Investigation of the Effect of Spinal Defects on Spondylolysis & Stress Fracture of Vertebral Bodies

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INTRODUCTION

Spondylolysis (SL) of the lower lumbar spine is frequently associated with spina bifida occulta (SBO). A recent investigation revealed a 3.7 fold increase in the presence of SL in individuals with SBO. However, it is unclear if SBO is a predisposition for the development of SL. SL is recognized as being a fatigue fracture with an increased incidence among athletes participating in disciplines requiring repetitive forceful hyperextension, axial loading & rotation of the spine.

AIM

To model both a SBO defect & an intact spine under combined axial load & rotation, assessing the stresses observed on the vertebral bodies, and their distribution on the ipsilateral & contralateral inferior isthmus lines, where fatigue fracture is likely more likely to occur.

METHOD

A 3D model of a validated intact L4-S1 human lumbar motion segment including ligaments was utilised[1-2]. The intact model was adapted to mimic the SBO condition, by removing a section of the L5 vertebral arch & spinous process (Figure 1)[3]. The sacral slope of both intact & SBO models were orientated to 66°, mimicking the degree of sacral slope in athletes with a high pelvic incidence. Two load conditions were studied (Figure 2), an axial load of 1kN applied to the superior vertebral endplate of the L5 spine segment, & the same axial load combined with a 3° axial rotation. Stresses on both ipsilateral & contralateral inferior lines of the L5 vertebra were assessed & compared (Figure 3 & 4). Mean & alternating stress values were obtained & used in a Goodman diagram with the Söderberg relationship to find the stress amplitude & mean stress to an equivalent alternating shear stress. These values were then used to predict the number of cycles to failure ($N_f$), using the following relationship from Literature [4]:

$$S = S_o + S_1 \log(N_f)$$

Where:

- $S$ = Fatigue strength
- $S_o = 36.6$ MPa (Shear strength in a single fatigue cycle failure)
- $S_1 = -2.9$ MPa

RESULTS

Under static load conditions, the SBO ipsilateral pedicle experiences higher stresses in the mid-region of the isthmus line (ventral to dorsal) compared to the intact model (Figure 3), with a maximum observed at a position 37% of the length from the ventral side.

The maximum stress amplitude for the SBO & intact models were 22.5 & 13.6 MPa, respectively (Figure 4). A stress amplitude above 16.3 MPa will result in a fracture in under 10 million cycles. In the intact case, the maximum shear stress amplitude remained below 14 MPa & is unlikely to failure. However, the SBO model will result in a fatigue fracture after 70,000 cycles, & will most likely be located along the red section as indicated in Figure 5.

DISCUSSION

SBO predisposes SL, by generating increased stresses across the inferior isthmus of the inferior articular process, especially under combined axial load & rotation. Axial loading alone was not sufficient to generate stresses that would cause fracture or failure.

CONCLUSION

The study suggests that SBO increases load across the pars & predispose the vertebral body to early fatigue fracture, especially in athletes involved in activities requiring forceful rotational loading. This leads to the hypothesis that mechanical factors play a dominant role in the increased incidence of SL in patients with SBO than genetic predispositions.