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The design, production and clinical application of 3D patient-specific implants with drilling guides for acetabular surgery

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ABSTRACT

An innovative procedure for the development of 3D patient-specific implants with drilling guides for acetabular fracture surgery is presented. By using CT data and 3D surgical planning software, a virtual model of the fractured pelvis was created. During this process the fracture was virtually reduced. Based on the reduced fracture model, patient-specific titanium plates including polyamide drilling guides were designed, 3D printed and milled for intra-operative use. One of the advantages of this procedure is that the personalised plates could be tailored to both the shape of the pelvis and the type of fracture. The optimal screw directions and sizes were predetermined in the 3D model. The virtual plan was translated towards the surgical procedure by using the surgical guides and patient-specific osteosynthesis. Besides the description of the newly developed multi-disciplinary workflow, a clinical case example is presented to demonstrate that this technique is feasible and promising for the operative treatment of complex acetabular fractures.

Introduction

Operative treatment of complex acetabular fractures is challenging [1]. The goal of surgical treatment of the fractured acetabulum is to restore the articular surface and provide a stable fixation, which allows immediate postoperative exercising. Proper fracture reduction might be demanding due to the large forces needed to manipulate the bone fragments, the soft tissue involvement, and the limited surgical access to position reduction clamps. After the reduction, we are faced with the challenges for stable fracture fixation. Unfortunately, no uniform osteosynthesis plate is available that fits the shape of each pelvis and the variability of the fracture patterns perfectly. In current routine, the plates require multiple intra-operative bending and contouring manoeuvres and adjustments, in order to adequately fit an individual pelvis. Occasionally, the shape of the plate is suboptimal to buttress comminuted quadrilateral plate or posterior wall fractures. The optimal screw positions might be challenging to determine and hard to verify with fluoroscopy. Taken all this into account, it is obvious that preoperative planning is mandatory to achieve optimal results in acetabular fracture surgery. 'Plan your operation, and operate your plan' is one of the adages taught during our surgical training.

Recent developments in three-dimensional (3D) imaging technology expand the capabilities for planning surgical treatment. 3D visualisation and virtual planning of surgery has been used for preoperative planning and postoperative evaluation of complex cranio-maxillofacial reconstructions for years [2,3]. Mandibular or maxillary defects that often resulted from tumour resections can be reconstructed by using free vascularised fibula flaps. Three-dimensional preoperative planning of this procedure was reported to be successful for an accurate translation of the virtual planning towards the actual surgery by the use of custom made plates and surgical cutting/drilling guides [2]. Based on this

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validated approach, as applied in our hospital, we explored whether it would be feasible to use patient-specific plates and drilling guides for acetabular fracture surgery. Refining the preoperative planning of acetabular fracture surgery with the development of patient-specific implants and drilling guides may improve the surgeon's efficiency and the quality of the reduction and fixation. So far, there have been no reports on the design, production and application of personalised implants used in conjunction with surgical drilling guides for treating these injuries. Our aim was to develop custom made reconstruction plates with matching drilling guides for acetabular surgery. We assessed the feasibility, accuracy, and efficiency of this innovative procedure through a clinical case.

Design, production and clinical application of 3D patient-specific implants with drilling guides

Patient

A 48-year-old healthy male patient was transferred to the emergency department, arriving from another hospital, after falling from his bicycle onto his left hip. At physical examination he had functional impairment and pain in his left hip but without neurovascular compromise. He was admitted at the level 1 trauma centre for operative treatment of a displaced fracture of the left acetabulum (Fig. 1). A CT scan of the pelvis demonstrated a both column fracture of the left acetabulum (AO/OTA fracture and dislocation classification type C3.3).

3D model and plate designs

A 3D model of the fractured pelvis was created based on the CT data (slice thickness of 1 mm), using ProPlan CMF 2.1 (Materialise, Leuven, Belgium) software. In order to obtain an adequate 3D model, a threshold-based bone segmentation (automatic) was performed. In addition the individual fragments where checked and adjusted (manual) where necessary. After the segmentation process each bony fragment was labelled and assigned a different colour. The uninjured side of the pelvis was mirrored over the injured side as a supportive model for restoring the pelvic integrity. Using the translational- and rotational tools in the virtual planning software, each individual fragment was repositioned in order to reduce the fracture. The anatomically reduced pelvis was discussed and authorised in a multidisciplinary meeting with surgeons, technical physicians, and engineers (Fig. 2). Subsequently, patient-specific implants were designed on the reduced pelvis in 3-Matic

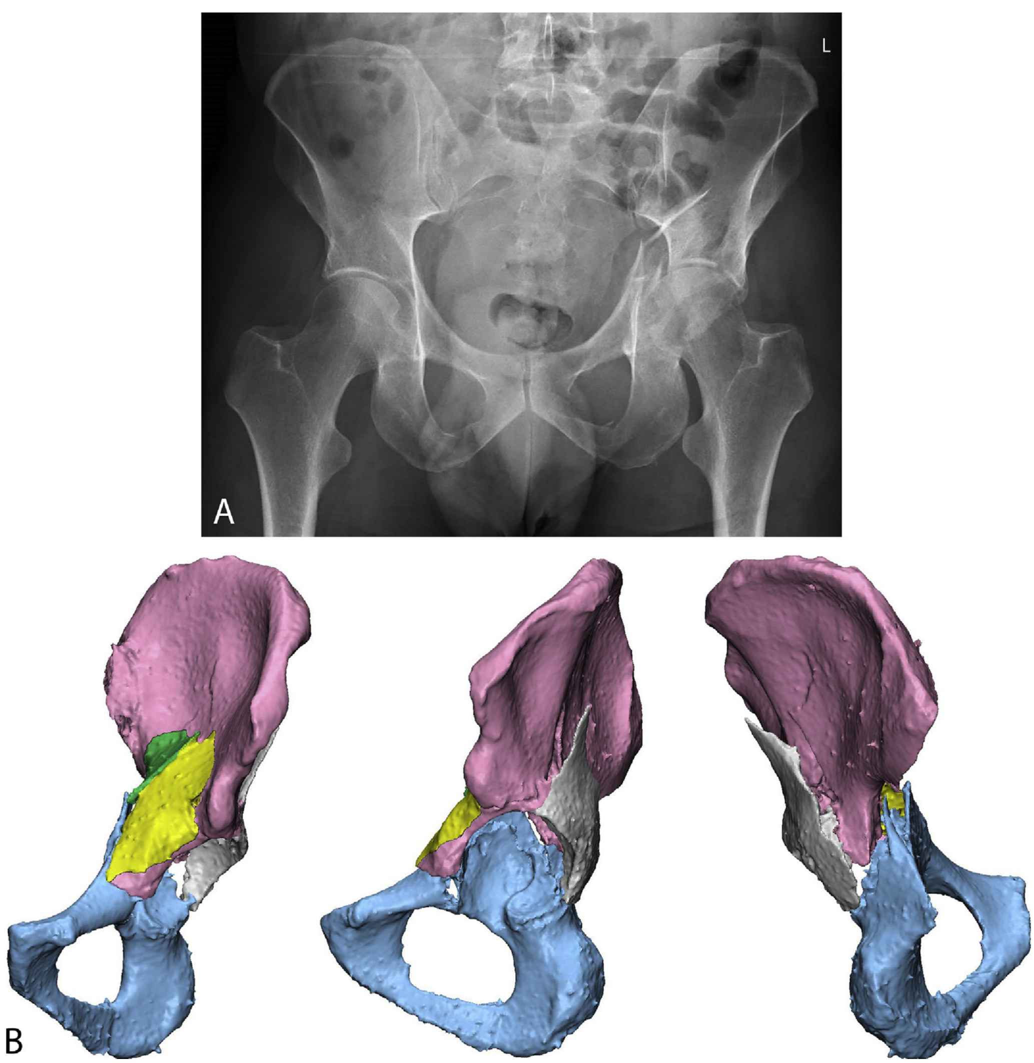

Fig. 1. Pelvic radiograph AP view (A) and 3D reconstruction (B) of a left acetabular fracture (type AO/OTA 62-C3.3). The CT scan showed a mild protrusion of the femoral head due to a displaced acetabular fracture involving the iliac wing, extending to the acetabular roof, reaching up to the quadrilateral plate, and involving both the anterior and posterior columns.