Finite Element Analysis of an Antiprotrusio Cage

Darrick Lo¹, Joseph Lipman¹, Jonathan Vigdorchik, MD².
¹Hospital for Special Surgery, New York, NY, USA, ²NYU - Hospital for Joint Disease, New York, NY, USA.

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Introduction: Antiprotrusio cages (APC) are used to reconstruct the hip joint when insufficient host bone is available for biologic fixation of an uncemented acetabular component. They are capable of bridging large bony defects, and can protect underlying structural bone graft. Their reported revision rates, however, are high, ranging from 0 to 24%¹. Mechanical failure has been associated with poor superior bone support, but in general, the way these devices fail is not yet well understood. The objective of this study is to measure the stress in an APC finite element model (FEM) using realistic in vivo boundary conditions, determine which regions are susceptible to failure, and see if these regions correlate with fracture locations seen in a corresponding retrieved component.

Methods: 24 retrieved CONTOUR® (Smith & Nephew) APC’s were identified using a retrieval database, 12 of which exhibited mechanical failure at the flanges. Cages were manually examined for breakage location and radiographs were reviewed to confirm findings. We selected one retrieval which exhibited several fracture locations (Figure 1). The patient was 60 years of age at the time of revision, the APC had a length of implantation of 5 years, and was revised after two flanges had fractured at multiple locations (Sections 1, 2, and 3) with one broken bone screw. The fracture pattern at these sections was evaluated using a Keyence digital microscope.

An FEM of a right hip APC was created and analyzed in ABAQUUS v6.10 (Dassault Systemes) (Figure 2). The orientation of the cup matched the specimen in vivo, and four screws were placed at their respective positions. Since the screw holes are elliptical and the screw heads are conical in shape, contact occurs only on opposing edges. The screws were bonded and meshed directly to the flange at these locations of contact, creating a rigid connection. The model contained 158908 elements (10-noded tetrahedral elements), and isotropic material properties for Ti-6Al4V were used. A single load P (3409N) was applied in a direction consistent with normal gait at peak.
The screws were rigidly fixed in space 5mm below the surface of the flange to minimize edge effects at the screw-flange interface. No underlying bone support was modeled. This represents a model in which bone has resorbed or a flange that has not fully seated against the bone, both scenarios of which have been supported by radiographic evidence. A cross-section was taken through Sections 1, 2, 3, and 4 and the maximum von Mises stress values were recorded at subsections between the screw holes (e.g. 1A, 1B, 1C). Yield strength of Ti-6Al4V is 827MPa, and its fatigue strength is 400-700 MPa, but can drop to 140-270 MPa if notched.

**Results:** Serial radiographs of this retrieval suggest that failure may have been initiated at Section 2 and at the most inferior ischial bone screw, followed by fractures at Sections 1 and 3. In the FEM, ischial flange Section 3 exhibited the highest stress, exceeding the yield strength of Ti-6Al4V, followed by Sections 1, 4, and 2 (Figure 3). The magnitude of von Mises stress at specific subsections is ranked from 1 to 11, 1 being the largest and 11 being the smallest (Figure 4).

**Figure 2. A) FEM and applied load, B) Flange sections**

Stress concentrations can be seen around the holes of both the ilial and ischial flanges whether or not a screw is present. Stresses in subsections 1C, 3B, 3C, and 4B were below the fatigue strength of Ti-6Al4V, but all the subsections in Section 2 were above. The fracture pattern seen in several sections of the retrieval showed a precrack region with deep fissures followed by a clean break, characteristic of fatigue failure. Stress concentrations seen at load P and directly above P are artifacts of point load
Discussion: Our FEM showed that when a patient is within the range of loads associated with normal gait, both the ischial and ilial flanges are at risk to fail in fatigue at multiple locations. Compounded by the fact that APC flanges are intended to be contoured at the time of surgery, this will only make them weaker in fatigue. With high cycle fatigue, even if the applied stress is within the elastic range, plastic deformation can occur at a crack tip / notch. The crack can then propagate slowly through the material in a direction normal to the main tensile axis until the flange fails. The stress distribution within the APC is also dependent on unknown variables such as dynamic loading conditions, patient bone stock, extent of intraoperative bending of flanges, and torque applied to the screws.

Future studies will include closer evaluation of fracture patterns seen in other retrieved APC's, as well as additional FEM's that have different screw configurations and APC orientations. This FEM recreates a worst-case scenario representative of failed APC constructs we have seen and revised at our institution.

Significance: Successful use of APC's are possible, but likely the result of incorporated superior bone graft which improves the overall stiffness of the construct, and/or selecting patients with smaller cavitary defects. Should the underlying bone no longer adequately support the dome of an APC, it is possible that the flanges will catastrophically fail in fatigue. In addition, great care should be taken when contouring flanges intraoperatively to prevent notching.

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