An In-Vitro Spine Model with Muscle Replication Demonstrated The Importance of Semispinalis Cervicis And Multifidus Muscles in Maintaining Cervical Curvature and Stability

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Disclosures:

Introduction: Neck muscles are essential in not only facilitating the normal movement of the cervical spine but more importantly, it is critical in maintaining the cervical curvature and stability. Based on their anatomical orientation, neck muscles can be classified into either as the superficial or deep muscles and it is generally accepted that the superficial muscles control and produce most of the head motion where the deep muscles control and maintain the cervical curvature. It has been well established that invasive cervical surgical procedures such as laminoplasty can have detrimental effect on the deep muscles with the most common consequence being the marked muscle atrophy soon following surgery. Despite the well accepted link between muscle atrophy and laminoplasty, the exact effect of surgery and the resultant muscle atrophy on the cervical biomechanics isn’t well established. In this study, we aim to construct an in-vitro cervical spine model with six pairs of simulated cervical muscles to investigate the biomechanical impact of decreased muscle function on the curvature and stability of the cervical spine. Given the known importance of the deep muscles on optimal cervical function, particular attention will be given to the semispinalis cervicis and multifidus muscles.

Methods: Ten C2-7 cervical spines were dissected from 6-month-old porcine with the ligaments and facet capsules preserved but all the other soft tissues were carefully removed. Plaster was used as the upper and bottom fixtures with the C4-5 disc positioned parallel to the ground. Six pairs of cervical muscles were constructed to replicate the biomechanical properties of an intact cervical spine. The muscles of interest included sternocleidomastoid (SCM) (7N), scalene (3N), trapezius (5N), splenius capitis (SPL) (4N), semispinalis capitis (SSC) (1N) and semispinalis cervicis + multifidus (two pairs of posterior deep muscles combined for 10N) (Fig 1). The center of lower fixture was set as the point of origin. Pulley systems were installed replicating muscle forces in reference to the point of origin in a static state. The choice of pulley coordinate and relevant forces were based on commonly accepted published data. The complete intact specimen model with all six muscles attached was firstly used to obtain the angle between upper and bottom fixture in order to determine the neutral cervical alignment curvature. A 4 Nm pure moment was then applied and the neutral zone (NZ) was determined as the displacement angle of the spine model at the point when 0.5 Nm of resisting moment was obtained. In order to investigate the effects of marked muscle atrophy, each pair of cables were removed one at a time to simulate marked muscle dysfunction with NZ recorded for each condition. The same processes were repeated for all 10 porcine models. A paired t-test was utilized to identify any significance on the removal of muscles on the cervical alignment and NZ.

Results: Flexor dysfunction: For the change of alignment, the lordotic angle increased by 14% and 11% for the SCM and Scalene respectively when removed. In contrast, the NZ decreased by 33% and 24% for SCM and Scalene respectively when compared to the intact model. A significant difference was found for the SCM removal on the alignment change (p=0.01) and both the SCM and Scalene removal were found to be significant for NZ (p<0.007). A summary of the results is presented in Figure 2. Extensor dysfunction: For the change of alignment, the lordotic angle decreased for the Trapezius by 21%, SPL by 8% and posterior deep muscles by 28%. However, when the SSC was removed, the lordotic angle increased slightly (<1%). In contrast, NZ was found to increase for all the extensor muscles when removed: Trapezius by 80%; SPL by 32%; SSC by 5% and posterior deep muscles by 101%. For both the alignment change and NZ displacement, the Trapezius (p<0.016) and posterior deep muscles (p<0.001) were found to be significantly different to the intact model. Significance was found for the SPL for the NZ (p=0.01) but not alignment change (p=0.114).

Discussion: The results from the current study demonstrated a trend that the cervical spine became more lordotic when the flexor muscles were removed and inversely, the model became kyphotic with the removal of the extensor muscles. Such alternation pattern in the curvature is similar to what is commonly observed clinically and can be explained from a biomechanical point of view as a direct consequence of the change of exertion and moment force. This finding also
demonstrated the importance of intrigue balance of flexor and extensor forces required in maintaining an optimal neutral spinal alignment. Furthermore, our result is consistent with those published by Cheng et al., (2011) who used a similar method to simulate the SCM, SPL and SSC muscles in-vitro. It is therefore plausible to suggest that the simulated model presented here is a reasonable replication of real-life models and can be utilized for future research. It is now well accepted that NZ is an important indication of spinal stability. Current study demonstrated that the removal of Trapezius and Posterior deep muscles will have the greatest influence on the change of NZ. It is reasonable to expect the high influence of the Trapezius muscle on cervical stability since it possess the longest lever arm with the greatest force component. However, despite the relatively short lever arm and small force exertion, the posterior deep muscles were found to have the greatest influence on the cervical stability. We speculate that the biomechanical advantages of the deep muscles due to its local multi-segmental insertion have contributed to this strong influence on maintaining stability. An interesting observation identified with the results was the decrease in NZ after the removal of SCM and Scalene muscles. It is possible that the removal of the flexor muscles which lead to a more lordotic spine will inevitably lead to a more stable (stiffer) spine. Similarly, such finding may be reflective of the greater influence of extensor muscles on the NZ than flexor muscles due to its greater available exertion of forces on the spine. It is acknowledged that given the in-vitro nature of the design, current study results will need further validation for its clinical applicability and a study utilizing the same protocol on human cadaveric spines is currently underway.

Significance: The in-vitro experimental model with muscle replication is shown to be an appropriate model for future research and the identified important role of the Semispinalis cervicis and Multifidus muscles on the overall cervical curvature and stability reinforces the importance of specific and targeted rehabilitation for cervical disorders.

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Fig 1. Schematic representation of C2-7 cervical spine model with 6 muscles attached for replication.
Fig 2. Cervical alignment angle after the removal of the individual muscles compared with the intact model.
Fig. 3: Associated neutral zone after removal of the individual muscles compared with the intact model.

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