INTRODUCTION

Ossification of the posterior longitudinal ligament (OPLL) is a common cause of cervical myelopathy due to compression of the spinal cord. Patients with multiple levels of OPLL usually require the posterior decompression surgery. Clinical studies have reported that the decompression extent play an important role in the clinical outcomes [1, 2]. Thus, there is a need to better understand the optimal surgical extent with which sufficient decompression without excessive posterior shifting can be achieved. However, few quantitative studies have clarified this optimal extent for decompression of cervical OPLL. In this study, we used finite element (FE) modeling of the cervical spine and spinal cord to investigate changes in stress, strain, and posterior shift of the spinal cord for posterior decompression extent that occur with three different surgical methods.

METHODS

The FE model of the human C2-C7 cervical spine was reconstructed from the CT images. The FE model of spinal cord consisted white matter, gray matter, dura mater with nerve roots, denticulate ligaments (DLs), and a cerebrospinal fluid (CSF) layer (Fig 1). Material properties of white and gray matter obtained from Ichihara’s study [3] then fitted to hyperelastic model. A single tangent modulus for dura mater derived from the Persson’s study [4]. The DLs were modeled as 22 triangular extensions, using link element at each spinal level that attached laterally from the cord to the dura mater, and material property was obtained from a previous study [5]. The CSF layer was demonstrated Newtonian fluid characterized by viscosity of CSF derived from previous literature [6]. Three type of posterior decompression models for laminectomy, laminoplasty and hemilaminectomy were developed based on conventional surgical protocols with different extent of decompression (Fig 2a). The extent of decompression ranged from one- to five- levels: C5, C4-C5, C4-C6, C4-C7, C3-C6, and C3-C7 for each types of model, where the continuous OPLL placed through the C4 to C6 vertebral bodies (Fig 2b). The OPLL was modeled as simple rigid body model, and an OPLL occupying ratio of 20% to 60% was imposed to the spinal cord based on plain radiographic findings. Under various OPLL occupying ratios, the von-Mises stress and maximum principal strain in the spinal cord as well as the posterior spinal cord shift were analyzed for pre-operative and various posterior decompression models using FE analysis (ABAQUS™, ABAQUS Inc., Providence, RI, USA).

Figure 1: FE model of the cervical spine and spinal cord. (a) axial view and (b) sagittal view.
RESULTS AND DISCUSSION

The von-Mises stress and maximum principal strain in the cord decreased as the extent of posterior decompression increased, regardless of the occupying ratio and the type (Table 1). The maximum stress in the cord was decreased by 30% to 90% from 1- to 5-levels of decompression by laminectomy and laminoplasty. The C3-C6 and C3-C7 in the laminectomy and laminoplasty at the 60% occupying ratio of OPLL had a maximum posterior shift of greater than 3 mm, which was associated with positive clinical outcomes after laminoplasty [2] and which showed substantial reductions in stress and strain. In contrast, the stress and strain reductions of hemilaminectomy differed from the values of laminectomy and laminoplasty due to maximum values at the lateral column arising from lateral decompression of the spinal cord. Our results showed that hemilaminectomy is inferior to laminectomy and laminoplasty in terms of cord decompression.

In conclusion, stress and strain in the spinal cord decreased and posterior shifting of the cord increased as posterior decompression extended. The location of the decompression extent also influenced shifting, depending on the patient’s anatomy. Laminectomy and laminoplasty were very similar in terms of decompression results, and both were superior to hemilaminectomy in all parameters tested. Decompression to the extents of C3-C6 and C3-C7 of laminectomy and laminoplasty could be considered sufficient with decompression itself. Our findings provide fundamental information regarding the treatment of cervical OPLL and can be applied to patient-specific surgical planning in the future.

REFERENCES


Table 1: von-Mises stress, maximum principal strain, and posterior shift in the cord at the 60% occupying ratio of OPLL in the pre-operative model and posterior decompression models.

<table>
<thead>
<tr>
<th></th>
<th>Pre-op.</th>
<th>Laminectomy</th>
<th>Laminoplasty</th>
<th>Hemilaminectomy</th>
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<tr>
<td></td>
<td>C5</td>
<td>C4-C5</td>
<td>C4-C6</td>
<td>C4-C7</td>
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<td>Stress (kPa)</td>
<td>210</td>
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<td>Strain</td>
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<td>Shift (mm)</td>
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