Loss of Cervical Deep Muscle Function Is Associated with An Increase in Cervical Kyphosis after Laminoplasty Surgery: In-Vitro Experimental Spine Model with Muscle Function Simulation

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Introduction: Cervical laminoplasty is a commonly employed decompression surgical procedure for spinal cord compression due to dysfunction such as ossification of posterior longitudinal ligament (OPLL). Laminoplasty involves the opening of lamina at nerve compression side and creating a hinge articulation at the contralateral side in order to release the pressure on the spinal cord. With this procedure, it is inevitable that the deep muscles (multifidus spinae and semispinalis cervicis) attaching to lamina are dissected during surgery. Long term follow-up reveals that complications such as significant deep muscle atrophy and increased kyphotic cervical alignment change are frequently observed. Considering the biomechanical functions of the deep muscles, i.e. maintaining cervical lordosis and stability, deep muscle injuries was considered to be responsible for post-operative kyphotic change, neck stiffness and axial spinal pain. Despite the proposed link between laminoplasty and a change of cervical biomechanical properties, limited evidence is currently available regarding this association. Current study proposes to address this gap in evidence by developing a biomechanical model to evaluate the association between deep muscle function and the maintenance of cervical spine curvature and stability after laminoplasty in OPLL patients.

Methods: Specimens. Ten multilevel cervical spines (C2-C7) were dissected from 6-month old pigs. All soft tissues were carefully removed, except the surrounding ligaments and facet capsule. The specimens were embedded in epoxy at both ends for further examination.

Protocols. In order to quantify the effect of muscle function on neck stability, the in-vitro experimental spine model with muscle function simulation was constructed (Figure 1). For the intact group, cables and weights were used to simulate muscle tension of four pairs of main superficial neck muscles including: sternocleidomastoid (7N), scalene medium (3N), trapezius (5N), splenius capitis (4N), semispinalis capitis (1N), and two deep muscles including multifidus spinae and semispinalis cervicis with a combine force of 10 N. After the construct of each spinal model, the C2-C7 neutral curvature was measured to determine the alignment angle and the cervical stability was indicated by the obtained neutral zone under 4 Nm pure moment loading. After completing the testing of the intact specimens, a rubber cylinder was inserted along the posterior cortex of vertebra from C2-7 in order to simulate the effect of OPLL. The alignment angle and neutral zone were then again determined and recorded. After the completion of the intact and OPLL simulations, 4-level (C3-C6) laminoplasty replicating those performed in humans were then carried out on all specimens. In order to simulate the progressive muscle atrophy, muscle tension was sequentially adjusted to 70%, 50% and 30% of the original weights for the two deep muscles and the cervical curvature and neutral zone were determined for each simulation accordingly. For the statistical analysis, paired t-test was used to determine the significant
difference between the intact and OPLL states and the different simulated levels. All tests were considered significant at $p<0.05$.

**Results:** (1) OPLL simulation. For the intact model, the cervical lordotic angle and neutral zone were 17.2(2.4) degrees and 7.8(1.7) degrees respectively. In comparison with the intact model, cervical lordotic angle and neutral zone decreased significantly to 9.3(2.4) degrees and 6.9(0.8) degrees in the OPLL state. These results were in good agreement with the clinical data in OPLL hence validated this OPLL model for further analysis. (2) Simulation of deep muscle dysfunction after laminoplasty. The cervical lordosis decreased with deep muscle function, indicating the cervical alignment is more kyphotic with deep muscle dysfunction. The lordotic angle were 12.9(1.4)/9.6(1.0)/5.6(1.1) degrees at 70/50/30% of deep muscle function respectively. When the deep muscle is at 30% of original function, the lordotic angle was significantly smaller when compared to both the intact ($p<0.001$) and the OPLL group ($p<0.001$). In contrast, the lordotic angle of 70% of deep muscle function is higher than the one of OPLL group ($p=0.002$), but less than the one of intact group ($p<0.001$). For the neutral zone results, no significant difference was found between the different muscle function levels and the intact group, however, a significant increase was found from the OPLL group to the 30% muscle function group ($p=0.03$).

**Discussion:** In this study, an in-vitro experimental spine with muscle function simulation and pathological OPLL model was constructed and shown to be replicable of real life situations. The findings of a decrease in cervical lordosis with a decrease of muscle function is in good agreement with the frequently observed increase in cervical kyphosis after laminoplasty surgery clinically. It is well established and accepted that the deep cervical muscles play an essential role in maintaining the neutral position of the head and neck and the findings of the current results demonstrated that after laminoplasty, at least 70% of the deep muscle function is required in order to gain an increase in cervical lordosis when compared to pre-operative OPLL state. However, given all of the muscle function levels failed to reach the same lordotic level compared to the intact group after laminoplasty, it is clear that a loss of lordosis is an inevitable consequence following laminoplasty. This finding highlights the importance of addressing the deep muscle dysfunction post-operatively with specific and targeted muscle retraining. This is of particular significance given the recent emerging evidence pointing to the importance of maintaining cervical lordosis as a clinical outcome. In contrast to the significantly altered cervical lordosis, laminoplasty appears to have limited impact on the cervical spine neutral zone with no significant difference identified between the intact and the post-operative models. This is somewhat contradicting to the common findings in the literature, however, it is acknowledged that current study used porcine spine which has been shown to have better stability characteristics than human spines and subsequently perhaps providing a more accommodating neutral zone range. It will be of interest to replicate the protocol employed here on human cadaveric spine to investigate this contrasting findings further.

**Significance:** The constructed porcine model was able to simulate the biomechanical characteristics of an intact and OPLL spinal column and the identified decrease of cervical lordotic angle after laminoplasty highlights the importance of early and specific deep muscle retraining post-operatively.
Figure 1. The schematic diagram of specimen setup. The cables and weights are used to simulate the muscle direction and force.
Figure 2. The cervical alignment change under different simulated conditions. The bars below the dotted line indicating a kyphotic change.
Figure 3. The neutral zone. Higher bar means more instability.