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3-DIMENSIONAL MAGNETIC RESONANCE IMAGING MODELING OF THE PELVIC FLOOR MUSCULATURE IN CLASSIC BLADDER EXSTROPHY BEFORE PELVIC OSTEOTOMY

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ABSTRACT

Purpose: We provide a 3-dimensional (3D) model of the pelvic floor musculature in patients with classic bladder exstrophy using magnetic resonance imaging (MRI).

Materials and Methods: Five male infants 1 day to 12 months old underwent MRI of the pelvis, which was compared to pelvic MRI of 1 male infant without pelvic floor abnormalities. Of the patients 3 were studied before primary closure and 2 before reclosure. None of the patients had a prior pelvic osteotomy. While the entire pelvic floor was imaged, special attention was paid to the contours of the levator ani muscle group which were drawn on T1-weighted axial and coronal images. The overlap of contours in these 2 planes was used to construct a 3D model of this muscle group. The diastasis of the pubic symphysis was also measured for all patients on a plain pelvic radiograph.

Results: The levator ani muscle group conformed to an elliptical dome shape in the control. For the patients the 3D shape was somewhat irregular with an apparent kink in the ellipse. The elliptical shape of the group was described by a shape factor, s, which equals the ratio of the maximum height-to-the length of the base of the ellipse. The shape factor was equal to 0.176 in the control compared to a mean of 0.448 for the patients. There was no relationship between diastasis of the pubic symphysis and the extent of disproportionate curvature of the levator group.

Conclusions: To our knowledge this is the first qualitative description of the pelvic floor anatomy in bladder exstrophy using MRI. Our model gives further insights into the true pelvic floor anatomy in exstrophy cases and is the first to suggest that abnormalities in the pelvic floor may not correlate with abnormalities of the bony pelvis.

KEY WORDS: bladder exstrophy, pelvic floor, magnetic resonance imaging

Classic bladder exstrophy represents a congenital anomaly complex characterized by musculoskeletal defects in the abdomen and pelvis, as well as genital defects. The primary objectives of surgical management are secure abdominal closure, attainment of urinary continence and genital reconstruction.[1] For a few select patients continence is achieved after primary closure alone, whereas others may require further surgical procedures. Differences in the anatomy and orientation of the pelvic floor musculature may directly influence which patients attain urinary continence following a primary closure. Further elucidation of the pelvic floor anatomy may aid surgeons in planning and executing surgical correction.

Previous studies of the pelvic anatomy in patients with bladder exstrophy have revealed significant variations from normal anatomy. Sponseller et al compared 2-dimensional (D) transpelvic computerized tomography (CT) in patients with exstrophy to that of age matched normal controls and found significant external rotation of the exstrophy pelvis.[2] Further studies by Stec et al using 3D-CT revealed externally rotated sacroiliac joints and an inferiorly placed exstrophy pelvis with a larger volume than controls.[3]

Currently, to our knowledge no studies exist using magnetic resonance imaging (MRI) for unoperated bladder exstrophy. The indications for MRI of the pelvis in the pediatric population include evaluation of congenital anorectal or gynecological anomalies, suspected pelvic soft tissue masses and undescended testes.[4] In the case of anorectal anomalies imaging of the pelvic floor, namely the levator sling group, is important to determine the surgical approach and predict the attainment of fecal continence.[5] Formerly, 2D and 3D computer assisted scanning has been used in this population. However, CT is limited by the relatively high dose of radiation and by difficulties in always reliably differentiating muscle from the bladder and other pelvic structures, particularly in neonates.[6,7]

We generated 3D models of the pelvic floor muscles from multiplanar MRIs. The shape of the levator ani muscle group was quantified in children with bladder exstrophy and compared to that of normal anatomy. We thought that better anatomical delineation of the pelvic floor musculature might better define not only the nature of the pelvic floor in exstrophy, but also explain why some select patients attain urinary continence after closure alone.

MATERIALS AND METHODS

Five male subjects 1 day to 12 months old born with bladder exstrophy underwent MRI of the pelvis at presentation. Of the patients 3 were evaluated before primary closure, while 2 had undergone previous attempts at closure. None of the patients had undergone a prior pelvic osteotomy. Of the 2 patients with prior attempts at closure 1 had undergone the first stage of a modern staged repair and the other had undergone complete repair. Pelvic MRI of 1 male patient 3.5 months old without pelvic floor abnormalities was used as a control. The diastasis of the pubic symphysis was measured on pelvic radiographs for all of the patients.

MRI was performed using a 1.5 Tesla scanner (Sigma, General Electric Medical Systems, Milwaukee, Wisconsin). Scans were taken in the axial, coronal and sagittal planes using a head coil. The 3D, T1-weighted images were acquired in the axial and coronal planes. The MRI pulse sequence for these scans consisted of a repetition time of 500 ms and echo time of 10 ms, with slice thickness of 5 mm and a gap of 1 mm. The field of view was 20 to 24 cm. On average 3.5 axial (range 2 to 5) and 4 coronal (3 to 7) images were used to reconstruct the levator ani muscle group. The images were manipulated using a customized visualization and segmentation software package.[8] Controls of the levator ani muscle group were drawn on T1-weighted axial (fig. 1) and coronal (fig. 2) images. The overlap of controls in these 2 places was combined to generate a 3D model of the levator ani musculature.

RESULTS

The levator ani muscle group conformed to the shape of an ellipsoid in the control (fig. 3). For the patients the 3D shape was somewhat irregular with an apparent kink in the ellipsoid shape (fig. 4). The ellipsoid shape of the levator ani was described by a shape factor, s, which equals the maximum height of the ellipse divided by the length of the base of the ellipse. This shape factor was equal to 0.176 for the control compared to a mean of 0.448 for the patients. The diastasis of the pubic symphysis had a range of 2 to 6 cm (mean 4.2). There was no relationship between the pubic diastasis and the extent of disproportionate curvature of the levator muscle group in the patients (see table). Finally, the exstrophy group had a wider angle of divergence of the levator muscle in the axial plane (62 degrees versus 37 degrees in the control).

DISCUSSION

Investigations into the true nature of the pelvic floor did not begin until the pioneering gross dissections of Symington in 1911.[9] Not until the 1950s was any further work done when the levator muscle group was imaged by injected contrast medium by Berglas and Rubin.[10] New imaging techniques in the 1990s generated interest in using 3D models of the pelvic floor to help understand its functional anatomy. The first actual investigation into the nature of the pelvic anatomy in exstrophy was published by Sponseller et al in 1995 when they reported a 30% deficiency in the pubic bone and external rotation of the anterior and posterior parts of the true pelvis.[2] This work stimulated interest in the true anatomical nature of the pelvic floor musculature and its relationship to defects in the bony pelvis in exstrophy. It was judged important as questions have arisen why some patients with exstrophy especially females have achieved some degree of continence after primary closure alone.[5]

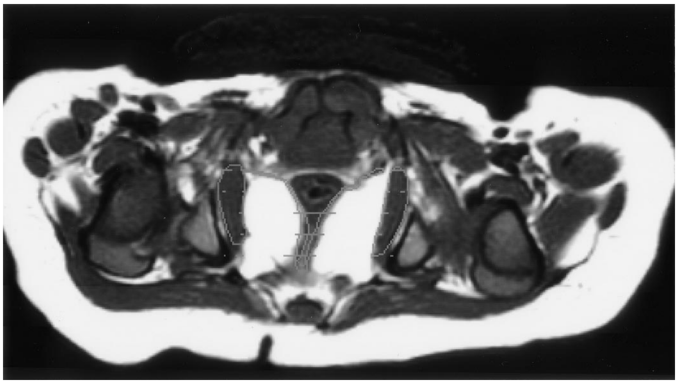

FIG. 1. T1-weighted axial MRI with contours of levator ani and obturator internus.

FIG. 2. T1-weighted coronal MRI with contours of levator ani and obturator internus.

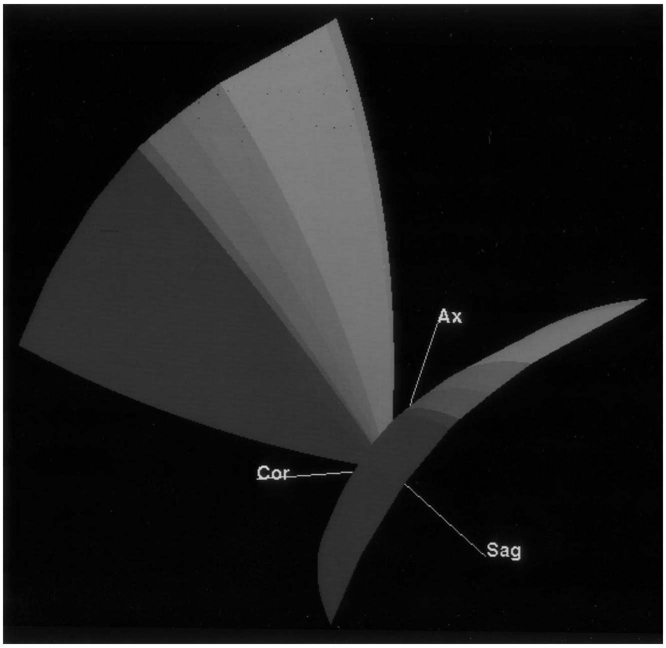

FIG. 3. 3D model of levator ani musculature in control

The focus of our study was to apply new imaging modalities to image the pelvic floor musculature. Knowledge of the anatomy of the bony pelvis in exstrophy is important because muscles of the pelvic floor insert onto the bones of the pelvis. The obturator internus muscles serve as a frame for the attachment of the pelvic diaphragm to the laterally displaced pelvic bones.[5] The lateral aspect of the levator group is the thin sheet-like muscle known as the iliococcygeus, and the bulkier medial muscle sling is called the pubococcygeus. It has been shown in the fetus by Fritsch and Frohlich that the shape and course of the pelvic diaphragm as well as the

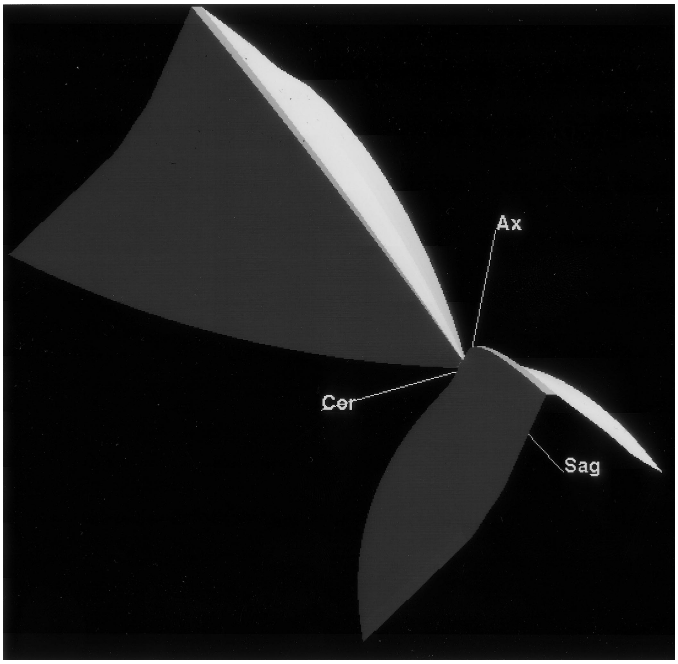

FIG. 4. 3D model of levator ani musculature in patient

Shape factor in patients

Pt No.	Shape Factor (s)	Pubic Diastasis (cm)
1	0.382	4.2 cm
2	0.403	6.0 cm
3	0.410	2.0 cm
4	0.444	4.0 cm
5	0.603	5.0 cm

levator group depend on the shape of the skeletal pelvis.[11] Thus, this important finding suggests that bony changes as seen in the exstrophy pelvis may bring aberrations in pelvic floor musculature.

Significant differences have since been demonstrated between the pelvic floor musculature in patients with classic exstrophy and controls.[5] Using modern CT imaging it has been found that the levator muscle group lies in the plane between the symphysis pubis and the coccyx (pc plane). This muscle comprises the ileococcygeus and pubococcygeus including the puborectalis. Thus, this muscle is not a single muscle but 2 functional components that vary in thickness, origin and function.[12] The ileococcygeus and pubococcygeus have a mainly supportive function, whereas the puborectalis has a sphincteric function. Using 3D-CT Stec et al demonstrated for the first time significant differences between the pelvic floor musculature in patients with exstrophy and controls, namely a wider area of the levator musculature, flattening of the puborectal sling, and outward rotation of the levator ani group, obturator internus and obturator externus muscles.[6] Similar findings were found in our study with regard to levator anatomy and configuration. The axial divergence of the levator group in the exstrophy group and control paralleled that seen by Stec et al.[6] While the angles were somewhat larger (62 degrees in our study versus 39 degrees in the study by Stec et al in the patients, and 37 degrees in the control in our study and 23 in the control of Stec et al), this may simply reflect differences in technique between the 2 modalities. This finding also parallels the results seen using MRI in postoperative exstrophy cases by Halachmi et al.[13]

Thus, preoperative and postoperative MRI of the patient with exstrophy has the advantage of excellent soft tissue contrast without the use of ionizing radiation. In addition, MRI allows accumulation of multiplanar imaging, thus enabling greater image resolution without interpolation. Gearhart et al used pelvic MRI to assess prostate size and configuration in adults born with classic exstrophy and noted that the 4 patients who were continent in adulthood had undergone posterior iliac osteotomy at the time of initial closure and had a puborectalis sling angle of less than 60 degrees.[14] These findings raise the question of the significance of a narrow angle of the puborectalis in establishing continence. In a more recent study using MRI postoperatively in exstrophy cases Halachmi et al found a wider intrasymphyseal distance, laterally diverted levator ani muscle groups and flattening of the pelvic floor even after surgical correction using anterior osteotomies.[13] Interestingly, in 2 patients continence was achieved after primary closure alone. These 2 patients had the shortest distance between the pubic symphyseal halves and the sharpest angle of diversion of the levator muscle group. What the continence rate would have been with a more extensive osteotomy and bringing the pubic symphysis more into apposition continues to be of interest.

We constructed a 3D-MRI model of the pelvic floor. While no prior MRI studies of the pelvic floor for exstrophy have been published, Stec et al used a 3D-CT modeling technique to better establish pelvic floor anatomy.[6] Because of the reputed better soft tissue differentiation using MRI, we wanted to apply this technology to patients who had not been operated on or who had no prior osteotomy with its effect on the pelvic floor. Interestingly, in the control patient without exstrophy the levator muscle group conformed to the shape of an ellipsoid. However, for the patients the shape was somewhat irregular. Clearly based on prior studies and the postoperative exstrophy MRI study by Halachmi et al, the precise anatomy of these muscles depends on the configuration of the bony pelvis especially separation of the pubic symphysis and external rotation of the pelvis.[2,3,13] Also data by Stec et al have shown for the first time that the pelvis in exstrophy has a nearly 15-degree rotation in the superoinferior plane.[3] Thus, the pelvis in exstrophy is rotated significantly more inferiorly than that in controls.

This inferior rotation will affect the insertion of the lateral parts of the levator group (ileococcygeus) to the lateral pelvic wall. This rotation combined with external rotation of the anterior and posterior pelvis and separation of the pubic symphysis manifests a severe pelvic anomaly. This anomaly clearly has a role in the preoperative and postoperative shape of the pelvic floor whether or not an osteotomy has been performed. Thus, the perfect ellipsoid shape in the control has been altered to an irregular ellipsoid shape by the bony defect. In addition, the amount of the pubic diastasis did not correspond to the alteration of the shape factor changes in the ellipsoid.

This interesting preliminary new finding brings into focus a long held unproven concept, which is that the pubic symphysis diastasis alone does not account for all of the pelvic floor anomaly in exstrophy, as well as the role of the bony defects in the derangement of the pelvic floor musculature. As suggested by Halachmi et al in their MRI study after osteotomy, future studies of all cases closed with and without osteotomy are needed to determine their impact on soft tissue structure and function.[13] Certainly, based on our findings combined with the postoperative findings of Halachmi et al one could postulate that the length of the levator muscle group could be lengthened and its configuration could be changed by pelvic osteotomy and more tissue placed anteriorly to support the pelvic viscera and bladder neck.[13]

The best type of osteotomy to accomplish this task is unknown as an MRI series of preoperative and postoperative patients cases not exist. However, the combined anterior innominate and posterior iliac osteotomy does restore pelvic bony anatomy more completely and there is less postoperative drifting of the pubis.[1] Preoperative and postoperative MRIs are being accumulated to see if indeed this will be the osteotomy of choice in the long term.

CONCLUSIONS

We present the first qualitative description of the pelvic floor anatomy of classic bladder exstrophy before pelvic osteotomy using pelvic magnetic resonance imaging. Our 3D model gives new further insights into the true nature of the pelvic floor in exstrophy. The discovery of the angle of divergence and symphyseal diastasis before and after surgery as suggested by Halachmi et al may be the key factors in determining pelvic muscle correction by osteotomy and future continence.[13] Preoperative and postoperative MRI studies are being accumulated to assess this problem as it will be interesting to find out whether it is the type of exstrophy repair versus the pelvic correction with osteotomy that ultimately determines future urinary continence.

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