Inter- and Intra-Subject Variance in Lumbar Disc Heights and Joint Ranges Across Four Seated and Standing Postures

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I. INTRODUCTION

Finite element (FE) human body models (HBMs) are often based on a single individual's geometry, and then leveraged to examine variability in occupant responses to crash- and vehicle-related factors (e.g. sensitivity to seated position) [1]. The geometry of these models can also be morphed to examine response variability to occupant-related factors [2]. Via FE models, kinematic responses have been shown to vary with initial spine posture within a single individual in frontal collisions [3], and different metrics have been proposed as targets for spine positioning [4-5]. However, current target spine-positioning studies often assume there are similar amounts of joint motion at all spine levels, or that the joint motion ranges for one individual apply to all individuals and are not correlated to subject-specific geometry. This study aims to use medical images of volunteers in different seated and standing postures to evaluate if there are levels of the lumbar spine that have increased joint range within an individual, and if trends in joint range by level are consistent across individuals of varying age and sex.

II. METHODS

Ten volunteers (5F; ages 24–56 years; height 172 ± 11.6 cm; BMI 24.6 ± 3.3) underwent a combination of in-vehicle measurements and magnetic resonance (MR) scans to determine their lumbar spine geometry in four postures (self-selected preferred driving posture, reclined posture, seated forward flexed posture and standing). Disc heights were measured for lumbar discs in all postures. Further detail on study methods can be found in [6].

Volunteer Measurements and Imaging: each volunteer was asked to sit into a 2017 Honda Acura TLX driver's seat and adjust the seat to their preferred driving posture. In-vehicle measurements were taken in this preferred posture and in a 50° reclined posture, and were then used to replicate these postures in an MR-safe seat in an Upright MRI. Following imaging in these two seated postures, volunteers were asked to flex their torso as far forward as possible (towards their legs) while still seated. Subjects were permitted to rotate their pelvis forward. The final posture was imaged while volunteers stood with their arms resting on a support bar. Volunteer testing methodology was reviewed and approved by the University of British Columbia's Clinical Research Ethics Board.

Calculation of Midsagittal Lumbar Disc Height Metrics: MR images of the lumbar spine were analysed to determine the anterior and posterior disc heights from T12-L1 to L5-S1. Points were selected on the mid-sagittal image of each subject for each posture. Selected points included the most anterior and posterior points on each lumbar endplate. The Euclidian distance between the two most anterior points and the two most posterior points of adjacent endplates were calculated, yielding an anterior disc height and a posterior disc height, respectively. The difference between the anterior and posterior disc heights (ΔAP height) for each disc was calculated (Fig. 1, left); positive values indicated a flexed disc and negative values indicated an extended disc. Minimum and maximum ΔAP heights for each disc level across all postures were determined, and these joint ranges (from minimum to maximum) represented the amount and direction of each joint's change across the four postures.

III. INITIAL FINDINGS

Joint ranges varied across subjects and across lumbar disc levels within a single subject (Fig. 1). Maximum joint range for all males occurred at the L4-5 or L5-S1 level, and maximum joint range for all females occurred at the L3-4, L4-5, or L5-S1 level. Minimum joint range for males occurred at the T12-L1, L1-L2, or L2-3 level, whereas minimum joint range for all but one female subject occurred at the T12-L1 level. Subject 8 (S8) had a minimum joint range at the L5-S1 level, where the disc was notably smaller than the subject's other discs (Fig. 1, right). Most

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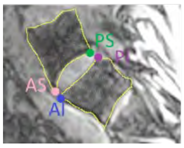
joint ranges included both flexion and extension, but the L2-3 level for S15 and the L3-4 level for S14 remained extended in all postures, while the L3-4 level for S6 and the L1-2 level for S7 remained flexed for all postures.



$$Anterior\ Height = \sqrt{(AS_x - AI_x)^2 + (AS_y - AI_y)^2}$$

$$Posterior\ Height = \sqrt{(PS_x - PI_x)^2 + (PS_y - PI_y)^2}$$

$$\Delta\ \boldsymbol{AP\ Height} = Anterior\ Height - Posterior\ Height$$

	Joint Range (mm)					
	T12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
S3, M, 25 yr	-6.3	-3.5	-6.7	-4.5	-5.2	**-9.2**
	0.8	2.7	0.34	**7.7**	4.64	3.3
S6, M, 30 yr	-2.9	-1.7	-0.2	0.9	**-3.7**	-3.5
	3.3-	4.9	3.1	**6.9**	4.8	0.6
S4, M, 31 yr	-1.8	-0.7	-2.2	-3.6	-1.9	**-8.4**
	0.6	2.0	0.5	**5.0**	4.6	1.8
S14, M, 52 yr	-1.1	-1.0	-2.0	-5.5	**-6.2**	-5.9
	1.2	1.0	0.8	-0.03	**2.9**	1.3
S15, M, 56 yr	-6.9	-9.6	-5.0	-7.2	**-13.8**	-5.7
	0.9	**3.7**	-0.5	0.4	1.29	0.9
S5, F, 24 yr	-1.7	-1.3	-5.8	**-7.5**	-4.2	-3.5
	2.3	4.5	**4.8**	2.4	3.2	1.0
S7, F, 27 yr	-0.1	1.9	-1.1	-5.2	-4.9	**-6.3**
	2.6	5.0	5.0	6.4	**6.9**	0.7
S8, F, 34 yr	-2.7	-4.2	-5.5	**-9.3**	-2.7	-3.8
	3.9	1.4	1.6	2.5	1.2	0.6
S9, F, 41 yr	-0.6	-4.6	-1.6	-6.6	**-7.8**	-6.5
	0.1	1.9	4.2	**5.6**	4.1	1.7
S12, F, 56 yr	-1.4	-2.9	-0.3	-1.5	-1.1	**-8.1**
	0.4	2.7	3.7	**5.1**	3.4	3.0

Subject 8 (F, age 34, BMI 21.5)

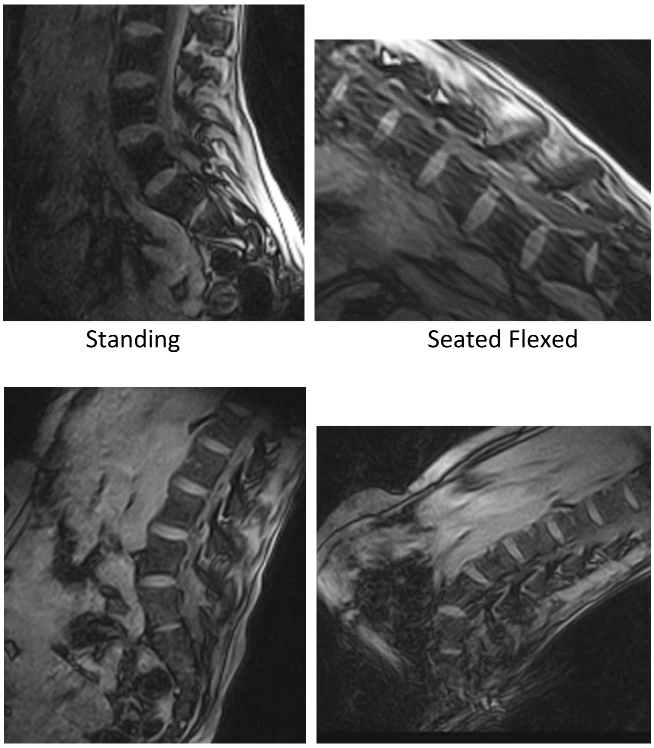


Fig. 1. Schematic (top left) defining the ΔAP disc height calculation. Table (bottom left) showing joint range determined by minimum ΔAP disc height in mm (upper value in each cell) and maximum ΔAP disc height in mm (lower value in each cell) across all four postures at each lumbar level (table columns) for each subject (table rows). Negative values indicate extended joints and positive values indicate flexed joints. The most flexed and extended joints across levels and postures are bolded for each subject. Lumbar level with the greatest range (green) and smallest range (yellow) are also indicated. Visualisations (right) of the four postures for an exemplar subject (S8).

IV. DISCUSSION

Across the seated and standing postures considered here, we found that the largest lumbar-disc joint range typically occurs in the lower lumbar spine and the smallest lumbar-disc joint range typically occurs in the upper lumbar spine, regardless of age. These data also suggest that females may have more flexibility than males in the upper to middle lumbar spine. While most joints experience both flexion and extension within their ranges, some disc levels for some subjects always remained either flexed or extended across the examined postures. This study demonstrates large inter- and intra-subject variability in lumbar disc joint ranges across seated and standing postures. This pattern may be correlated to local vertebra geometry (with many vertebrae not having parallel endplates), disc geometry (e.g. subject- and height-specific disc volume), and local disc material properties. Further work is needed to determine if spine position data are correlated to these local and subject-specific metrics. Collectively, these data suggest that each individual's lumbar spine uses a different combination of joint angles to achieve a given posture. These results demonstrate that there could be additional variability in occupant response due to the natural variability in disc heights and available joint ranges in the lumbar spine, and future lumbar spine positioning targets for FE models should consider both subject-specific geometry of each model (e.g. disc heights) and inter-subject variance in joint range when determining lumbar spine position.

V. REFERENCES

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