageware 9.0 software was analyzed.

Design of screws channel and navigation template

Different situations of reduction (total reduction, half reduction and non-reduction) were simulated using Imageware 9.0 software. The best direction and location of extract iliosacral lag screws were defined using reverse engineering according to these three situations and navigation templates were designed according to the anatomic features of the postero-iliac part and the channel. The exact navigational template was made by rapid prototyping.

Clinical application

Drill guides were sterilized. According to the situation of reduction, different navigational templates were used intraoperatively to assist in surgical navigation and the placement of iliosacral lag screws. Accurate screw placement was confirmed with postoperative X-ray and CT scanning.

RESULTS

The navigation template was found to be highly accurate. After six months to two years of follow-up, two cases of Dennis type I and three type II were recovered completely. One case of Dennis III with neurological damage was improved significantly.

Typical cases

A male patient with type III sacral fracture was fixed with two lag-screws using navigation template technique. The X-ray images showed the situation of fracture (Fig.1). The 3D fracture models were reconstructed via the Amira 3.1 software and displayed by different colors (Fig.2). Simulation of fracture reduction was created using “orient bar” in Imageware 9.0 software (Fig.3). The surgical plan was specifically developed so that the screw channels passed into the vertebral body without damaging other tissues. The optimal screw size was also determined (Fig.4). A navigational template was constructed based on reverse engineering principle according to the anatomic features of the postero-iliac part and the channels. The inner diameter of the hollow cylinder was created to accommodate the preplanned channels for drilling (Fig.5). Navigation template was made (Figs.6A, 6B). In this case, navigation template was used for the total reduction in the location of lag-screws. K-wires were inserted by the navigational template (Figs. 6C and 6D). Lag-screws were fixed through K-wires (Fig.6E). Fluoroscopy showed the good placement of lag-screws (Fig.6F). A female patient with type II sacral fracture was fixed with one lag-screw and plate using navigation template technique (Fig.7).
Fig. 4. The location of lag-screws and the channels.

Fig. 5. The fitting of navigation template.

Fig. 6. The navigation template and operative procedures. A, B: Navigation template; C: Inserting navigation template; D: Inserting K-wires through the navigational template channels; E: Fixing lag-screws through K-wires. F: Fluoroscopy shows the placement of lag-screws.

Fig. 7. A female patient with type II sacral fracture was fixed with one lag-screw and plate using navigation template technique. A: CT reveals the fracture; B: 3D reconstruction of sacral fracture and navigation template; C: Setting navigation template; D: X-ray shows the good placement of lag-screw and the plate; E: CT shows the location of lag-screw.
DISCUSSION

Different techniques have been described for inserting sacroiliac lag screws to stabilize sacral fractures or iliosacral dislocations. The problem of each technique is how to insert lag screws in order to avoid the sacral foramen of S₁ and S₂, the nerve roots of L₅ anterior and superior to the sacral ala and the spinal canal. Direct palpation of the sacral foramen of S₁, recognition of anatomic landmarks, and the sacroiliac joint on the outer table of the innominate bone can be indicative for the surgeons. However, obesity, intra-abdominal contrast agents, and meteorism often make fluoroscopic imaging difficult. Advances in radiology and computer technology have made 3D representation of anatomic structures in living subjects easily available. Using the modern rapid prototyping techniques, computers can accurately reproduce 3D models of actual osseous anatomy now, which is invaluable for the understanding of the fracture characteristics, preoperative contouring of plates, and selection of screw trajectories. The surgical precision can be achieved under the guidance of computer image in the treatment of complex acetabular fractures and insertion of pedicle screws. Computer-guided drilling was accurate and safe, allowing the insertion of two 6.5 mm screw in the vertebral body of S₁ and one 4.5 mm screw inserting into S₂. The mean translational error of the entry points was 2.7 mm and the mean error of the target points was 3.5 mm, with an angular deviation between the bore hole and the planned trajectories.

Rapid prototyping is an advanced manufacturing technology that enables one to generate real 3D models from virtual 3D renderings. Surgeons can perform surgical procedures on nearly exact solid 3D models before carrying out the procedure in the operating room. With this technology, complex fractures with overlapping osseous fragments can be easily evaluated and then treated with improved precision and a better clinical outcome. Fixation hardware is preplanned, pre-contoured and pre-positioned on the model so that it fits intraoperative situation. Computer-generated inter-positioning templates can be created by producing a rapid prototype model of the contra-lateral, intact anatomic part. These templates or jigs for plate and screw placement can provide the surgeon a quick and accurate way to stabilize fracture fragments near the hip joint and insert pedicles or other screws near the spinal canal. The jigs can fit in only one place on the patient’s spine or pelvis, and the pre-planned trajectory holes guide the surgeon’s drilling with computer-aided precision. The technique is easy and accurate and allows preplanning of trajectories and osteotomies, which results in short operative and fluoroscopy time. In the study, we just provided a method in the fixation of sacral fractures with lag screws using navigation template. It is concluded that the navigation template may be a useful method in minimal invasive fixation of sacroiliac joint fracture. It needs further research to apply our technique to different situations so as to confirm the reliability and reproducibility.

REFERENCES


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