Passive and Active Stability of the Sacroiliac Joint is Influenced by Coupled Axial Rotation Motions, Differing between Left and Right, and Men and Women: A Cadaver-Based Biomechanical Study

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INTRODUCTION: The sacroiliac joint provides stabilization and force transmission between the spine and lower extremities. However, these stabilizing properties remain largely unexplored, especially as these properties may be influenced by sexual dimorphism, with downstream effects on pathology phenotyping and therapies. The goal of this study was to characterize the passive and active stability of the sacroiliac joint across both sexes. We aimed to define the Neutral and Elastic zones of motion (ROM) and their coupled motions. We hypothesized that lateral bending would be the most stable. We hypothesized that left-right asymmetry would be present in both men and women.

METHODS: Twenty-six paired fresh-frozen, asymptomatic human cadaveric sacroiliac joints (12M:14F Age-48±11:51±12) from L4 to Pelvis, were obtained for this study. Each specimen was screened for sacroiliac joint deformity / bridging, and pubic symphysis diastasis using donor histories and computed tomography scans. Quasi-static multidirectional bending flexibility tests on each intact joint in a single-leg stance model were performed, and the relative orientations about each anatomic axis, between the sacrum and the iliac during nutation-counternutation (NC), lateral bending (LB), and axial rotation (AR) loads were measured from 0 to 7.5 Nm at 1.5 Nm intervals using an optical tracking system after 3 preconditioning cycles. The On- and Off-axis components of the Neutral Zone (NZ), and Elastic Zone (EZ), were calculated as ROM outcome measures. The On-axis motion contributions of the NZ (NZP) and EZ (EZP) were calculated as stability outcome measures. The On-Axis Ratios (On-Axis/ Total ROM) were calculated as alignment outcome measures. Outcome measures were compared between planes, directional pairs, laterality, and sexes. Paired t-tests were performed in all comparisons except male-female comparisons which utilized unequal variances t-tests.

RESULTS: All male and female joints completed testing. NZ Outcomes are shown in Figure 1. Female joints produced larger NZs than male joints in all directions of loading ($p<0.01$). The On-axis NZs were smallest during LB in females, and largest during NC in males ($p<0.02$). The On-Axis NZ ratios were the smallest during LB in both groups ($p<0.01$). The off-axis NZ motions of both groups during NC loading were comprised mostly of AR ($p<0.05$). The right joints in males and the left joints in females had 33% and 21% significantly larger NZs during NC ($p<0.05$). EZ magnitudes and proportions are shown in Figure 2. Female joints produced larger EZs than male joints ($p<0.01$). In males, the LB NZPs were significantly lesser than the NC NZPs ($p<0.01$). The male nutation and ipsi-axial rotation EZPs were significantly greater than the female, while the female counternutation EZPs were significantly greater than the males ($p<0.05$). In male joints, the AR NZPs were significantly lesser than their EZPs ($p<0.05$). In female joints, the NC NZPs were significantly lesser than the counternutation EZPs ($p<0.04$). In both groups, the LB NZPs were significantly lesser than the ipsilateral EZPs ($p<0.02$). In female joints, the counternutation and ipsilateral EZs were significantly greater than those of nutation and contralateral bending respectively ($p<0.01$). In male joints, the left contra-axial EZs were 82% greater than those of the right ($p<0.02$). The off-axis EZ ROMs are shown in Figure 3. Female Off-axis EZ ROMs were significantly greater than the male joints during NC and contra-axial rotation loads ($p<0.02$). The off-axis EZ ROMs during male NC, and during female counternutation and ipsilateral bending were comprised mostly of AR ($p<0.02$). The female on-axis EZ ratios were significantly greater during ipsi than contralateral bending ($p<0.02$). In the female joints, the right joints during nutation and the left joints during ipsi-axial rotation had 75% and 160% greater off-axis EZ ROMs, while in males, the left joints during contra-axial rotation had 29% greater on-axis EZ ratios ($p<0.04$).

DISCUSSION AND CONCLUSION: Men are more stable in nutation than women, while women are more stable in counternutation than men. In men, the left joint is more stable during NC and exhibits less coupled motions during contra-axial rotation. While in women, the right joint is more stable during NC and exhibits less coupled motions during ipsi-axial rotation, but more coupled motions during nutation. Lateral bending is the most stable and most coupled loading plane during passive loading. Ipsi-lateral loading is less coupled and is the most actively stable direction. Axial rotation is the predominant loading plane of the sacroiliac joint. During ipsilateral bending in female joints, axial loading is present. During passive and active NC bending in both sexes, axial loading is present. Coupled motions may play a role in stabilizing the sacroiliac joint, as symmetric off-axis motions during passive loading, and asymmetric off-axis motions (specifically skewed to axial rotation) during active loading coincides with greater stability.

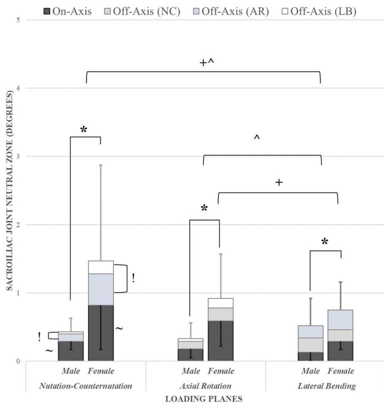

Figure 1. NZ in three planes. The exclamation (!) indicates significant differences between off-axis NZ motions within each loading plane and sex. The tilde (~) indicates significant differences in on-axis NZ between left and right joints. The asterisks (*) indicates significant differences in On-Axis NZ between sexes. The carat (^) indicates significant differences in On-Axis NZ Ratio between loading planes. The plus (+) indicates significant differences in On-Axis NZ between loading planes.

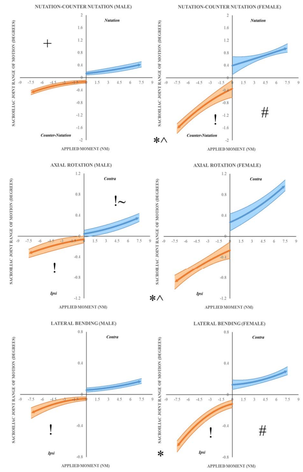

Figure 2. Plot of On-Axis motion zones in three planes and six directions. The x-axis lists the applied pure moment. The y-axis displays the On-Axis ROMs. The exclamation (!) indicates significant differences between NZP and directional EZP. The hashtag (#) indicates significant differences in EZs between directions. The tilde (~) indicates significant differences in the directional EZ between left and right joints. The asterisks (*) indicates significant differences in the directional EZs between male and female joints.The plus (+) indicates significant differences in the Nutation-Counternutation NZPs vs Lateral Bending. The carat (^) indicates significant differences in EZPs between male and female joints.

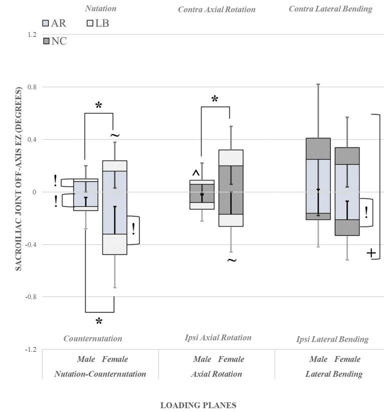

Figure 3. Off-Axis EZ in six directions. The exclamation (!) indicates significant differences in Off-Axis EZ motion planes within each direction. The asterisks (*) indicates significant differences in total off-axis EZ between sexes. The plus (+) indicates significant differences in On-Axis EZ Ratio between directions. The tilde (~) indicates significant differences in total off-axis EZ between the left and right joints. The carat (^) indicates significant differences in On-Axis EZ Ratio between left and right joints.