SURFACE STRAIN MEASUREMENT OF A CADAVER HUMAN FEMUR USING HIGH-SPEED DIGITAL IMAGE CORRELATION

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Introduction

In-vitro mechanical testing experiments have been made on proximal human femora [Cristofolini, 2010] to address the strain surface response, and to serve for development and validation of numerical models [Viceconti, 2005]. Strain gauges are commonly used, but can only provide a limited number of measurements over a femur surface due to space constraints and attachment difficulties. The digital image correlation (DIC) technique may overcome this issue, providing thousand of strain measurements over a femoral surface using optical methods. The aim of the present study was to investigate the mechanical response of a cadaver proximal femur to a rapid load, using a DIC system equipped with high-speed cameras.

Methods

A fresh-frozen proximal cadaver femur specimen was obtained (Ethical permission 5783/04/044/07). The shaft was cut 5cm below the greater trochanter, and embedded in epoxy. A white background was painted on the anterior surface of the femur using a spray, and a random speckle pattern was applied manually. The bone was loaded in a quasi-axial configuration at a loading rate of 15mm/s (Instron, Inc.). Images were recorded at 3000 fps, using two high-speed 1MPx cameras (Photron, Inc.). Image correlation was performed with Vic 3D 2010 software (Correlated Solutions, Inc.), and the deformation gradient was extracted. The strain-force behaviour was investigated in three selected areas, resembling strain gages, and 3 simulated extensometers over the fracture line (Fig 1b).

Results

DIC provided about 50000 uniquely traceable points (Fig 1a, 1b). Fracture occurred at 7856N as a brittle event (1ms, Fig 1a-b). The principal strain-force behaviour (Fig 1c), produced a determination coefficient over 0.94. The simulated extensometer data were highly correlated with the applied force (R^2=0.99), as well as the displacement of the actuator (R^2=0.99, 1000N< force<7856N).

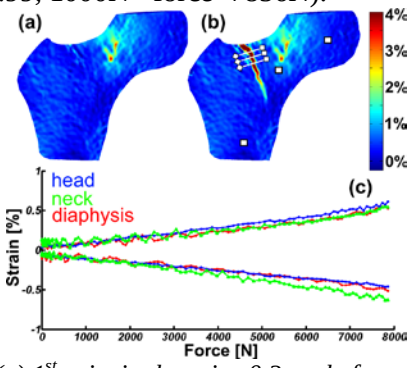

Fig 1:(a) 1st principal strains 0.3 ms before, and (b) at fracture: simulated SGs and extensometers are shown; (c) principal strains Vs. force.

Discussion

The femur showed linear behaviour when loaded at a displacement rate close to physiological conditions. This conclusion is corroborated by the low von Mises strain recorded after fracture (average 0.44±0.46%), with significant residual strains confined near the fracture rim. The simulated extensometer data showed a high linearity with the applied force. The high-speed video recordings evidenced that the fracture started on the superior aspect of the femoral neck, which is mainly solicited in tension (Fig 1b). No principal strain or von Mises strain concentration was evident in the fracture area 0.3ms before fracture (Fig 1a), and a deeper analysis of the strain evolution around the crack tip is planned. Two more samples have been tested. However, the analysis is pending. Based on the present results, the in-vitro testing protocol used may provide a detailed high-frequency strain mapping of a whole femoral surface, including the fracture region. This may help towards understanding the femur fracture mechanisms.

References

Cristofolini *et al*, J Biomech, 43:826-35, 2010

Viceconti *et al*, Clin Biomech, 20:451-4, 2005.

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