The effects of tether pre-tension within vertebral body tethering on the spine motion: a finite element analysis

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INTRODUCTION: Adolescent idiopathic scoliosis (AIS) is a three-dimensional (3D) spine deformity. For severe cases with Cobb angle > 30° surgery is recommended, where Posterior Spinal Fusion (PSF) instrumentation is the standard procedure. Vertebral body tethering (VBT) is an alternative which allows the preservation of spinal growth and motion, and it is suitable for cases where a young patient still has growth potential. Despite its potential in AIS treatment, the VBT is a relatively new technique, approved by the FDA in 2019, and thus there remains a need for further improvement of the system and a better understanding of the biomechanical effects of the implant on the spine, since it may lead to problems such as over- and/or -under-correction, tether breakage, and revision surgery. Addressing a better understanding of the spine biomechanics while instrumented with a VBT system, the effects of different cord pre-tensions on the spine's range of motion (ROM) were evaluated using a Finite Element (FE) model. We hypothesized that the spine post-surgical ROM is directly affected by the pre-tension in the cord during the VBT instrumentation surgery.

METHODS: An extensively calibrated and validated FE model of the L1-L2 spine segment was employed to investigate the effects of VBT instrumentation with different cord pre-tensions on its biomechanics. The FE model was adjusted within a standard deviation of anthropometric data to represent an average healthy spine. The mechanical properties of soft tissues, including ligaments, facet joints, and discs, were calibrated using experimental data from stepwise resection studies. The nucleus pulposus and annulus fibrosus were modeled using hyperelastic Mooney-Rivlin and Holzapfel-Gasser-Ogden formulations, respectively. Tie constraints and frictionless soft contact interactions were utilized between vertebral surfaces and intervertebral discs, while the spinal ligaments were modeled as nonlinear bar elements. Simulations were performed by applying pre-tensions of 50 N, 100 N, 200 N, and 300 N to the tether and conducting tests with external pure moments of 5 Nm in the anatomical directions (flexion-extension, lateral bending, and axial rotation) to assess the ROM for each pre-tension level and analyze spinal parameters (Nicolini *et al.*, 2022, 2023).

RESULTS SECTION: The results in Table 1 show the ROM for various spinal motions of both the native spine and instrumented with VBT, considering different tether pre-tensions. In all cases, the ROM decreased as tether pre-tension increased. The ROM of the instrumented segment with pre-tension of 300 N for extension, flexion, left lateral bending, right lateral bending, right axial rotation, and left axial rotation was, respectively, 46%, 60%, 17%, 28%, 47%, and 51% of the ROM of the native segment. With VBT instrumentation, but without pre-tension, the ROM results of the segment only differ from the native segment in the right lateral bending motion.

DISCUSSION: VBT aims to correct AIS curves while preserving spinal motion. The results presented here show that ROM decreases as tether pre-tension increases, as hypothesized. At the highest tether pre-tension normally used for especially severe scoliotic curves, 300 N, little motion is preserved in lateral bending due to the increased stability to correct the curvature, while in flexion-extension and axial rotation, approximately 50% of the native ROM is preserved. The FE model's geometry and calibration were meticulously designed based on the average characteristics of non-scoliotic young man spines, facilitating validation through comparisons with cadaveric biomechanical experiments. Although VBT targets adolescent scoliosis patients, utilizing adolescent geometry imposes challenges due to the absence of relevant resection studies in the literature for precise model calibration. For this reason, the adult model was chosen for evaluation of the biomechanical effects of VBT. The motion is better preserved with lower pre-tensions, demonstrating the compromise necessary between mobility and curve correction while providing a reasonable reference for surgeons to determine the appropriate pre-tension to apply during surgery.

CLINICAL RELEVANCE: This work may contribute to research on the biomechanics of spine and spine surgeons.

REFERENCES:

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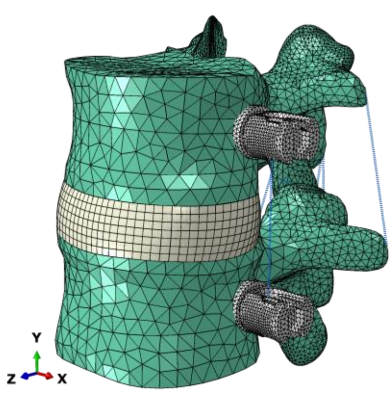

Figure 1 – Computational model of L1-L2 segment instrumented with vertebral body tethering. The tether was modelled as a bar element and shown by the blue line connecting the screw heads.

Motion	Native spine	Spine with VBT with pre-tension				
		0 N	50 N	100 N	200 N	300 N
Extension	-3.13	-3.13	-2.57	-2.20	-1.75	-1.44
Flexion	3.09	3.09	3.35	3.15	2.47	1.86
Left lateral bending	-4.20	-4.20	-2.68	-1.48	-0.91	-0.72
Right lateral bending	4.12	1.61	1.60	1.54	1.36	1.15
Right axial rotation	-1.94	-1.93	-1.70	-1.50	-1.16	-0.91
Left axial rotation	1.93	1.93	1.89	1.70	1.31	0.99

Table 1 – Range of motion (in degrees) of the native and instrumented L1-L2 spine with vertebral body tethering considering different tether pre-tensions under a pure moment of 5 Nm. The results of the instrumented spine were calculated with respect to the post-surgery position. The results were partially adapted from our studies (Nicolini *et al.*, 2022, 2023).