Finite element analysis of the lumbar intervertebral disc – a material sensitivity study

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Background

Assessment and diagnosis of back pain require detailed imaging of the patient's spine in a variety of realistic postures, but with current technology this is not possible, and is unlikely to be realisable in the near or medium future. The aim of this research is to demonstrate how finite element models of the spine could be used to assist in this problem.

It is proposed that standard images obtained in an unloaded, recumbent state could be used to generate a representative computer model of a patient's spine. The model would be loaded and analysed and the results then used to modify the original images of the spine and surrounding soft tissues to reveal the patient's condition under that loading scheme.

The intervertebral disc will be the most critical component of such a computer model, and the work presented here explores the sensitivity of the disc's characteristics to the material properties used and the basic modelling assumptions.

The finite element model

A sample finite element model was generated directly from CT data. For example, figure 1 shows the L1-L2-L3 motion segments, and figure 2 shows the details of the L2-L3 disc. The structure of the disc was similar to that used by Shirazi-Adl et al. (1984) and consisted of an annulus ground substance with embedded annulus fibres (modelled by tension only cable elements), and the nucleus pulposus (modelled as an incompressible solid). The annulus was structured so that the angle of most of the fibres was about 30°.

Figure 1  Finite element model of the L1-L2-L3 motion segments (undergoing flexion).

Figure 2  Finite element model of the disc.

Confirmation that the material properties were reasonable and that the model was producing representative output was achieved by comparing the characteristics of the basic model with values previously reported in the literature. For example, figure 3 shows the disc's performance in compression and flexion.

The effect of material and geometry non-linearities

The posterior annulus may experience strains of up to 50% in full flexion. Such a large strain requires a non-linear geometry analysis in the finite element solution. In addition the material properties of the disc's collagenous fibres are non-linear, so that their stiffness values change with increasing strain. The effects
of these two non-linearities have not been quantified before, and many previous analyses have ignored one or both of them.

**Figure 3** A comparison of the disc in compression and flexion with previously published experimental data.

The results showed that the non-linear geometry assumption had a significant effect on the compression characteristics, whereas the non-linear material option did not (figure 4). In contrast, the material non-linearity was more important for the flexural and torsional loading schemes.

**Figure 4** An examination of the effects of non-linear geometry (G) and material (M) properties on the basic stiffness characteristics of the intervertebral disc.

**Sensitivity to material properties**

The effect of varying the equivalent Young's modulus of the fibres was examined for all loading modes. Figure 5 shows the results for compression and flexion (with linear fibre properties in this study). It was found that increasing the fibre modulus increased the stiffness of the disc in all loading modes, but the effect was particularly marked in flexion and torsion. The Young's modulus of the annulus also had a significant influence on all three modes of loading, although it affected the compressive stiffness the most (not shown).

When the effect on disc bulge was examined, it was observed that the posterior bulge was not sensitive to the fibre modulus for a specified axial displacement, but the anterior bulge was affected, as shown in figure 6.

**Conclusions**

For accurate patient-specific spine models, both non-linear geometry and non-linear material properties must be considered.

This study has identified and quantified those disc characteristics and loading conditions which are
most affected by the material properties assumed in the model. The sensitivity of the results to the properties used must be incorporated into the patient-specific spine models to ensure valid and reliable predictions.

Figure 5 An examination of the effect of fibre stiffness on the compression and flexion characteristics of the disc.

Figure 6 An examination of the effect of fibre stiffness on the bulge of the disc under compression.

References

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