Finite Element Analysis of the Lumbosacral Spine: an Evaluation of Stress Concentrations at Entheses

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BACKGROUND Entheses, or attachments of tendons, joint capsules, ligaments or fascia to bones, are sites of stress concentration. Bone spur formation can occur at entheses (enthesophytes) as an adaptive tissue reaction to mechanical stress [1]. In ankylosing spondylitis (AS), lesions are characteristically localized at entheses. Such patients clinically present with subjective and objective tight and stiff lower back muscles [2]. A constitutional axial (spinal) passive myofascial hypertonicity is hypothesized to be a primary predisposing factor in AS and a contributor to enhanced development of entheseal lesions [2].

Finite element analysis (FEA) of the spine and its components has been performed extensively [3]. This method is helpful in understanding load transfer and geometrically-driven stress concentration. FEA of enthesis sites promises to be an integrative approach for better understanding of AS through a detailed investigation of the structural mechanics. The specific objective of this study is to determine stress distributions and quantify stress concentrations at enthesis sites in a resting, supine state at the L4 and L5 vertebrae.

METHODS A novel finite element model of the lumbosacral spine was developed using Abaqus® 6.9-1 (Simulia, Providence, RI). Specifically, the L4, L5, and S1 vertebrae, intervertebral discs, endplates, and ligaments were modeled as solid elements based on geometry from another study [4]. Material properties of spinal components were assumed to be linear and elastic with values derived from literature [5]. Boundary and loading conditions were applied on the model to accurately simulate anatomical load transfer in a resting, supine state.

RESULTS The distribution of stress within spinal structural components has been generated and provides a visual representation of stress dispersal and concentration in the model. The stress concentration at enthesis sites on the lumbosacral spine was also quantified. The interface regions between the bone and the intervertebral discs indicate areas of high stress concentration. This may be due to the mismatch of material properties at these transition regions.

CONCLUSIONS A novel finite element model has been developed to determine stress concentration and distribution at enthesis sites. The current model will be expanded to evaluate effects of varying human resting muscle tone on stress concentration at entheses. Evaluation of ranges of stress concentrations at enthesis sites may provide novel insight into critical limits that could exceed tissue tolerances. Chronic overloading could lead to micro-injury, early inflammatory reactions as well as later bony proliferation and syndesmophyte formation.

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