STRAIN FIELD ACQUISITION ON OVINE FRACTURE CALLUS WITH ELECTRONIC SPECKLE PATTERN INTERFEROMETRY

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INTRODUCTION

Fracture callus exhibits structural and constitutive heterogeneities, which provide biomechanical conditions inductive for fracture healing[1]. Quantifying strain gradients in fracture callus provides a unique opportunity to characterize biomechanical conditions which affect callus differentiation and fracture healing. This study assessed compressive strain distributions in an ovine fracture callus using an optical strain measurement approach based on the Electronic Speckle Pattern Interferometer (ESPI) [2-3].

METHODS

The fracture callus of an ovine tibia with heterotrophic non-union was harvested and frozen. A 3 mm thick sagittal cross-sectional slice of the callus was extracted with a diamond saw and thawed. First, its gross histology was documented photographically. Subsequently, a contrast powder was applied, ensuring adequate reflective properties of the specimen surface for optical strain measurement. The specimen was mounted in a custom-built compression stage. Specimen ends were rigidly clamped to induce unconfined axial compression over a 50 mm long section under displacement control. Displacement was applied manually with a micrometer screw in combination with a precision linear translation stage. The entire setup was assembled on a rigid base plate, ensuring stable conditions for laser-based strain acquisition with an Electronic Speckle Pattern Interferometer (ESPI, Q100, Ettemeyer AG, Nersingen, Germany). This laser-based non-contact measurement system generated speckle images of the specimen surfaces before and after callus compression. Subsequent speckle image subtraction and fringe analysis algorithms enabled quantification of surface strain fields in absence of specific surface markers. The particular ESPI system used in this setup sequentially captured speckle images from three linear independent illumination directions for computation of three-directional surface displacement vectors. It acquired three-directional displacement reports at 512 x 512 individual locations over a 25 x 50 mm region of interest (ROI). Not to exceed the measurement range of the ESPI system, displacement was applied in 50 increments of 1 µm, and the sum of all 50 displacement reports was calculated. Based on this summary displacement report in response to 0.1% specimen compression, the minimal principal strain distribution (i.e., compression) was computed over the callus ROI. Throughout the measurements, the callus specimen remained in a humidified atmosphere.

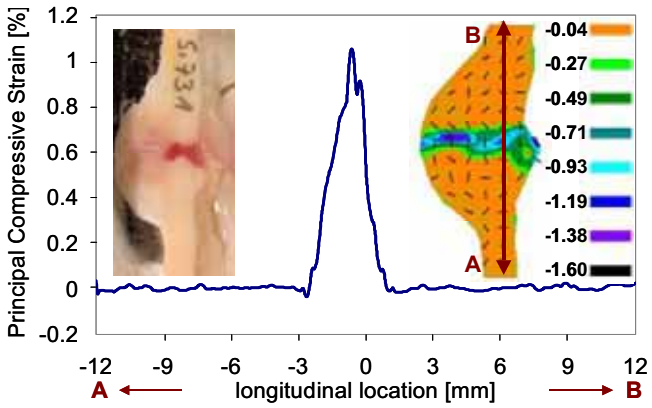

Figure 1. Principal compressive strain distribution on fracture callus.

RESULTS AND DISCUSSION

ESPI measurements on the cortex and callus delivered continuous strain reports. In callus, a clearly demarcated layer of elevated strain was observed which bisected the fracture callus transversely. This high-strain region correlated closely to the fibrous non-union layer visible on the specimen cross-section. Compressive strain in this fibrous zone exceeded 1% in response to 0.1% overall specimen compression. Corresponding strain vectors were perpendicular to the orientation of the fibrous layer. In the reminder of the callus tissue and on cortical bone, compressive strain remained below 0.1%, and was one order of magnitude smaller than that in the fibrous non-union layer. This small strain magnitude did not allow for consistent calculation of compressive strain vectors. Soft tissue in the intramedullary cavity of the ovine specimen was structurally unstable and had geometric incontinuities, for which reason it was excluded from continuous strain field acquisition with ESPI.

CONCLUSIONS

ESPI provided the unique ability to measure minute surface deformation and strain over a considerably large ROI, which allowed capturing of continuous strain maps over an entire fracture callus cross-section. Results reflect constitutive heterogeneities of a fracture callus in a quantitative manner. As such this approach provides a unique tool for analysis of mechano-biological factors in fracture healing and for validation of computational models thereof.

REFERENCES

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