Mechanical Analogue Facet Joint Design in a Synthetic Lumbar Spine

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Statement of Purpose

Intervertebral fusion, facetectomies, and interbody implants are common procedures used to treat back ailments[1]. The effects of these procedures on the mechanical behavior of the adjacent facet joints are still not fully understood and require further investigation. Cadaveric spine specimens have a variety of limitations when used for mechanical testing. A mechanical analogue synthetic spine is an attractive supplement to cadaveric tissues for testing effects of devices and surgical procedures. In development of the mechanical analogue spine model, each substructure (IVD, ligaments, and facet joint) must be designed, tested, and validated before assembly. Analogue facet joints are critical features of the model that present particular difficulties in manufacturing. The objective of the present study was to design and validate synthetic facet joints with a straightforward manufacturability and repeatable mechanical properties that are within the range of human cadaveric facet joint tissues.

Methods

Six fresh frozen human cadaveric L3-L4 functional spine units (4 males, 2 females, ages 50 to 80, without spinal disease) were potted in neutral position and mounted in an MTS Spine Simulator. The intervertebral disc, ligaments, and the left facet were dissected while the FSU was maintained in place in the spine jigs. Prior to dissection the FSU was subjected to a 10 N compressive force and the displacement was zeroed. The specimens were tested under displacement control in flexion-extension (FE) up to ±2°/±4°. They were subjected to five tests of five FE cycles each, at a rate of 0.46 deg/min. Slopes of the neutral (NZ) and elastic (EZ) zones were determined from tangent lines drawn on the loading portions of the sigmoidal curves.

Synthetic analogue left facet joints were isolated in correct anatomic alignment and tested in flexion and extension. To create functional analogue facet joints, a layer of paraffin was applied to each synthetic facet bone surface to simulate the low friction contact motion provided by the cartilage and synovial fluid. Polyurethanes of different Shore hardness with and without polyester reinforcing meshes were employed. Third-generation composite SawBones® L3-L4 analogue vertebrae (Pacific Research Laboratories, Seattle,WA) were used for all synthetic facet joints. The isolated synthetic facet joints with varying capsules were tested in a manner identical to the isolated cadaveric facet joints. Rigidity data were compared.

Results/Discussion

Tests of cadaveric FSUs versus isolated facet joints indicated that the contribution from the facet capsule on average accounts for only 5% of the total stiffness of the FSU. Tests also showed that use of reinforcement in the polyurethane matrix was difficult to control in the complicated anatomic structure of the facet.

The most consistent and easily reproducible synthetic capsule/joint combination was the paraffin wax joint surface coating with an A15 polyurethane capsule. Those synthetic specimens yielded stiffness values in the range of those obtained from the human specimens (Figure 1). Only flexion and neutral zone extension were compared as the EZ rigidity of the extension was governed by contact of the articular surfaces, not the facet capsule material properties.

The curves from the human specimens clearly illustrated the discrepancies of mechanical behavior between individuals and the impossibility to consider an average behavior. Despite constant hydration their mechanical properties degraded over time so the NZ and EZ stiffness were considered on the low side of the human range.

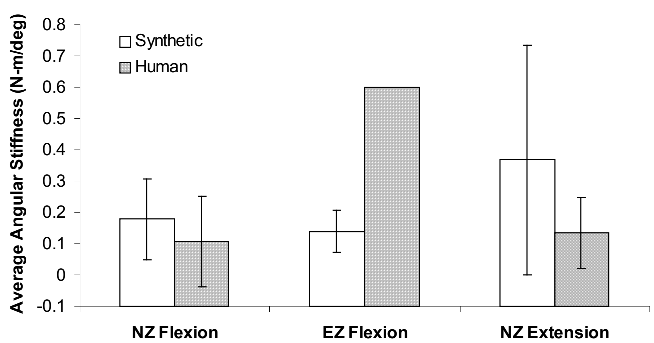

Figure 1. Human vs. Synthetic NZ and EZ stiffness

Conclusions

Despite the limitations, the goal to find a synthetic capsule, inexpensive and easy to implement from a manufacturing standpoint, was fulfilled. Paraffin can be applied to simulate an inverse function cartilage, while A15 polyurethane formed the capsular ligament. The stiffness of this capsule is adjustable by modifying its thickness at strategic locations.

References

1-White, Panjabi, Clinical Biomechanics of the Spine, 1990