A Validated Surrogate Model of the Revision Acetabulum

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Introduction: Biomechanical testing of the cadaveric acetabulum yields valuable information on the performance of various implant geometries, surface textures and fixation. However, the mechanical properties of cadaveric specimens are inherently subject to large variation due to inconsistencies in boney morphology and bone quality. Cadaveric testing is also limited by its expense and procurement difficulties. Anatomical surrogates can be used to circumvent these problems and effectively isolate one independent test variable for experimentation purposes. Therefore, the goal of this study was to design a surrogate model of the revision acetabulum and validate its mechanical properties through comparative testing of cadaveric specimens.

Materials and Methods: A surrogate model of the revision acetabulum was fabricated from a composite construction of low-density (0.16g/cm3) polyurethane foam with rigid polymeric reinforcement (tensile strength=200MPa) simulating the native cancellous bone bed (0.1-1.4g/cm3) and the periacetabular cortex (tensile strength=166-198MPa) respectively. An axi-symmetric design of the simulated boney anatomy permitted the reuse of individual surrogates 4 fold. This was made possible by removing 11.5mm of foam and rigid polymer to expose uncompressed material with consistent mechanical properties. In addition to the composite bone bed, the surrogate model replicated critical anatomic features of the acetabulum, including an acetabular notch (Ø10 mm), an external chamfer of the bony margin (30°) and reinforcing columns representing the ilium, ischium and pubis. The hemispheric cavity within each surrogate was prepared using custom milling fixtures which held the internal diameter of the implantation site to a tolerance of ±0.15mm and resulted in a 5.5±0.25mm acetabular wall. A Paprosky Type IIb defect spanned 100° and was located 230 ± 0.5° from the center of the notch to replicate the discontinuity in rim contact often present in the revision acetabulum.

Results: The stiffness profile of the surrogate was matched to the stiffness of the cadaveric acetabulum. To validate the surrogate, 7 unilateral cadaveric acetabula (mean age 75.1 years) were reamed by an experienced surgeon to simulate the normal intraoperative preparation of the revision acetabulum. The specimens were potted in a custom fixture and mounted to an x-y table on the base of a mechanical testing machine (MTS Bionix) such that the acetabular margin was oriented parallel to the transverse plane and deflection of the specimen during loading was permitted. A frictionless, one millimeter over-sized, stainless-steel hemisphere was attached to the vertical actuator of the machine and positioned in the mouth of the reamed acetabular specimen under a preload of 10N. The displacement of the cross-head was zeroed and an implantation load of 1000N was applied at 100N/s. The displacement of the hemisphere and the implantation force were continuously recorded. The implantation stiffness of each cadaveric specimen, defined as the slope of the resistance force versus the depth of insertion of the hemisphere was used to design the surrogate and validate its mechanical response. Two specific stiffness metrics were compared using the student’s paired t-test: the effective stiffness and the total implantation stiffness. The effective stiffness was calculated by a linear approximation of the force versus displacement relationship in an intermediate range (400-800N implantation load) while the total stiffness was calculated over the entire range (0-1000N implantation load).

The effective stiffness of the surrogate (273±31N/mm) and the total stiffness of the surrogate (212±12N/mm) were statistically identical to the cadaveric specimens (273±86N/mm, p=0.95 and 251±167N/mm, p=0.51 respectively). On average, the standard deviation of the cadaveric specimens was 8 times that of the surrogate. The effective and total stiffness of a given surrogate that was reused 4 times was maintained within ±5.0% and ±3.7% of the effective and total stiffness respectively. The reusability of the surrogate decreased the fabrication cost per surrogate by 80%.

Discussion: A revision surrogate acetabulum that accurately simulates the mechanical response of the native acetabulum during the press-fitting of an over-sized component has been designed and validated with cadaveric reference data.

This surrogate significantly reduces the variability in mechanical properties that is inherent to all cadaveric testing.

This surrogate provides an inexpensive, standardized tool to investigate a multitude of implant fixation issues related to implant design, the use and placement of bone screws and surgical techniques.