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Boundary Conditions Affecting Finite Element Analyses of a Spinal Segment

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In this issue of the *International Journal of Spine Surgery*, Ciriello et al[1] report their study on a biomechanical finite element analysis (FEA) of various conditions, including the use of the stand-alone Cervical Interfacet Fusion Systems (CIFS), in conjunction with an anterior disc cage (ADC) for treating degenerative cervical spine pathologies leading to instability. The study utilizes a C2-C7 finite element model to simulate 3 surgical scenarios: ADC alone, CIFS alone (specifically using the Sharkage system, SKC), and CIFS combined with ADC. The interventions were performed at C4-C5, C5-C6, and C4-C6 treated levels under flexion, extension, axial rotation, and lateral bending. The FEA model indicates that stand-alone CIFS may offer a viable surgical option for selected patients with degenerative cervical spine disease, providing sufficient stabilization.

The primary analysis was based on a computational model of the implanted functional spinal unit (FSU) by way of an FEA. FEA has been successfully used in the design process of modern-day medical implants. Pioneers in the field, including the late Professor Vijay Goel,[2,3] have devoted many years to the validation of FSUs and even consecutive motion segments, such as L3-L5. In each model, painstaking empirical studies were used to validate the input parameters for the model. Often, the spinal segments were tested on cadaveric biomechanical specimens under a pure moment test protocol.

The pure moment test protocol was first adapted and described in the Conceptual Framework[4] article by Manohar Punjabi and is now considered the de facto test standard. It has been adapted in numerous laboratories worldwide. The fundamental principle behind pure moment bending protocols is that they serve as a repeatable, standardized form of spinal FSU testing, provided every effort to mitigate the effects of shear is employed during pure moment testing. Computationally, this is straightforward in terms of applied load or torque to a computer-generated FEA. Therefore, from the FEA, results at the index level bring a certain level of fidelity that has been accepted from empirically validated FEA of spinal models. Certainly, boundary conditions, including interfacessuch as facet interfaces and osteoligamentous structures, are areas worthy of debate. However, the utilization of FEA results beyond comparative indications should be taken into careful consideration.

Pure moment testing, as stated, minimizes shear and, more importantly, applies a known moment to each of the FSUs in the spinal segment. This is true for the adjacent level at the time of intact testing or baseline. As is often the case in biomechanical testing, the same specimen is then subjected to additional treatments, which may include a destabilization treatment such as a laminectomy or laminotomy created iatrogenically, followed by stabilizing treatments from the least instrumentally invasive to the most invasive. All such treatments are performed at the index level. Therefore, when it comes to "adjacent level effects," it would be extraordinary to detect biomechanical changes at index levels unless the boundary conditions have changed, for example, iatrogenic disruption of the facet joint complex. Pure moment testing dictates this repeatability and reliability.

Moreover, the clinical setting is another confounding situation requiring many data points, including what biomechanical information offers. To make best use of the results from a computational model relying on empirically derived biomechanical data, specific thresholds should be established. Often, biomechanical data are "normalized" to the intact condition. This is an effort to reduce the biological variability associated with empirical testing. Thus, when claims are made on a physiological basis, specific thresholds for such parameters should be clearly stated. A clinical example would be biomechanical stability to return to work. Modern data instrumentation for anterior cervical

discectomy and fusion with instrumentation provides a significant stabilization through plating that does not rely on arthrodesis per se. Modern instrumentation has been proven biomechanically stiff to offer immediate stabilization and fixation. Motion-preserving devices, particularly to detect adjacent level changes, require the same burden of proof.

When computational models suggest changes at the adjacent levels, it defies the laws of physics unless the boundary conditions have been violated. Models that are reported should be coupled with more exact descriptions of the test methodology (and a clear understanding of those ramifications) before extrapolating to a clinical condition.

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