Patient specific spine models
– development of a laboratory intervertebral disc for validation of the models

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Introduction

In 1993 there were an estimated 2 million people in the U.K suffering from chronic low back pain at a cost to the economy of approximately £6 billion. Accurate diagnosis and assessment of such back pain can be extremely difficult using current methods. Diagnostic techniques available to the clinician are limited to manual examination and imaging in an unloaded, recumbent state. It is proposed that these standard images could be used to generate an accurate, patient specific computer model of the spine. The model could then be loaded to represent a variety of realistic postures allowing detailed analysis of the condition of the patient's spine.

This research project is aimed at evaluating the feasibility of the modelling technique through the development of an artificial validation spine. The validation spine will be tested under controlled laboratory conditions and the results used to verify those found from analysis of the computer model.

The intervertebral disc is the most critical component in the spine. Thus, the initial aim of this research was to develop a representative artificial disc. Concurrent development of a finite element model of the disc permits development theories to be analysed and laboratory results to be verified.

Methods

The interchangeable artificial validation disc (Figure 1) has undergone several stages of development, both in terms of geometry and material. At present the outline of the disc is generated from a CT image taken from the lower surface of an L2 vertebra.

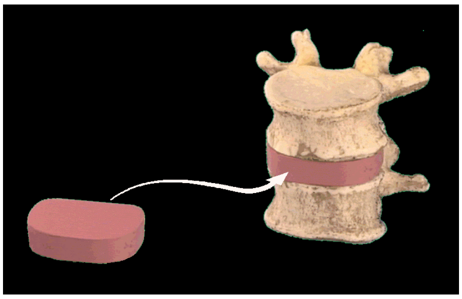

Figure 1: Schematic diagram of a section of validation spine.

Figure 2: A sealed validation disc.

The disc is formed in two parts from a silicon rubber (Silcoset 101). The annulus and base of the disc are produced as one, while the lid is created separately. Consequently, the disc can be filled with an appropriate medium to represent the gelatinous nucleus pulposus, in present studies lubricating grease is used. Alternatively the cavity can be left empty to mimic a denucleated disc. Figure 2 shows a sealed disc.

Non-linear finite element models of both the intact and denucleated validation discs have been generated in the software package ANSYS. These models can be realistically loaded to gain verification or prediction of results from laboratory studies. Figure 3 shows an isometric view of one of the finite element models.

Investigations into the stiffness characteristics of validation discs have been undertaken in the laboratory using a Hounsfield universal testing machine with a modified extensometer. Discs representing intact and denucleated were deflected to a known degree and the resultant reaction force recorded. Finite element studies looking at the behaviour of the disc have also been carried out along with finite element studies into bulge profiles.

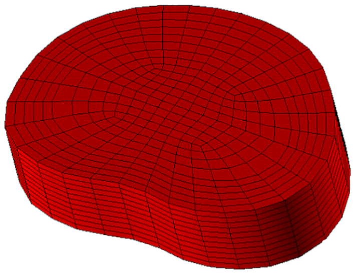

Figure 3: Isometric view of the finite element model of the validation disc.

Results and Discussion

The following graphs illustrate reaction force against deflection results from the laboratory tests and non-linear finite element analyses for compression of the discs. Natural disc data found in literature is also incorporated into both graphs for comparative purposes. It can be seen from figure 4 that the experimental and finite element results for the denucleated disc compare well with each other and the target values for the natural disc. However figure 5 illustrates that while the finite element model of the intact disc shows the correct behaviour, its stiffness is approximately half that required, indicating that the 'stiffening' effect of the nucleus in this disc version is inadequate.

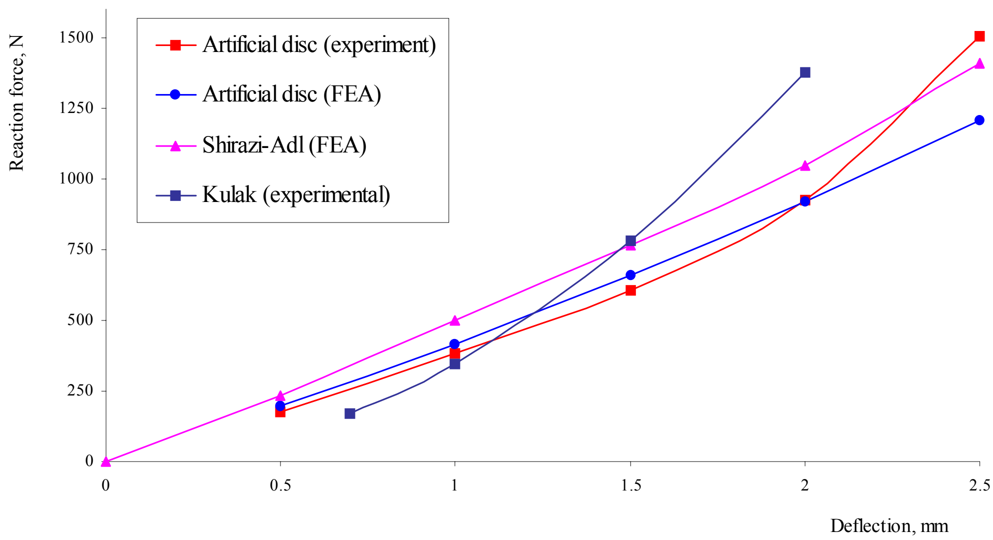

Figure 4: Compression results for the denucleated disc.

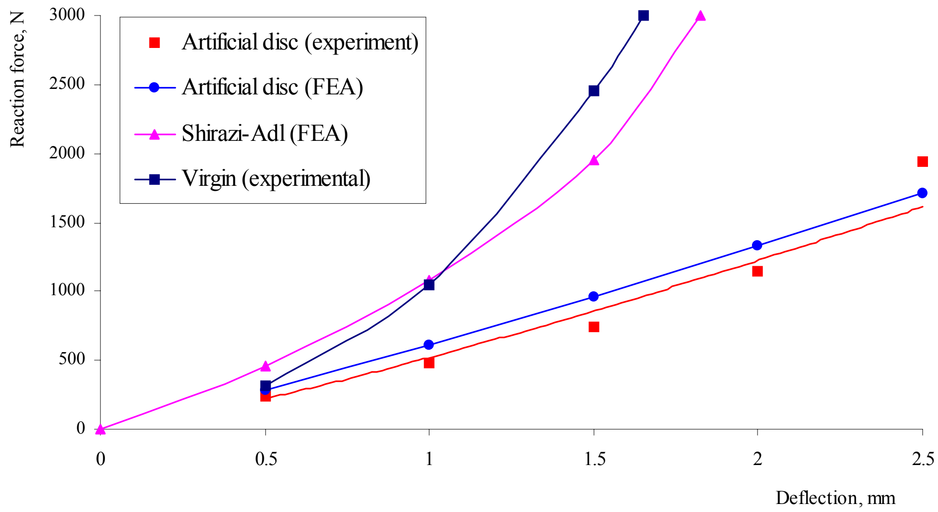

Figure 5: Compression results for the intact disc.

Figure 6 shows data from finite element analyses predicting the behaviour of the validation disc in both flexion and extension. Sample results are included for studies into both isolated natural discs and spinal motion segments (SMS). The graph indicates that in flexion there is excellent agreement between the finite element and literature results. However, the finite element data for extension is on the lower limits of the literature range, though this can be explained to some degree by the articular processes of a vertebra which contribute significantly to the overall rigidity in extension of an SMS. So if the literature results for only the isolated discs are considered the finite element results agree more closely, especially up to angles of around 2.5^{o}.

To conclude, an artificial intervertebral disc is under development for use in an accurate laboratory model of a human spine; it will be used to validate a parameterised finite element model of the spine. The artificial disc itself is being developed and verified with the aid of finite element methods. Initial results are encouraging although the intact disc requires further modification to meet the requisite characteristics. The patient specific spine models should make a significant contribution to the diagnosis of back pain and potentially be of enormous financial benefit. In addition, the laboratory spine will have a potential market in the development and evaluation of spinal instruments, as well as significant demand for education and training.

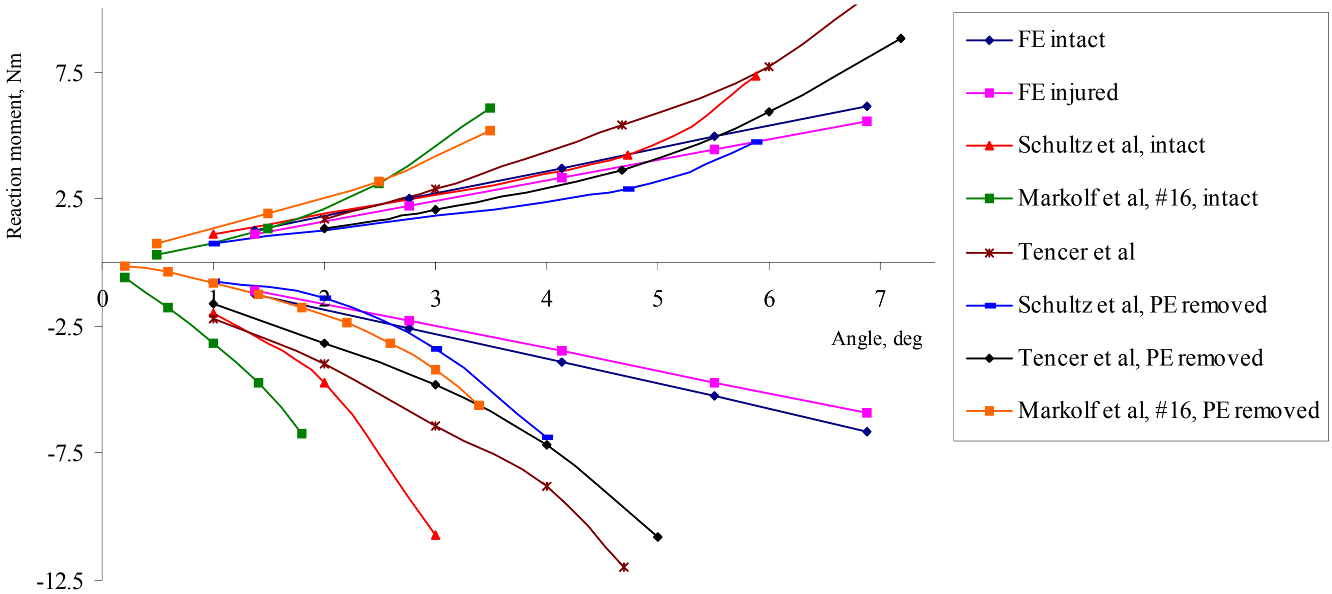

Figure 6: Flexion and extension data from finite element investigations compared to different experimental data. (#16 = sample no 16, PE removed = tested with posterior elements removed).

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