EFFECT OF FACET ARTHROPLASTY ON THE BIOMECHANICS OF THE LUMBAR SPINE – A FINITE ELEMENT STUDY

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INTRODUCTION

Spinal stenosis is due to the encroachment of the spinal neural foramina by hypertrophic facets and displaced soft tissues, which compress the nerve roots, often resulting in functional impairment due to neurological symptoms in the legs. Surgical decompression with instrumented fusion, which restricts mobility of the spine at the operated level, is the current standard of care. The incidence of reoperation post-decompression due to adjacent level disease can be as high as 20% [Gillet, P., 2003].

The Total Facet Arthroplasty System® (TFAS®) (Archus Orthopedics Inc., Redmond, WA) is a novel device designed to treat spinal stenosis. TFAS® allows a comprehensive decompression by complete removal of the facets and lamina. TFAS® is intended to stabilize the spine and reinstate proper segmental biomechanics. We hypothesize that TFAS® will: (1) maintain the physiological range of motion at the operated level and (2) will not overload the disc at the operated or adjacent levels. TFAS® is currently undergoing clinical trials in the United States.

METHODS

A 3-dimensional, nonlinear finite element (FE) model of an intact (Intact) adult human lumbar spine (L1-Sacrum) was developed (Figure. 1A). The geometry was derived from the MRI scan of a single subject. The intact FE model was validated by comparing the range of motion (ROM) calculated after applying pure flexion/extension (+8.0/-6.0 Nm), unilateral bending (6.0 Nm) and unilateral rotation (5.0 Nm) moments to equivalent experimental results generated on a cadaveric spine simulator [Phillips, F.M. et al., 2006].

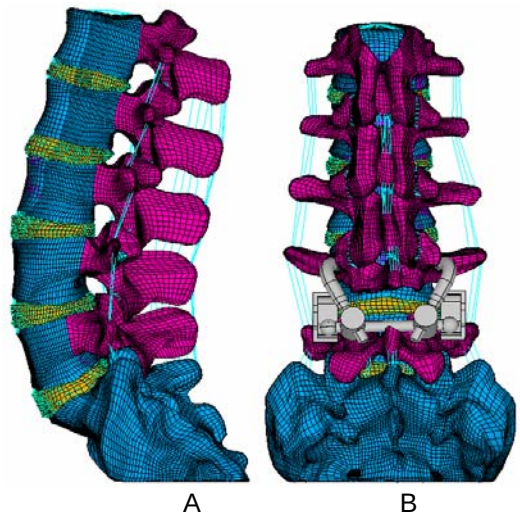

Figure 1: (A): Intact and (B): TFAS models

The intact model was modified to include the TFAS® at the L4-L5 level (TFAS) (Figure 1B). The TFAS® surgical technique was simulated by removing all of the supraspinous and interspinous ligaments, ligamentum flavum and facets across L4–L5 and the majority of the L4 spinous process and lamina. Interactions of the natural facets and TFAS® bearings were defined as nearly frictionless generalized contact between deformable bodies. Finally, the model was modified to simulate a posterior fusion (Fusion) with instrumentation at the L4-L5 level. The TFAS® and fusion hardware were rigidly anchored at the pedicles. All models were rigidly constrained at the sacrum and pure moments

were applied to L1. The analysis was performed using ANSYS v10.0 FE software.

Each loading mode was analyzed at its loading limits at the operated and immediately adjacent levels for: (1) peak ROM and (2) strain energy density (SED) in the disc. These measurements were used to evaluate how the different treatment modalities affected the segmental kinematics and load sharing of the intervertebral discs.

RESULTS AND DISCUSSION

The TFAS® replicated the intact ROM at the instrumented segment (L4L5) in all loading modes, while the Fusion model reduced ROM (Figure. 2).

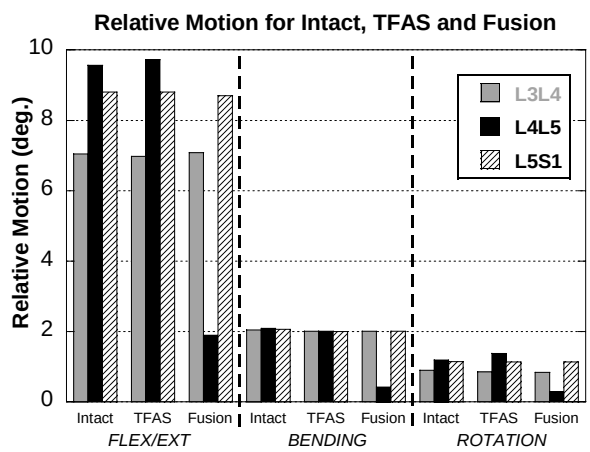

Figure 2: ROM for Intact, TFAS and Fusion at instrumented and adjacent levels.

For Fusion, the SED (Table 1) in the L4-L5 disc was reduced in all loading cases, indicating an unloading of the disc tissue.

The TFAS model generally replicated intact disc tissue SED's at the operated and adjacent levels. The strain energy in the disc at the adjacent levels (L3-L4, L5-S1) for fusion did not change compared to Intact, which is counter-intuitive and requires further investigation.

SUMMARY/CONCLUSIONS

The inclusion of TFAS® at the L4-L5 segment maintained the mobility of the spine at the operated level with no effect on the motion at the adjacent levels. Additionally, the loading of the intervertebral disc at the operated level was more akin to the intact condition with TFAS® than with fusion.

To better understand the effect of fusion on adjacent levels, a loading protocol where the moments applied to the Fusion model are varied until their overall angular motion is equal to that of the intact case (hybrid approach [Goel, V.K. et al., 2005]) may provide a more relevant comparison of pre-and-post fusion function of the spine.

REFERENCES

Gillet, P. (2003). *J Spinal Disord Tech*, vol. **16:4**, pp. 338–345.

Phillips, F.M., Voronov, L.I. et al. (2006). *The Spine Journal*, vol. **6:5** (Supplement), p. 137S.

Goel, V.K., Grauer, J.N. et al. (2005). *Spine*, vol. **30:24**, pp. 2755–2764.

Table 1: Comparison of SED (Joules·mm^{-3}) of the disc under load for Intact, TFAS and Fusion.

Disc Level	FLEX/EXT			BENDING			ROTATION		
	Intact	TFAS	Fusion	Intact	TFAS	Fusion	Intact	TFAS	Fusion
L3-L4	604	602	603	180	181	182	48	47	47
L4-L5	686	829	37	236	225	10	76	95	6
L5-S1	960	964	953	158	158	158	78	77	76