Changes in Intervertebral Angles and Disc Heights in Lumbar Spine from Upright to Reclined Seating: A Reference Database for Human Body Model Positioning

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I. INTRODUCTION

Future autonomous vehicles will enable new seating postures, such as reclined seating, creating a necessity for upgrading conventional restraint systems. The development of such systems increasingly relies on virtual analysis with Human Body Models (HBMs). Currently, HBMs are by default positioned in an upright driving posture (approximately 20–25° seatback inclination), and yet no standardised methods exist to articulate them into reclined postures in a biofidelic manner. Existing spine target positions for reclined seating positions [1] may not be directly applicable to HBMs due to differences in anthropometry between HBMs and target positions [2]. Recent analyses by Roberts *et al.* demonstrated significant intra- and intersubject variability in lumbar spine alignment across different postures (standing vs. seated upright/reclined/flexed) [3]. Despite that variability, the authors hypothesise that comparing upright and reclined seating positions may reveal consistent vertebral alignment patterns, particularly regarding geometric dimensions of discs and relative vertebrae positions, which could constrain the range of motion. Thus, this study aims to analyse lumbar spine positions in upright versus reclined postures to identify patterns in intervertebral angles (IVA) and disc height changes that could serve as reference data for achieving physiologically accurate reclined postures in HBMs.

II. METHODS

Datasets [4-5] of two volunteer studies that imaged subjects in upright and reclined positions were utilised to analyse disc height and IVA in the lumbar spine in sagittal plane for both positions.

Volunteer Study Data

In [4-5], volunteers were asked to sit in a replica of a vehicle seat in preferred upright position (10–20° inclination) and reclined position (50° inclination) and were imaged with an open magnetic resonance machine covering the upper body from pelvis to clavicula. For the sake of comparability, only volunteers who chose the same upright position of 20° seatback inclination (12 out of 16) were selected, resulting in six male and six female subjects (age 39.25 ± 10.42 years; height 173 ± 7.6 cm; BMI 25.38 ± 2.53).

Posture Analysis: Calculation of Changes in Disc Height and IVA

Based on the method introduced by Roberts *et al.* [3], markers were placed in the MRI scans in the midsagittal plane on the most inferior/superior position anterior and posterior on each vertebral endplate from T12 to L5, resulting in two markers on each endplate per vertebra (Fig. 1, red). Anterior and posterior disc heights were calculated as the Euclidean distance between corresponding markers (green), and the delta between these values as $\Delta AP = d_A - d_P$ [3].

Additionally, the markers were used to calculate IVAs as the angle between the vectors (white) normal to the vector connecting the midpoint between the two markers (blue) on each endplate, respectively. For each subject the delta in IVA between positions was calculated as $\Delta IVA = IVA_{Reclined} - IVA_{Upright}$. For both measurements, IVA and ΔAP, positive values indicate extension while negative values indicate flexion of the joint. In addition, lumbar lordosis angle was calculated as the sum of IVAs from L1 to L5 in midsagittal plane.

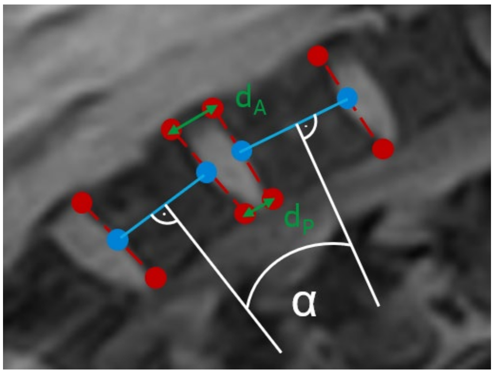

Fig. 1. Scheme of calculation of anterior and posterior disc heights d_A/d_P according to [3] and IVA α (midsagittal plane) in lumbar spine.

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III. INITIAL FINDINGS

The lumbar lordosis angle in the reclined position (25.3 ± 18.0°) was significantly greater than in the upright position (10.2 ± 14.9°). In both seating positions, IVAs varied within the lumbar spine, with lower lumbar joints exhibiting larger IVAs, reaching up to 34° (Fig. 2). The change in IVAs between positions is not evenly distributed along the lumbar spine and appears to be more pronounced in the lower lumbar region. Major effects in ΔIVA were observed at the L4/L5 and L3/L4 lumbar joints (Table I). Additionally, a greater anterior disc height was associated with an increased difference between anterior and posterior disc height (Fig. 3). Up to an anterior disc height of approximately 10 mm, joint flexion was observed, whereas at greater heights only extension was measured (positive ΔAP). In the upright position, both anterior disc height and ΔAP tended to be smaller than in the reclined position.

TABLE I:
DELTA OF IVA FOR EACH SEGMENT IN LUMBAR SPINE BETWEEN SEATING POSITIONS

Spinal Segment	L4/L5	L3/L4	L2/L3	L1/L2	T12/L1
ΔIVA (°) ± Standard Deviation	7.3 ± 5.0	6.4 ± 4.8	0.2 ± 5.6	1.2 ± 5.1	3.6 ± 3.7

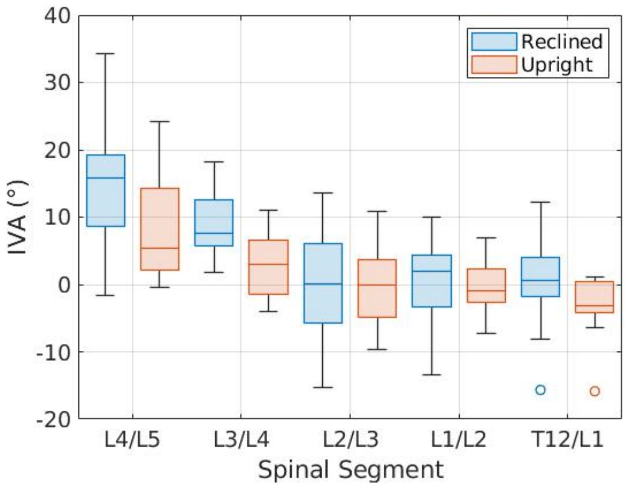

Fig. 2. IVAs for both inclination levels in each spinal segment of lumbar spine.

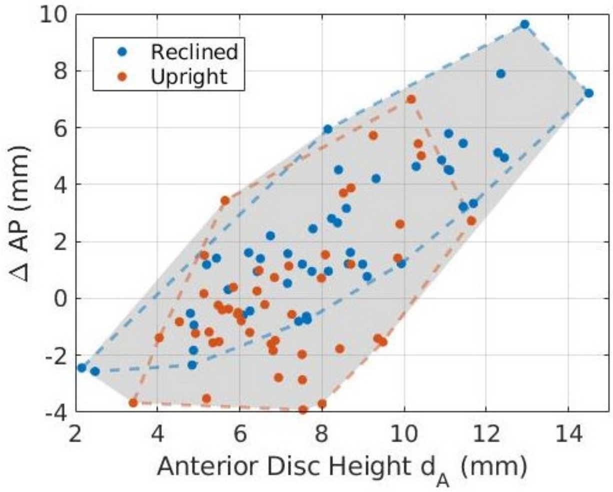

Fig. 3. Delta between anterior and posterior disc height (ΔAP) in relation to anterior disc height.

IV. DISCUSSION

The results are in line with other studies [6-7], confirming that lumbar spine angles differ significantly between seating positions, causing larger lordosis angles in reclined positions. Variations in IVAs, particularly the larger IVAs observed in the lower lumbar segments, suggest that those spinal segments contribute more significantly in adaptation to seatback inclination. The trend between anterior disc height and ΔAP further supports the idea that disc geometry influences joint motion. A greater anterior disc height corresponds to an increased range of motion, especially in the reclined position. In the upright position, both anterior disc height and ΔAP are smaller, which could be attributed to increased spinal loading and reduced disc expansion due to compressive forces of the upper body. The presented data is particularly relevant for reclined positioning of HBMs. Given the observed pattern of greater contribution of the lower lumbar spine segments to change in seatback angle, this characteristic should be incorporated in positioning tools by addition of corresponding ΔIVAs. Observed ranges of both, IVA and ΔAP in regard to d_A, may serve as a reference guidance, with their respective minimum and maximum values potentially used as joint range-of-motion limits in positioning tools. However, only 12 subjects were analysed in this study. Thus, future work plans include a larger sample size to increase the database.

V. REFERENCES

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