# 3D PRINTING, THE FUTURE OF COST EFFECTIVE BIOMECHANICAL TESTING

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## Authors Biography

Constantinos is currently working towards his PhD at Cranfield University, Defence Academy of the UK, looking at spinal damage caused by vibration within land, sea and air environments. The research objectives involve creating a working model that will better predict spinal failures under various loading conditions. Prior to his PhD, he worked within the aerospace industry for two years, as a PED engineer, where he supported current and new project manufacturing.

His academic career started at the University of Liverpool where he obtained his MEng in Mechanical Engineering. His thesis involved heat transfer and fluid flow characteristics of impinging jet arrays. The industrial project dealt with looking into the optimisation of fluid flow and heat transfer characteristics of a heat treatment rig, for the use in aerospace components. His interests in Forensics then lead him to Cranfield Forensic Institute in 2011 where he completed his MSc in Forensic Engineering and Science. Elements of the course included: Failure of Materials and Components, Fires and Explosions Investigation, Aircraft Accident Investigation and Response. His Master's research involved the characterisation of welds, test-to-failure by fatigue and overload. This made use of microstructure, hardness and fractographic test methods.

## Introduction

There currently is a need for standardised test models within the biomedical research world; models that mimic the human musculoskeletal system both mechanically and morphologically. With the limited availability and (in some cases) absence of these standards, industrial testing of equipment starts becoming very challenging.

Combining the fact that human populations vary greatly and where there is a requirement for bespoke equipment, procurement and testing becomes a costly activity.

With the ever-growing difficulty of obtaining cadaveric specimens and the ethical restrictions; cost-effective, efficient testing becomes even more difficult.

The methodology presented here (3D printing coupled with DIC) highlights the possibility of conducting tests with limited requirements for cadaveric material. Two analogue cases are studied; a distinct morphological and histological anomaly on a human skull and a porcine spinal motion segment. When, for example, a bespoke helmet design might be required due to a specific clinical condition being present.

A major aim of the research is to develop a testing method that will allow for a quick and easy way of comparing a "normal" to an "irregular" case for biomechanical testing thus bringing the subject specificity that cannot otherwise be engrained within the standards.

## Methods and Results

CT scans were used to create the 3D models of both the human skull and the L1-L2 porcine spinal motion segment analogues. These models were printed in ABS using a *Stratasys* printer. The 6 skulls created (3 with excised lesions and 3 intact) utilised *Perma-Gel* in the brain cavity to mimic the mechanical response of the brain under loading. An optimised speckle pattern was applied prior to mechanical testing to aid the high speed camera capture and data analysis. Mechanical testing (dynamic loading) of skull specimens was carried out with an *IMATEK IM10* drop tower, whereas the testing of the spinal motion segments (quasi-static) on an Instron 5567.

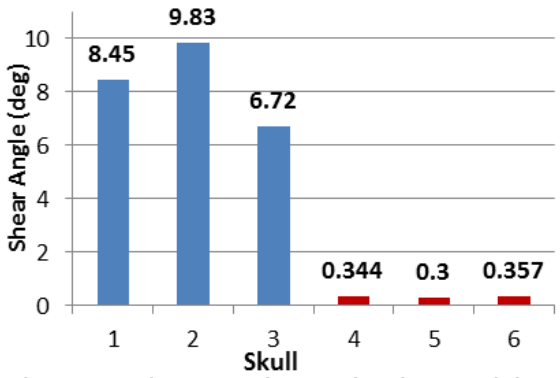


*Figure 1: Shear angle proximal to excision*

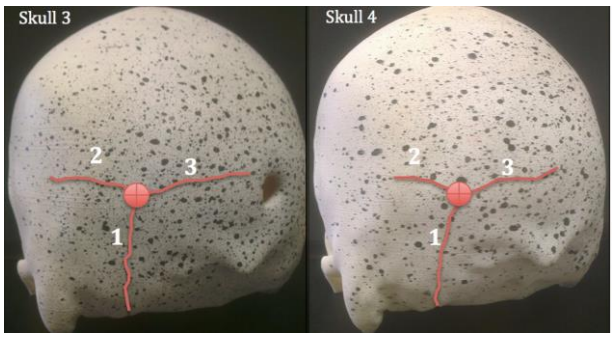


*Figure 2:Crack propagation on Skull 3 and 4*

Tests were conducted at striker velocities of 8 m/s and 9.5 m/s at 100 and 130 Joules respectively. All skulls with an excision experienced increased shear angles (Figure 1) as well as strains when compared to the "normal" skulls. Skull 3 and 4 failed, showing 3 distinct crack paths. In both cases the cracks originated near the impact zone, where the striker came in contact with the skull. This was true not only in the manner and sequence of the crack propagation but also in its magnitude (Figure 2).

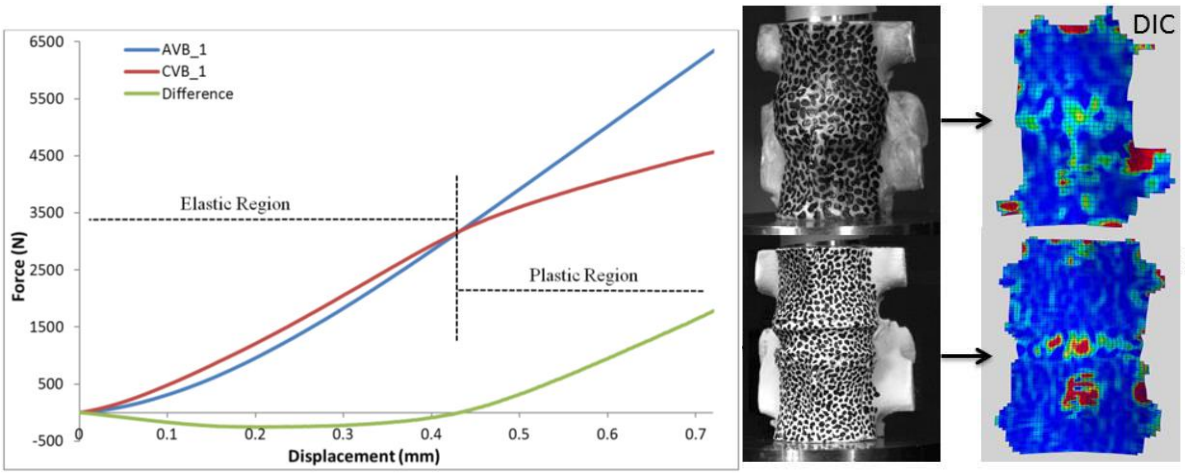


*Figure 3: Elastic-plastic loading variation in vertebral body loading*

The method produced vertebral body analogues that were similar in stiffness to cadaveric vertebral bodies, as shown in Figure 3. DIC also reported comparable stiffness for cadaveric and analogue motion segment samples. The intervertebral discs were significantly stiffer than the vertebral bodies. Cadaveric intervertebral discs deformed noticeably less than the manufactured analogue intervertebral discs. The preliminary results highlighted that further work should be conducted on the stiffness of the motion segment by varying the 2 part silicone making up the intervertebral disc. Once biofidelic stiffness of analogue motion segments is achieved, the method may be applied to create human spinal motion segment analogues.

**Conclusions and Recommendations**

Although this research is patient specific, it forms the basis for further research in the effects of such anomalies, not only on the skull but also the rest of the musculoskeletal system.

The research conducted demonstrates the potential usefulness of two modern techniques within biomechanical testing. Through appropriate DIC acquisition, full-field strains can be obtained for a wide range of biological specimens with high levels of accuracy and precision. When paired with the recent evolution of rapid prototyping, components for testing can be created in a repeatable and cost effective manner.

Due to the flexibility the aforementioned methodology can provide, it can be foreseen that more and more applications will adopt this method of testing within the forthcoming years, both *in vitro* and *in vivo*.