Effect of Radius on Load/Strain Distribution between Ulna and Radius: Experimental and Numerical Analyses

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Introduction

Aging brings about dramatic reductions in the mass and strength of the skeleton and a significant increase in a person's risk for having an osteoporotic fracture. These fractures have significant morbidity and mortality and the economic burden to the health care system.

Fundamental to preventing osteoporotic fractures is to develop strategies to increase bone mass. One of the theories of bone formation at the cellular level is that osteocytes are stimulated by mechanical deformation. The forearm compressive loading model is frequently used in experimental studies. The rat ulna model is often used to numerically study the effect of bone formation due to mechanical loading. However, the testing is done with the entire forelimb and the macroscopic strain, which is used as a metric, is measured with a strain gage placed on the ulna. Prior research has justified the distribution of load to the ulna at two thirds of the total compressive load. Numerical predictions often are based on using the ulna model only in finite element analysis (FEA).

Purpose

The objective of this study is to develop finite element models of the entire forelimb and the ulna only and compare force distributions and peak sectional strain values in both models as well as to verify the distribution of loads in each of the bones.

Hypothesis

Lrp5 and the Wnt/β-catenin signaling pathway were involved in bone responsiveness to mechanical loading. Local strain distributions in bone determine which osteocytes in bone perceive and initially activate β–catenin signaling in response to mechanical load. Previous FEA models do not adequately explain which osteocytes will respond to a given load , therefore:

We hypothesize that the presence of the radius will change not only the magnitude of deformation but also the distribution of strains in the ulna.

Materials and Methods

Finite Element Modeling
Previous FEA models of the ulna have excluded/ignored the contribution of the radius when the forearm is loaded and have not validated the model biologically.

Ulna Model vs. Ulna-Radius Model: The purpose of the development of the two models, namely the Ulna model (UM) and the Ulna-Radius model (URM) is to study the effect of the presence of the radius and its associated boundary conditions on the kinematic behavior of the ulna. It can be expected that the behavior represented by the URM will be different compared to the UM, especially in predicting the strains determined by the numerical modeling effort. The URM represents a significant advance over models found in literature in that the radius is included and the marrow cavity was incorporated into the modeling. Inclusion of the marrow cavity was made by a two solid objects subtraction approach.

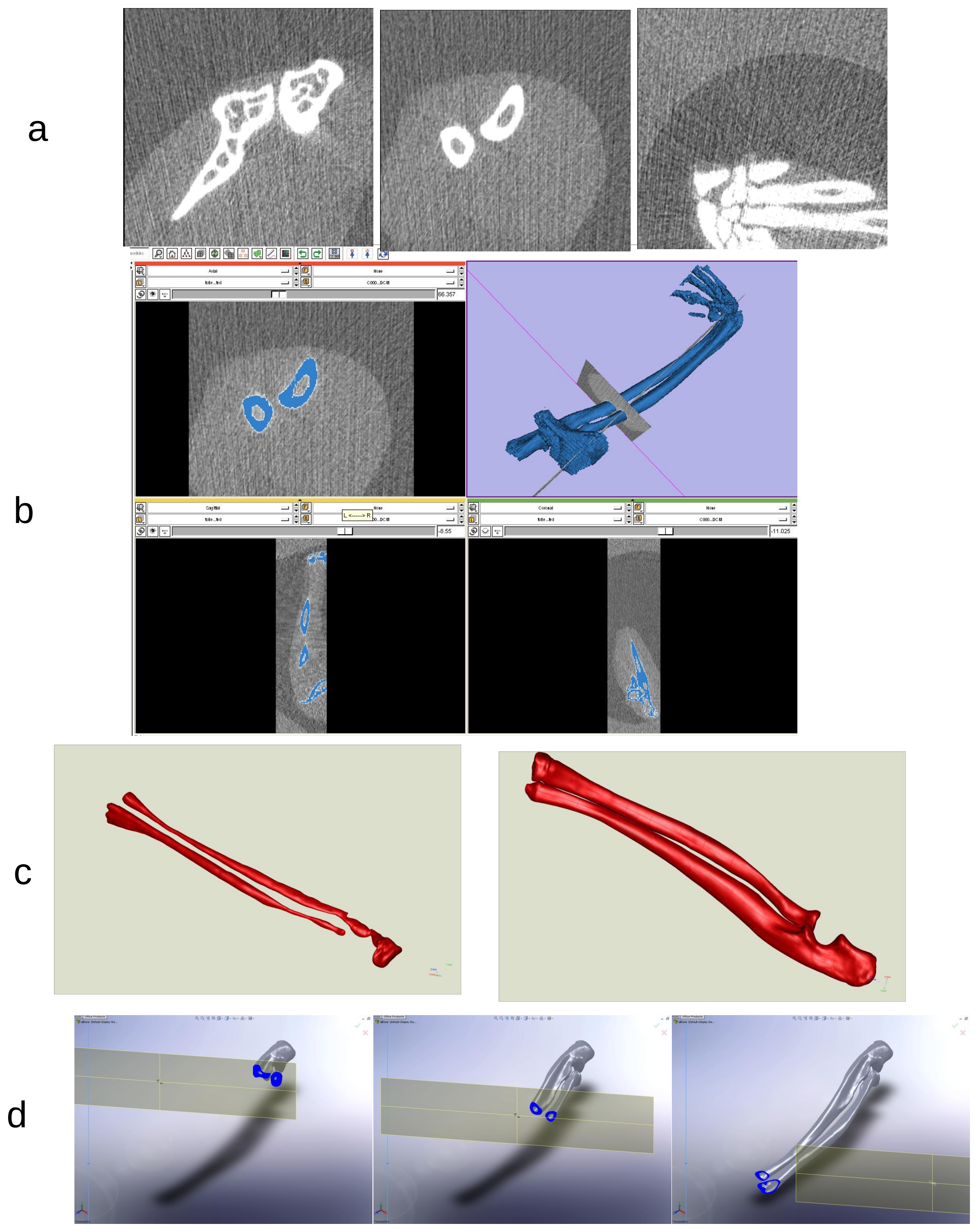

Figure 1: Modeling process (row a: selective μCT images; row b: image tracing; row c: final CAD model of cavities and ulna w/ radius; row d: selective sectional cuts revealing the cavities)

Results

Table 1: Maximal resultant displacement (units: mm)

	ABAQUS		ANSYS		LS-DYNA	
	UM	URM	UM	URM	UM	URM
10-node, coarse mesh	0.1669	0.1352	0.1647	0.1352	0.1536	0.1385
10-node, fine mesh	0.1833	0.1554	0.1832	0.1554	0.1810	0.1298
4-node, coarse mesh	0.0722	0.0418	N/A	N/A	0.0861	0.0752
4-node, fine mesh	0.1183	0.0878	N/A	N/A	0.1436	0.0987

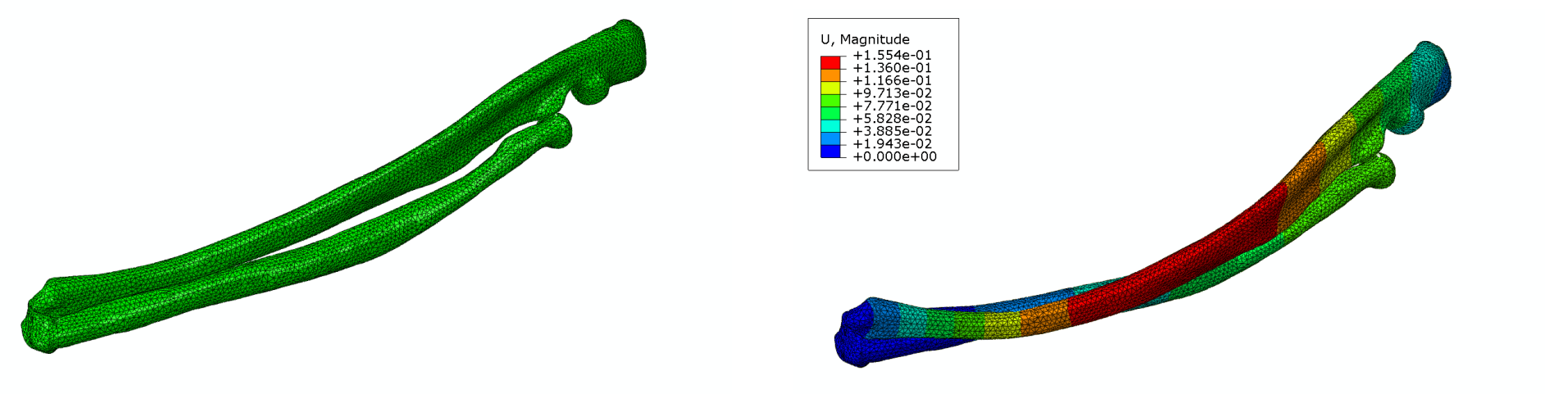

Figure 2: Unloaded FE model and deformed model

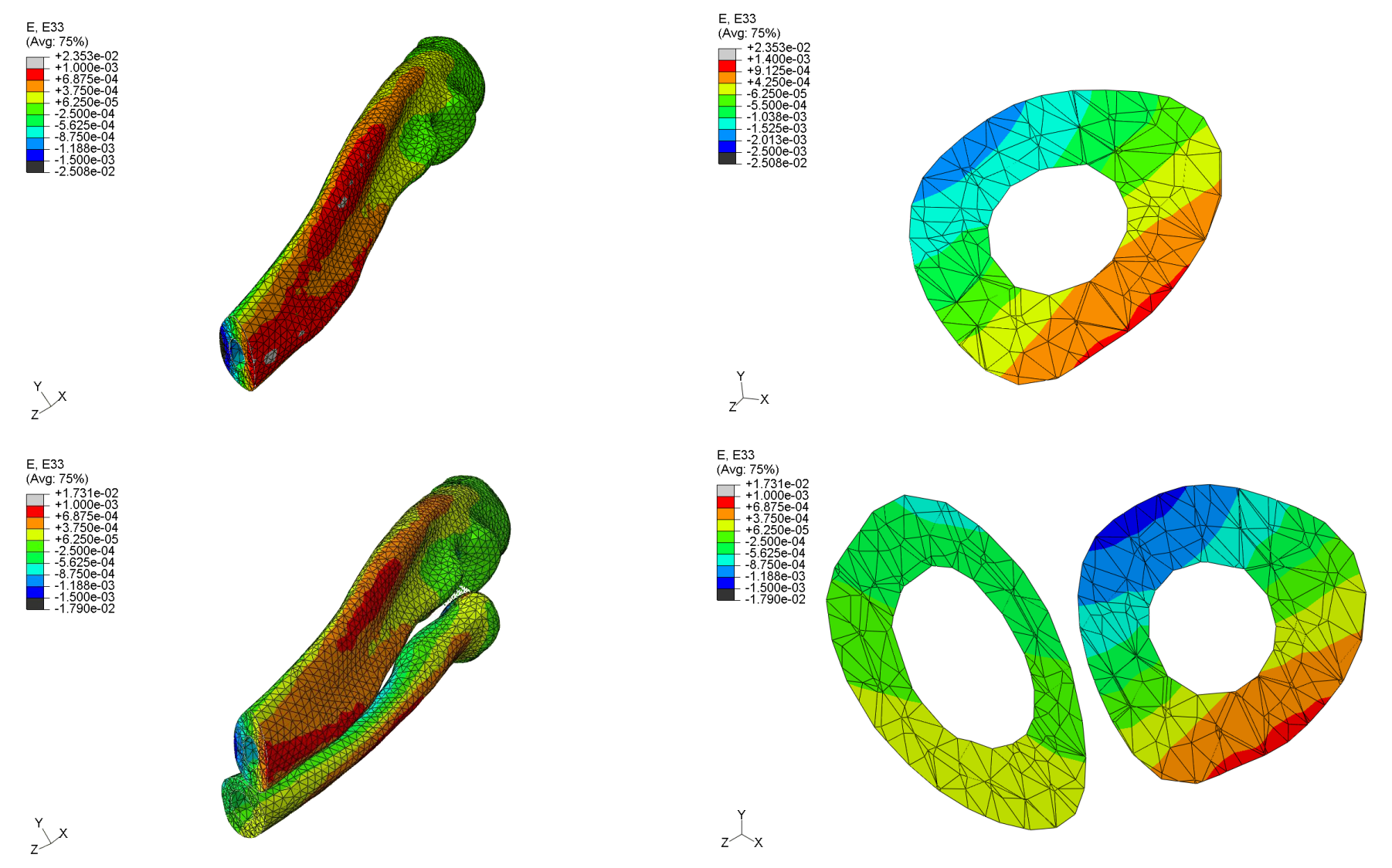

Figure 3: Strain contours at mid-shaft of UM and URM

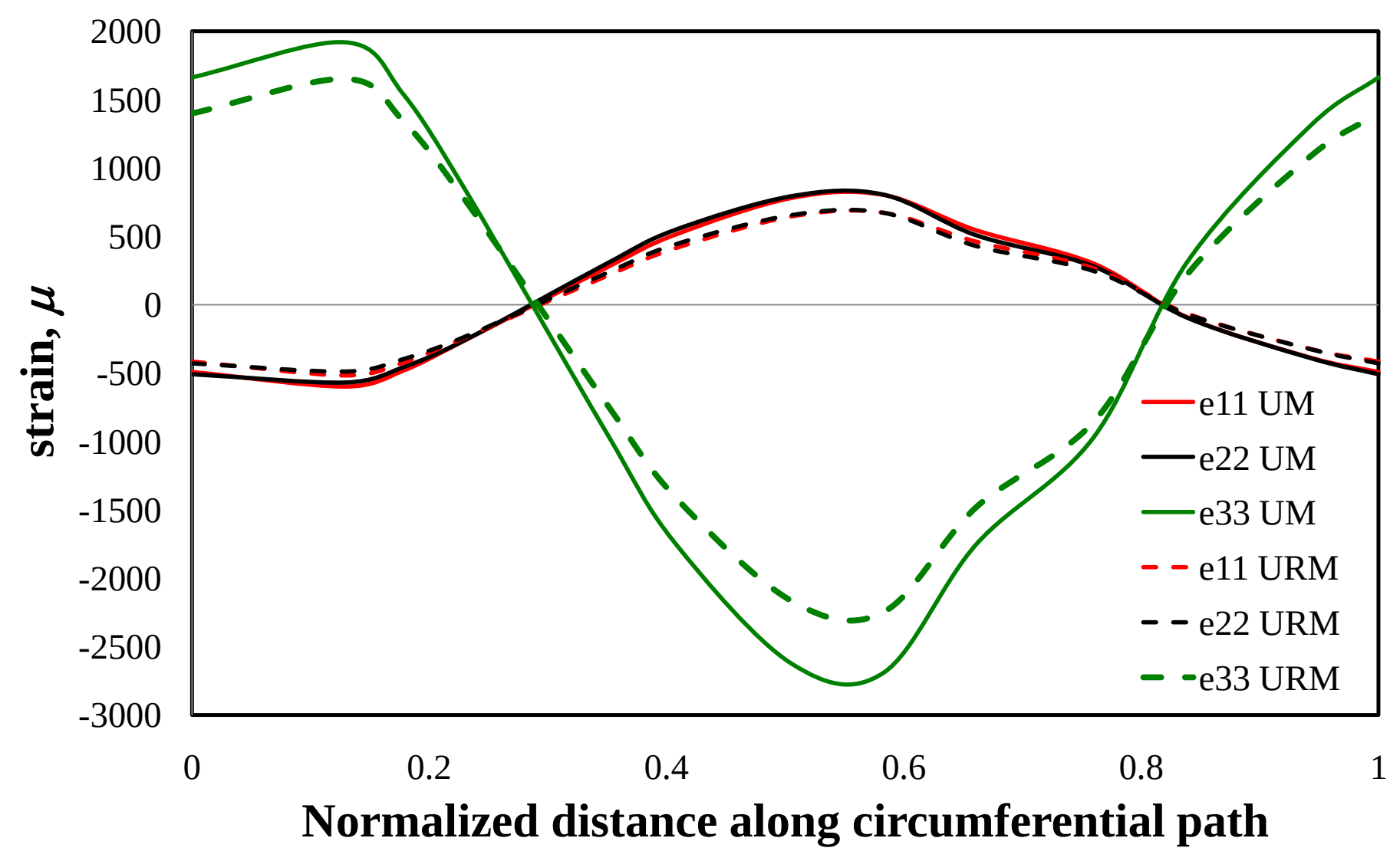

Figure 4: Strain variation along the peristeal circumferential path at mid-shaft of ulna (URM)

Experiment

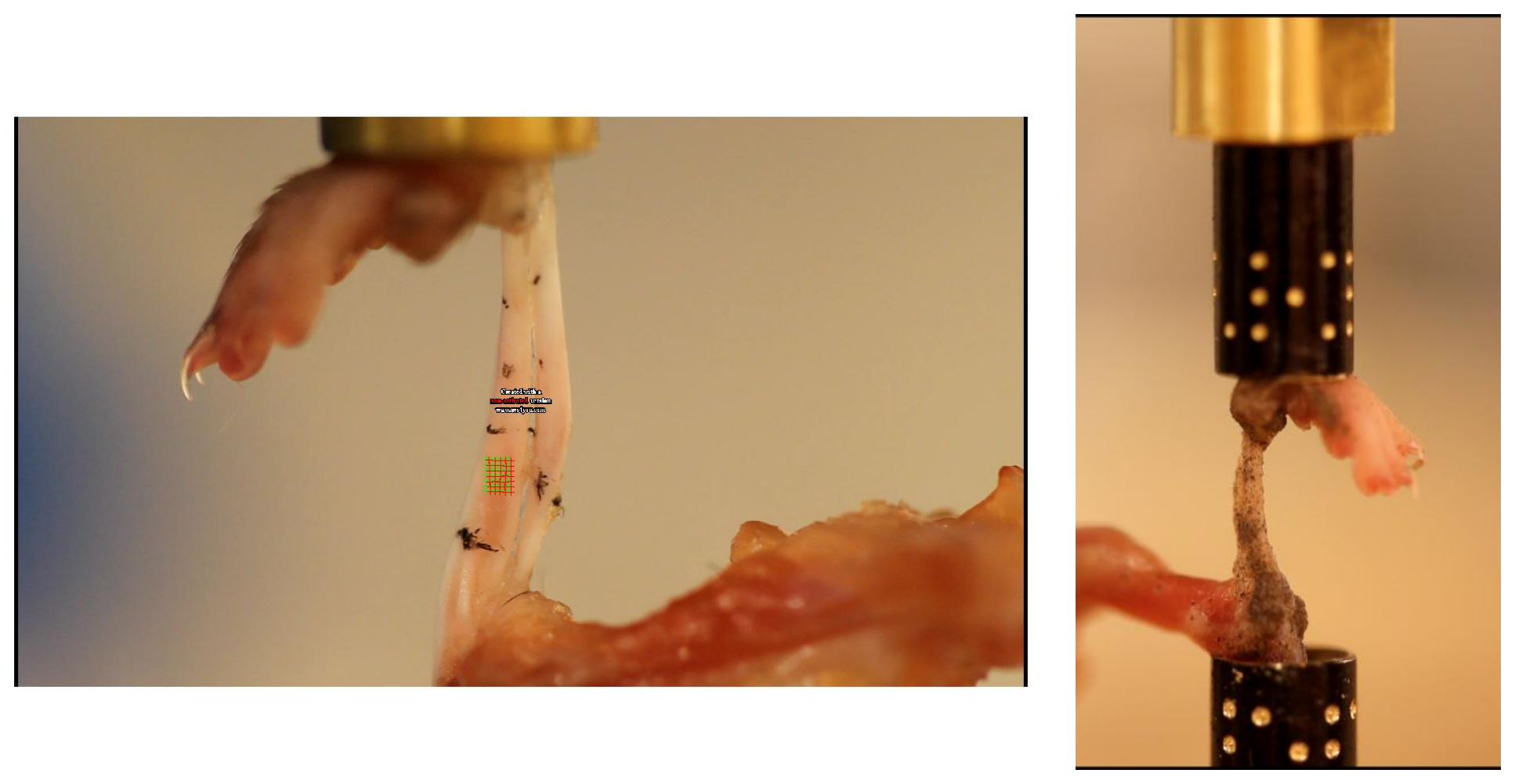

Figure 5: Experiment setup for model validation using DIC

Conclusions

1. CAD model of ulna/radius build from μCT images was validated. FE analyses were conducted in different software and good agreement among the results was achieved.
2. It was found out that ulna shares 65-80% of the total load based on the results from both displacement and strain data. The axial strain is the largest in magnitude among all the strain components. And the peak value of the compressive axial strain is about 1.5 times of that of the tensile strain.

Future Work

- Include two loading fixtures (caps) in the model to simulate the real testing condition
- Apply dynamic load to the model
- Calculate strains with DIC (digital image correlation) technique and compare the values with experiment/FEA

Potential Technology Transfer

Building FEA based models that enable us to accurately predict how strain fields in bone subjected to mechanical load are modified by aging and various pharmaceutical interventions could significantly advance our understanding of how bone responds to mechanical loading . This could be central to the design of better exercise regimens to build and maintain bone mass in combination with various bone anabolic agents. Also, by understanding how the inherent mechanisms within the skeleton are regulated by loading, then the design of new pharmaceutical agents that work through these mechanisms will be possible.

Acknowledgements

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