Bone Grafting With An Acetabular Reinforcement Ring: Effects Of The Graft Location According To 3-dimensional Finite Element Analysis

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Introduction: An acetabular support ring can be attached during total hip arthroplasty (THA), depending on the areas of bone grafting. Ganz developed the acetabular reinforcement ring with a hook for bone grafts for improved fixation of the grafted bone, initial fixation of the cup, and stability of the reconstructed acetabulum in the anatomical position. The finite element method is increasingly being utilized in biomechanical analysis. A few research groups have analyzed the load distribution of support rings using the finite element method, but detailed analysis, that takes into consideration the bone graft location, has not been conducted. In this study, we used the finite element method to develop a detailed model of the hip joint and analyzed the biomechanical effects of the location of a bone graft.

Methods: To develop a finite element model, geometric data were obtained using computed tomography of the Sawbone (Sawbones, Pacific Research Laboratories, Inc., Vashon, WA) left pelvic model at slice thickness of 0.6 mm. The support ring model was created based on the acetabular reinforcement ring with a hook (Ganz ring, 50 mm). The ring was affixed to the acetabulum by inserting the hook into the obturator foramen and by immobilizing the ring in the anatomical position using threaded 6.5-mm cancellous screws. The interface between the Ganz ring and the pelvic bone was assumed to be a nonlinear contact problem, with friction set to 0.88 according to the literature. An acetabular cup was mounted on the Ganz ring with a lateral opening angle of 45° and an anterior opening angle of 15°, assuming the cement fixation to be 1 mm thick. The femoral head was modeled as a hemisphere and bonded with the cup. By changing the material properties of the intact models, we created post-bone grafting models − SM (superomedial type), SL (superolateral type), and C (central type) − that simulate surgical treatment of acetabular defects with a morselized bone graft (Fig. 1). We used four nodes of solid linear tetrahedral elements to reconstruct the mesh of the cortical bone, of the trabecular bone, bone cement, Ganz ring, prosthetic head, and of the bone graft for the finite element models. Young’s modulus of these elements was 17000, 100, 2100, 110000, 230000, and 50 MPa, respectively, and corresponding Poisson’s ratio was 0.3, 0.2, 0.4, 0.3, 0.3, and 0.2. In this model, force magnitude and direction were normalized to the regular gait of THA patients (such values were set to 100%), and 2158 N was applied to the center of the head of each model. With regard to boundary conditions, the areas corresponding to the sacroiliac joint and pubic symphysis of the pelvic bone were considered completely restrained.

Results: The stress-affected area of the Ganz ring showed higher values of von Mises stress around the screw holes and the hook; in particular, bone graft models showed higher stress than did the intact model. In the SL model, the stress on a screw was highest on the posterolateral side of the screw (Fig. 2). In the distribution of von Mises stress in the acetabulum, the intact model exhibited a pattern of
dispersed distribution. The bone models showed lower values of stress in the bone graft and higher values around the bone graft. In the SM and C model, stress was concentrated at the superior acetabular edge, whereas the SL model exhibited the lowest stress at the superior acetabular edge and higher stress at the inferior acetabular edge (Fig. 3).

Discussion: The Ganz ring is fixed by placing its hook into the obturator foramen and by fixing the plate portion with cancellous screws. In the post-bone grafting models presented here, stress on the bone graft is low, whereas the stress on the Ganz ring and the host bone around the graft is high. These data suggest that the load is dispersed by the Ganz ring mechanically. In the SL model, stress on the hook of the Ganz ring and on the screws is high; this result is suggestive of an increased risk of failure of the hook or a screw and poor initial fixation. In patients with this type of bone defect, e.g., severe acetabular dysplasia, either more inserted screws or strut bone grafting are needed to achieve better fixation.

Significance: The Ganz ring can disperse the load in a morselized bone graft, but the stress peaks vary depending on the location of acetabular defects. Caution should be exercised when planning surgical treatment of a superolateral defect such as severe acetabular dysplasia.

Figure 1

*The 3-dimensional finite element model.*
(A) A frontal view: hatched areas in the sacroiliac joint and the pubic symphysis of the pelvic bone indicate absolute restraint. A magnified oblique view of the Ganz ring and 30-mm screws (× 3).
(B) Variations of the post-bone grafting model. (B) superomedial type, (C) superolateral type, and (D) central type.
Figure 2

Distribution of von Mises stress in the pelvic bone, the Ganz ring, and in the screws without an acetabular cup. (A) intact, (B) superomedial type, (C) superolateral type, and (D) central type.

Figure 3

Distribution of von Mises stress in the acetabulum of each model without the Ganz ring: (A) intact, (B) superomedial type, (C) superolateral type, and (D) central type.