The Sacroiliac Joint Axes of Rotation: Implications for Rigid and Dynamic Stabilization

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INTRODUCTION: Sacroiliac joint (SIJ) dysfunction accounts for approximately 25% of low back pain cases, but accurately diagnosing SIJ-mediated pain is challenging. The only current surgical treatment is arthrodesis, with efficacy varying among patient demographics. Understanding the joint motion quality is crucial to expanding diagnoses, and treatment options while improving efficacy. However, no adequately powered studies have biomechanically described joint motion quality between male and female groups. This study analyzed and characterized the axis of rotation (AoR) between sexes in six loading directions. We hypothesized that the center of rotation (CoR) moves between opposite loading directions in the same plane and the orientation of the female and male joint axes are different.

METHODS: 26 paired fresh-frozen, asymptomatic human cadaveric SIJ (12:14 Male:Female, Age 48±11:50±13) were obtained for this study. Specimens were screened for SIJ deformity/bridging and pubic symphysis diastasis. Each pair of joints were dissected with skin and fat removed. Care was taken to leave the posterior ligaments and pubic symphysis intact. Each joint was fixed in a single-leg stance and tested in six loading directions (flexion, extension, ipsi-and contra-axial rotation, and ipsi- and contra-lateral bending). An optical tracking system was used to track the relative motion of the sacrum to the ilium. Each AoR in the three planes and six directions were calculated using the position of the three points on the sacrum at the first and last loading steps. The CoR was quantified as the axis's intersection with the SIJ. The axes' orientation was quantified by the angle of the axis to the anatomical axes. Outlier analysis was performed using the median absolute deviation method. T-tests were conducted to compare the axes' location and orientation between sexes and loading directions.

RESULTS: The mean AoR during nutation and counternutation are shown in Figure 1. The CoR is more anterior during nutation than counternutation in both male and female joints ($p<0.03$). The male CoR during nutation was more anterior and superior than the female ($p<0.03$). The CoR change between nutation and counternutation in females and males is significantly different ($p<0.01$). The female joint AoR in the transverse plane is oriented in opposite directions between nutation and counternutation ($p<0.01$). The AoR was more deviated in the coronal plane than in the transverse plane during nutation and counternutation for both joints ($p<0.01$). The mean AoR during lateral bending is shown in Figure 2. The female ipsi and contra-lateral bending AoR are more deviated in the sagittal plane than in the transverse plane ($p<0.01$). The male ipsi-lateral bending AoR is more deviated in the sagittal plane ($p<0.01$), and is oppositely oriented to the contra-lateral AoR in the sagittal plane ($p<0.03$). The mean AoR during axial rotation is shown in Figure 3. The AoR in the sagittal plane during ipsi axial rotation is oriented in opposite directions between the male and female ($p<0.03$). The male joint contra-axial AoR is more deviated than the ipsi-axial rotation in the coronal plane ($p<0.05$) and is more deviated in the sagittal plane than in the coronal plane ($p<0.05$). The planar AoR was more similar to counternutation in the sagittal plane for both male and female joints ($p<0.01$) and ipsi-lateral bending in the coronal plane for male joints ($p<0.05$).

DISCUSSION: The anterior shift of the CoR from counternutation to nutation in both sexes indicates that the posterior ligaments play a major role in stabilizing counternutation while the anterior ligaments contribute more to stabilization during nutation albeit significantly more in men than women. The male AoR tilts forward from ipsi to contra-lateral bending, which places the stabilization (AoR) near the ventral ala surface. This phenomenon further supports sexual differentiation in the contribution of the anterior ligament to stabilization. Also, the superior-inferior axis was the predominant contributor to the deviation of the AoR during nutation-counternutation and lateral bending. This indicates that axial rotation would be the largest contributor to the off-axis motion. Planar AoR shows which direction is the more dominant motion in each plane. Counternutation is the dominant motion in the sagittal plane for both sexes and ipsi-lateral bending is the dominant motion in the coronal plane in male joints.

SIGNIFICANCE/CLINICAL RELEVANCE: Rigid stabilization will be most effective when it is farthest away from, and perpendicular to the AoR due to a longer lever arm, and interposing effect, respectively. Dynamic stabilization collinear with the asymptomatic AoR would be most effective at preserving/restoring joint motion.

IMAGES AND TABLES:

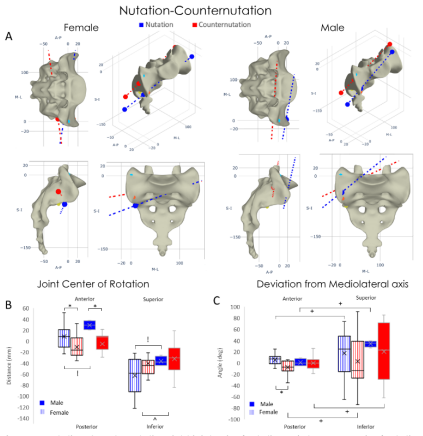

Figure 1. Nutation-Counternutation right joint axis of rotation. A) The mean axis of rotation of the joint (blue: Nutation, red: Counternutation). B) The location of the intersection point of the AoR on the joint plane. C) The angle of the rotational axis relative to the Mediolateral axis. The exclamation (!) indicates significant differences between sexes. The asterisks (*) indicates significant differences between the direction. The plus (+) indicates significant differences between the absolute angles. The carat (^) indicates significant difference in the nutation to counternutation change between male and female.

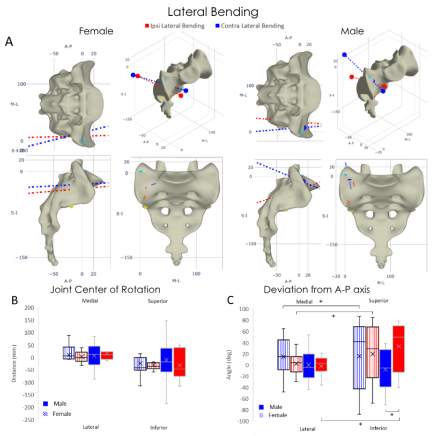

Figure 2. Lateral Bending right joint axis of rotation. A) The mean axis of rotation of the joint (blue: Contra Lateral, red: Ipsi Lateral). B) The location of the intersection point of the AoR on the plane that is parallel with the frontal plane and coincides with the midpoint of the joint. C) The angle of the rotational axis relative to the A-P axis. The solid color is male and the hatched female. The exclamation (!) indicates significant differences between sexes. The asterisks (*) indicates significant differences between the direction. The plus (+) indicates significant differences between the absolute angles. The carat (^) indicates significant difference in the contra to ipsi change between male and female.

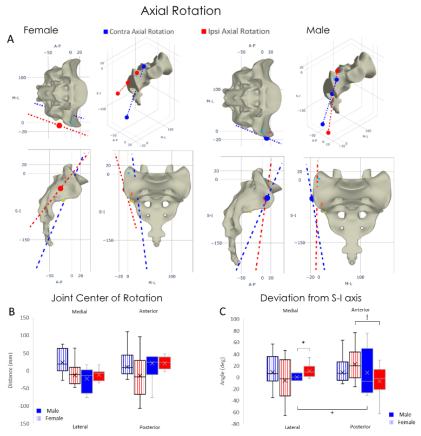

Figure 3. Axial Rotation right joint axis of rotation. A) The mean axis of rotation of the joint (blue: Contra Axial, red: Ipsi Axial). B) The location of the intersection point of the AoR on the plane that is parallel with the transverse plane and coincides with the midpoint of the joint. C) The angle of the rotational axis relative to the S-I axis. The solid color is male and the hatched female. The exclamation (!) indicates significant differences between sexes. The asterisks (*) indicates significant differences between the direction. The plus (+) indicates significant differences between the angles. The carat (^) indicates significant difference in the contra to ipsi change between male and female.