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Revision of Complex Acetabular Defects Using Cages with the Aid of Rapid Prototyping

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A B S T R A C T

This study details a method using rapid prototyping (RP) technique to assist in acetabular revision with complex bone defects. Hemi-pelvic RP models were built among 25 patients with complex acetabular bone defects. Each patient was scheduled to undergo revision using either commercially available or customized cages based on individualized RP models. Average follow-up was 4.4 years (range, 1 to 9 years). The average Harris hip score was 36.1 (range, 20 to 58) preoperatively and reached an average of 82.6 (range, 60–96) at the last follow-up. No mechanical failure or loosening was observed. One patient experienced hip dislocation 4 days postoperatively. The resultant findings of this study merit consideration of RP as a helpful clinical complement for dealing with some complex bone defect of acetabulum.

The reconstruction management of complex acetabular bone defects remains a challenging problem in revision total hip arthroplasty [1–3]. Especially the goals of placing the acetabular component in the anatomic position, equalizing leg lengths, restoring or preserving acetabular bone stock, and achieving stable fixation are not as readily achieved in such a situation [4].

Cage reconstruction is attractive in that it acts as a plate to bridge the bone defect, protecting underlying bone graft as it incorporates [5]; however, the mid-short-term and mid-term failures rate were documented from 12.5% to 34% [6–10]. The accurate preoperative assessment is of critical importance to improve revision outcomes. However, for complex defects, some key information related to surgical outcomes may be difficult to detect using current imaging methods that includes:

1. *The ability of the cage to be well supported by host bones*. For complex acetabular bone defects, although the stability of the cage may be initially achieved by structural bone grafts that provide an auxiliary support effect, subsequent bone resorption may cause the loosening and displacement of the cage [11]. The long-term stability of the cage depends on the establishment of firm contact between cage and the host bone, resulting in support of the cage provided by the host bones [12]. Valuable information regarding host bone support, however, is not generally provided by contemporary radiography or computerized tomography (CT) scanning, even when more advanced three-dimensional reconstruction methods are used.
2. *The ability of the cage to obtain rigid fixation*. The initial rigid fixation of cage depends on the number of screws in the upper cage available for fixation, the thickness of ilium, and the ability of the fixation hook below the cage to rigidly hook onto the inferior margin of the acetabulum. These parameters sometimes could not be assessed intuitively based on CT image or three-dimensional reconstruction.

Rapid prototyping (RP) is a technique used to convert standard CT information into an isometric physical object model in which physicians can accurately and intuitively simulate various surgeries and design implants. In the case of complex acetabular defects utilizing cages, RP technique provides clinicians with the aforementioned key information that may be difficult to obtain through imaging alone.

The current study details a method for the use of RP technique to assist in revision of complex acetabular defects utilizing cages, providing clinicians with specific cases wherein these techniques improved surgical outcomes and mid-term follow-up results.

Materials and Methods

General Information

A total of 25 patients (10 males and 15 females) with complex acetabular bone defects and an average age of 61 years (range,

This study was performed in Shanghai No. 9th People's Hospital.

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43–89 years) were enrolled in the current study between September 2001 and July 2009. Each patient whose operative plan cannot be made easily via discussion by the authors base on the radiography, including an anteroposterior (AP) view of the pelvis and AP and lateral views of the proximal part of the femur, and the thin slice CT scanning was scheduled to undergo revision utilizing either commercially available or customized cages based on individual's RP model. Twenty-two cases were primary revision, while 3 cases were re-revision. The diagnosis leading to the original THA was developmental dysplasia in 10 hips, osteoarthritis in 9 hips, femoral neck or acetabular fracture in 3 hips, avascular necrosis in 2 hips, rheumatoid arthritis in 1 hip. The reason for failure and need for subsequent revision was aseptic loosening in 24 hips, sepsis in 1 hips. According to the Paprosky classification, patients were initially categorized as IIB ($n = 4$), IIIA ($n = 10$), and IIIB ($n = 11$). Twenty-one patients underwent concomitant femoral component revision secondary to loosening at the time of acetabular revision. All patients received follow-up care for an average of 4.4 years (range, 1 to 9 years).

RP-Aided Selection and Design of Cages

By collaboration with the design and manufacturing industry, three dimensional prototypes were constructed in 25 patients using computer aided design (CAD) software and rapid prototyping techniques. Using this technology and specialized software (MIMICS—Materialise Interactive Medical Image Control System Software, Materialise, Belgium), CT scans with intervals of 1 mm for the whole pelvis were converted into three-dimensional digital models. These digital models were then used to manufacture life size three-dimensional hemi-pelvis models using a laminated objective manufacturing system called Dimension Elite (Stratasys Inc., MN, USA). The whole process can be completed in no more than 1 day.

Placement of the cage was simulated *in vitro* using RP models prior to surgery. If the commercially available cage could be well supported and hold by the host bone, this option is an excellent choice that is commercially available; however, in cases where bone abnormality presented additional challenges, customized cages were required. Two critical points must be considered in the design and placement of customized cages, including:

1. *Establishment of a secure host-bone support system for the cage*. The customized cage could get solid support from the supraacetabular bone by creating two crests on the superior surface of the cage in cases where the acetabular defect was severe. The site and size of the crests necessitates specific design according to the morphology of the supraacetabular bone defect.
2. *Assurance of rigid fixation of the cage to the acetabulum*. The superior margin of the cage is fixed via the iliac fixation wing or braid. The inferior surface of the cage was designed to be hooked to the inferior margin of the acetabulum during surgery, providing control of the height of the cage as well as bearing part of loading.

Customized cages, when necessary, generally required a construction time of approximately 3 days, and the completed cage was verified against the RP model prior to surgery.

Surgical Procedures

All the revision surgeries were performed by two surgeons (ZAZ, KRD) using the posterolateral approach. After removal of the failed implant, comprehensive removal of interface membranes in the acetabulum and areas of bone defect was conducted, yielding exposure of the acetabular morphology to resemble the morphology simulated during RP modeling. The inferior margin of the acetabulum was exposed, allowing for placement of the fixation hook of the cage. The soft tissue was separated along the iliac wing with a periosteal elevator designing to properly position the iliac fixation wing or braid of the cage. According to the RP model, the cage was positioned according to the predefined site, the anteversion and abduction angle were adjusted, and then the screws were inserted according to the predefined site, number, and angle. Allogenic morselized bone was used in all cases, and densely filled the gap between the cage and host bone either before or after cage placement. Upon completion of both cage placement and bone grafts, a polyethylene liner was fixed in the normal anteversion and abduction angles using bone cements.

Postoperative Recovery and Assessment

Non-weight bearing ambulation was permitted for the first week after surgery, and partial weight bearing ambulation was allowed for the following 6 weeks. Then, progressive weight bearing with crutches started and free ambulation was allowed after 3 months. All patients were examined both clinically and radiographically at 6 weeks, 12 weeks, and once yearly thereafter. Harris hip scores were recorded at each follow-up [13].

Radiographic Measurement

The stability of the cage was assessed according to the criteria of Gill et al. who differentiate an acetabular implant into definitely loose (screw breakage or acetabular migration >5 mm or progressive radiolucent lines at the cage-bone interface medially and superiorly or around the screws), probably loose (progressive radiolucencies present medially or superiorly), and possibly loose (nonprogressive radiolucent lines and not involving the screws) [8]. The grafted bone was considered to be integrated if the continuity of trabecula was present between the host bone and the grafts, and the absorption of the grafts were confirmed when the grafted bone visible immediately after surgery had vanished [14]. Absorption could be assessed on anteroposterior pelvic radiographs and graded as minor (<1/3 of graft resorbed), moderate (1/3 to 1/2 of graft resorbed), and severe (>1/2 of graft resorbed) [15].

One or more of the following situations were considered as failure after reconstruction (a) revision of the acetabular component for any reason; (b) migration or loosening of the cage; (c) severe resorption of bone allograft [16].

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Statistical Analysis

Statistical analysis was conducted with SPSS for Windows version 11.5 (SPSS Inc., Chicago, IL, USA). The significance of the findings was evaluated with a Student *t* test for comparison of all paired variables. A *P* value of less than 0.05 was considered statistically significant.

Results

Intraoperatively, the RP models were found match the pelvic anatomy accurately in all of the cases. With the aid of RP models, 12 patients were determined to use the commercially available cages (Lima-Lto, Udine, Italy), and 13 patients required customized cages (Table 1). In the 13 customized cage cases, one patient exhibiting severe osteolysis in the posterior wall of the acetabulum demonstrated very poor rotational stability by placing Lima-Lto cage on the RP models. Consequently, the patient required customized cage designed to enhance the antirotation ability of cage via fixation wings (Fig. 1). One patient presenting a shadowed and plain acetabulum also required customized cage with fixation wings to enhance the rotational stability of the cage (Fig. 2). One patient whose iliac cortex was observed to be extremely thin and difficult to be rigidly fixed using a