Feasibility of Full Body Thoracolumbar Model Personalization with Standing, Low Dose Biplanar Xray

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INTRODUCTION: Radiographic assessment of spinopelvic sagittal alignment during standing has become a cornerstone of operative planning and outcome assessment in adult spine deformity.[1] Preoperative workflows generally include identifying local radiographic drivers of the deformity (e.g., loss of lordosis), assessing impact on global head-to-foot alignment, and determining surgical re-alignment to restore an ideal upright posture (e.g. level gaze with low muscular effort).[2] Inadequate local re-alignment may result in segmental compensations proximal/distal to the fusion construct in order to maintain upright posture (e.g., pelvic retroversion, thoracic extension, knee flexion).[3] Malalignment and compensations are assumed to increase potential for post-operative complications such as decreased patient satisfaction or construct mechanical failures, in part due to increased muscle and intervertebral forces.[2] Physics-based models capable of estimating immeasurable biomechanics may add value, although precise and coherent full body 3D measurements are needed for personalization. Furthermore, associations between alignment and internal biomechanics are not yet fully characterized, even within normative reference populations. The objective of this study was to evaluate feasibility of personalizing full body 3D musculoskeletal models with biplanar standing radiographs, and to benchmark performance on a diverse asymptomatic population.

METHODS: Retrospective records from a multicenter study approved by local institutional review boards were used for this investigation.[1] Inclusion criteria were no history of surgical treatment for spinal disorder, no current neck or back pain (visual analog scale ≤ 2), minimal self-reported disability (Oswestry Disability Index <20%), and no radiographic scoliosis (Cobb <10°). Each subject underwent weight bearing, low-dose biplane EOS radiographs from which 3D skeletal anatomy was reconstructed using semi-automated workflows (sterEOS Workstation, EOS Imaging, Paris, France).[4] 3D locations and orientations of vertebrae from T1 to S1 were extracted, in addition to centers of femoral heads, femoral condyles, malleoli, and cranial auditory meatus. Standard radiographic alignment parameters computed by sterEOS were also extracted. Records were excluded if occlusions prevented full body 3D reconstruction, yielding 301 records for sub-analysis (Figure 1a). Reconstructions and patient demographics were used to personalize a generic, full body thoracolumbar musculoskeletal model (Figure 1b).[5] Muscle recruitment and intervertebral reaction forces were simulated in the measured standing posture using an optimization routine. Calibration was verified by comparing personalized model landmarks to sterEOS measurements.[4] Biomechanical outputs were compared to results from prior simulations that used similar methodology,[6] and to in vivo data for a subset with comparable demographics (N=10, males, age 40-50 years, BMI 22-25).[7] Correlations between alignment parameters and biomechanical outputs were evaluated with respect to clinical assumptions of association.

RESULTS & DISCUSSION: Models were successfully personalized with 3D skeletal reconstructions for all subjects. Differences between model landmarks and original measurements after scaling were acceptable (max RMSE<0.3 mm, SterEOS precision <1.6 mm).[4] Simulated intervertebral axial compression forces showed substantial variation along the spine and within each vertebral level (Figure 1c). Relative to the prior simulation study, forces in the lumbar region were comparable, despite a simpler model (rigid thorax, fixed pelvis), no lower extremities, and a smaller less diverse cohort (N=145).[6] Relative to the in vivo comparator, simulated L4-L5 axial forces fell within measurement uncertainty for upright standing, ranging 0.62-0.95 bodyweights, and highlighting the potential for varied biomechanics despite comparable sex, age, and BMI (N=10).[7] Sagittal vertical axis was moderately associated with recruitment in spine and hip extensor musculature (R=0.47), and weakly associated with L4-L5 axial compression (R=0.35). Strong associations were observed between knee flexion angle and ankle/knee muscle recruitment (R>0.6). Limitations of the workflow include sensitivity to intervertebral kinematic constraints, passive stiffness representation, and muscle model (recruitment criteria, force-length parameters). Extended contexts of use including severe pathology/deformity or dynamic tasks may leverage ancillary imaging such as MRI or functional poses with EOS (e.g., sitting, spine bending) for further personalization.

SIGNIFICANCE/CLINICAL RELEVANCE: Current clinical workflows in spine surgery are limited to radiographic assessment of spinopelvic alignment and may be improved by better understanding relationships between alignment and patients' underlying biomechanics. The current study demonstrated feasibility of personalizing full body 3D musculoskeletal models with biplanar standing radiographs and characterized biomechanics in a diverse asymptomatic cohort.

REFERENCES:
1. Sardar A, et al. 2022. *Spine*. 47:1372-81
2. Iyer S, et al. 2018. *J Bone & Joint Surgery Rev*. 42:799-807.
3. Day L, et al. 2017. *Spine*. 42:799-807.
4. Humbert L, et al. 2009. *Medical Eng & Physics*. 31:681-7.
5. Bruno A, et al. 2015. *J Biomechanical Engineering*. 137:081003.
6. Fasser M, et al. 2021. *Frontiers Bioengineering & Biotech*. 9:721042.
7. Wilke H, et al. 2001. *Clinical Biomechanics*.16:S111-S126.
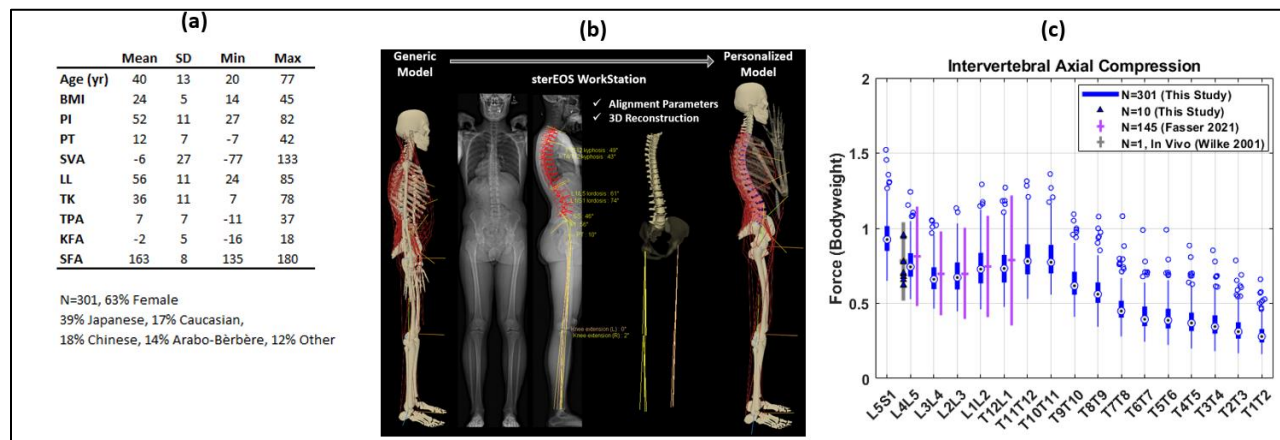
Figure 1 - (a) Demographics and alignment parameters; Pelvic Incidence (PI), Pelvic Tilt (PT), Sagittal Vertical Axis (SVA), L1S1 Lumbar Lordosis (LL), T4T12 Thoracic Kyphosis (TK), T1 Pelvic Angle (TPA), Knee Flexion Angle (KFA), Sacrofemoral Angle (SFA). (b) Modeling & simulation workflow informed by sterEOS (c) Intervertebral axial compression force due to posture, body mass, and muscle forces. Compared to prior simulation reports (mean ± 2 standard deviations),[6] and to in vivo intradiscal pressure measurements at L4-L5,[7] for a demographically matched subset (N=10).