Digital Image Correlation for Biomaterial Characterisation: Challenges and Applications in Soft Tissue Biomechanics

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Abstract

This study investigates the application of digital image correlation (DIC) for characterising biomaterials, including silicone phantoms and hydrogels. DIC offers full-field strain measurements critical for understanding tissue mechanics, yet significant challenges remain when applied to highly deformable biomaterials. This work presents preliminary findings from mechanical testing of silicone coupons and cardiovascular phantoms, highlighting procedural considerations and optical challenges specific to soft tissue biomechanics.

Introduction

Full-field optical measurement techniques, particularly DIC, have become increasingly important for biomechanical investigations [1]. Unlike traditional strain measurement techniques, DIC provides spatially resolved strain data essential for understanding heterogeneous tissue behaviour and validating computational models. However, biomaterials present unique challenges for DIC implementation that are not encountered in traditional engineering materials. The lack of standardised protocols for soft tissue DIC has limited the technique's adoption in clinical research and regenerative medicine applications, where accurate strain quantification is critical for understanding pathology, optimising surgical techniques, and validating tissue engineered constructs.

Key challenges include: (i) extreme deformability, with biological soft tissues routinely experiencing strains exceeding 50%, requiring robust correlation algorithms and appropriate reference frame selection, (ii) optical access constraints, as many biomechanical tests require physiological environments involving fluid immersion, temperature control, or complex loading fixtures that obstruct camera views, (iii) speckle pattern application, where traditional spray-on patterns may be incompatible with wet, compliant surfaces or may alter mechanical properties, and (iv) low contrast and translucency of many biological tissues, reducing correlation quality [2,3].

This work addresses these challenges through systematic testing of biomaterial phantoms with the aim of establishing robust DIC protocols for soft tissue characterisation.

Methods

Silicone elastomers were selected as baseline materials due to their durability, hyperelastic behaviour, and widespread use in medical device development. Mechanical tests were carried out on standard coupons under tension, as well as on more complex geometries such as heart valves.

Cardiovascular models, including silicone heart valves and bio-prosthetic implants with controlled geometric variations, were fabricated and tested in a flow loop system simulating physiological conditions [4]. High-speed stereo-DIC (6000 fps) captured leaflet dynamics during valve closure, synchronised with pressure measurements. Speckle patterning strategies for wet, curved surfaces were evaluated, comparing airbrush application, natural tissue texture, and base-coat approaches.

Results

Displacement and mean maximum principal strain were recorded at multiple points on valve leaflets during closure using high-speed stereo-DIC. Full-field strain distributions were successfully captured, demonstrating the feasibility of DIC for characterising cardiovascular phantom mechanics under physiological flow conditions.

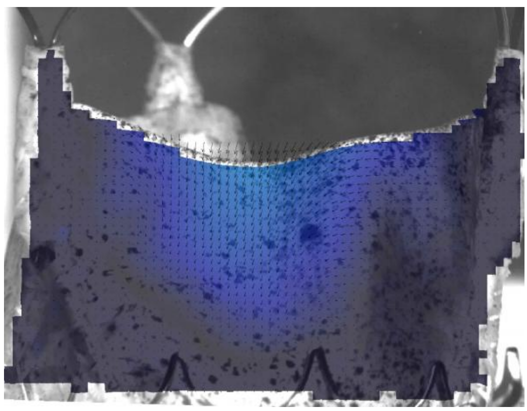

Figure 1: Displacement vector field recorded via DIC on a bioprosthetic heart valve specimen.

Discussion

This preliminary study demonstrates the feasibility of DIC for biomaterial characterisation while highlighting persistent challenges. The findings emphasise the need for application specific protocol development, particularly regarding speckle patterning and correlation algorithm selection for extreme deformations.

Further studies are needed to extend these methods to *ex vivo* biological tissues, develop standardised protocols for clinical tissue samples, and establish validation frameworks against alternative measurement techniques. Future work will focus on optimising DIC for skin biomechanics and establishing best practices for the biomechanics and DIC communities.

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