Osteotomy-Free Correction Of Acetabular Dysplasia: Proof of Concept of the SHALE procedure.

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Introduction. Acetabular dysplasia is a critical component of developmental dysplasia of the hip and neuromuscular hip instability. Surgical correction of acetabular dysplasia relies on re-directional pelvic osteotomies or shape-changing acetabuloplasties, which have been shown to be some of the most morbid orthopedic interventions (1). Due to anatomic and technical limitations, the magnitude of correction achieved by these procedures is limited, with some studies suggesting ~20-25 degrees(2-5) is the angular correction that one can expect, with most correction occurring in the superior lateral position. Posterior acetabular insufficiency remains a technical challenge. In this study, we investigate the feasibility of using a novel, minimally invasive, osteotomy-free surgical procedure that relies on pelvic growth to three-dimensionally re-orient the acetabulum within space to improve acetabular coverage.

Methods: Institutional IACUC was approved for this study. Twenty-Three 6-8 week-old mixed-breed, female swine were used in this study. Seven animals served as non-operative controls. The remainder of the animals were assigned to one of three surgical procedures and recovered. During the week prior to surgery, all animals had pelvic CT scans performed on a GE Medical Systems Discovery CT750 HD clinical CT scanner. Surgical Procedure: A 4cm longitudinal incision was made in the groin and a hinge plate and screws (Orthopediatrics) were placed along the anterior superior pubic symphysis with the screws directed in a superior-lateral manner between the acetabulum and the inner pelvic table crossing the anterior limb of the triradiate cartilage, the SHALE (Screw-Hinge Anterior Limb Epiphysiodesis) procedure (N=6). Separate Tension Band Symphysiodesis N=3 (TBS) and SHRS (N=7) Screw-Hinge Reversible Symphysiodesis) were also performed using a similar incision. Animals were recovered and underwent CT scans at 12 weeks of age and at 18 weeks of age. Image Analysis: Two different sets of applications were used to analyze the 3D shape of the pelvi following surgery. Initially, DICOM files from CT scans were uploaded to 3D Slicer software (Kitware) where files were converted to .stl files and analyzed for morphological changes of the pelvis using the Angle Planes module. Three landmarks (points) were placed on each acetabular rim. Planes were then constructed from these points for each acetabulum, providing the normal vector of each plane. A reference middle plane was established to determine the absolute positions of the left and right acetabulum and the angle between the planes of the left and right acetabulum measured (Acetabular Angle). This angle was used to compare changes in the mean position (°) of the acetabulum with age (in controls) and following each surgical intervention. Later in the study CT scans were segmented using Mimics Core (Materialise). Each sample segmentation isolated the respective pelvis, excluding the sacrum for ease of statistical shape modeling. Segmented pelvis samples were then exported to 3-matic (Materialise), for final preparations of the 3D model. Statistical shape modeling and other key measurements were performed via 3-matic, including the same angular measurements described above using Slicer. Additionally, using 3-matic, 3-points were selected on the acetabular rim to create a circle for measuring the external circumference of each acetabulum The circles were then adjusted to create best fit on the (external) acetabular rim (introitus) and the circumference and radius were then recorded. The internal (articular) circumference of the acetabula were measured by placing the largest, "best fit", sphere within each acetabulum. The circumference and radius of these spheres were recorded. Lastly, the surface area of each acetabulum was measured. Using the freeform tool within 3-matic, the acetabular rim was highlighted and converted to a 2-dimensional landscape of the acetabulum providing measurement of the surface area. Values were recorded and Student T-tests were then performed comparing the Acetabular Angle (combined/individual), external and internal circumference and radius, and surface area of the control and SHALE treated acetabula at each time point.

Results: The Combined Acetabular Angle increased in the control group from 6- to 18-weeks of age (100+/-7° vs 112+/-7°, p=0.004), while no significant difference was found between L and R acetabular angles (p=0.8). There was no significant difference in Combined Acetabular Angle in the preoperative CT scans between controls and the SHALE pelvis, despite a significant difference in age (controls 34.6+/-0.5 days vs SHALE 50.5+/-1.2 days). However, significant differences in Combined Acetabular Angles were found at the 12-week (110+/-6° vs 141+/-13°, p<0.001) and 18-week (112+/-7° vs 158+/-10°, p<0.001), CT scans. This indicates a mean 31+/-7° change in orientation for each acetabulum from the preoperative values. The external radius and circumference of the acetabular ridge was larger in the SHALE animals than the controls, but despite this and the differences in acetabular orientation in space, no significant differences in the inner (articular) circumference or surface area of the acetabula were found.

Discussion: This work demonstrates that pelvic growth can be harnessed to therapeutically re-orient the acetabulum. The magnitude of re-orientation is on par with that obtained using the most invasive of pelvic osteotomies (Triple innominate) in which the ilium, ischium, and pubis are all cut, leading to significant patient morbidity and lengthy recoveries. As the SHALE procedure is completely osteotomy free and relies on slow gradual correction, successful translation of the SHALE procedure would eliminate much of the morbidity and complications associated with current treatments. However, further study is necessary to understand the similarities and differences between swine and human pelvic growth, to identify the ideal (human) acetabular morphology that the SHALE procedure could address, and to determine the optimal procedural timing, prior to any clinical translation in humans.

Significance: Based in this work in a large animal model, the SHALE procedure appears to offer a paradigm changing strategy in the treatment of acetabular dysplasia, as it demonstrates that it is possible to re-orient the acetabulum without performing an osteotomy or loss of acetabular surface area.

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