# Virtual Mechanical Testing for Non-Destructive Assessment of Bone Regeneration in Large Ovine Tibial Defects

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## INTRODUCTION

**Virtual mechanical testing is a non-destructive image-based approach to evaluating bone healing that preserves the sample for other analyses.**

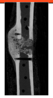
### PREVIOUS WORK

Previously, we developed and validated the computational methods for measuring the virtual torsional rigidity (VTR) of intact and healing ovine osteotomies[1]. For small defects (3 mm) and moderately large (17 mm) defects with autograft, we demonstrated that the virtual torsion tests are a reliable surrogate for destructive and labor-intensive physical biomechanical tests in ovine surgical models that progress to union within 9-12 weeks.

[1] Schwarzenberg et. al, *J Orthop Res.* **39**(4), 727-738 (2021)

### OBJECTIVE

The goal of this study was to assess the validity of virtual torsion tests in an independent dataset with a large-defect limb salvage model that heals much more slowly. Our **hypothesis** was that virtual torsional rigidity (VTR) is strongly correlated with the torsional rigidity measured in physical biomechanical testing.

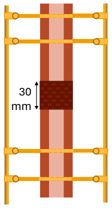
| Dataset | Country | Number of Sheep | Surgical Method | Defect Size | Time Frame of Healing | Scan Type |
|---|---|---|---|---|---|---|
| | | 24 |  | 3 mm,<br>17 mm | 9 wks<br>12 wks |  |
| | | 32 |  | 30 mm | 18 wks |  |

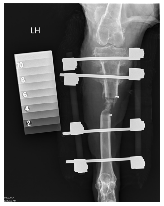
## METHODOLOGY

### *IN VIVO* IMAGING DATA

Thirty-four sheep had 30-mm tibial ostectomies stabilized by external fixators with two different resorbable graft containment systems. *In vivo* CT scanning was performed at intervals of 4 weeks up to euthanasia at 18 weeks post-op. In both groups of 17 sheep, 12 animals were used for postmortem torsion testing and 5 were reserved for histology.

CT Scan of External Fixators

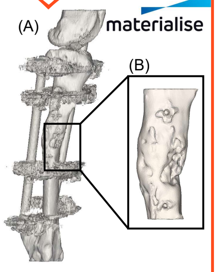




Radiograph of External Fixators

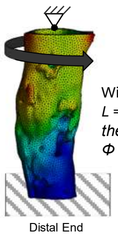
### MODEL SEGMENTATION

All scans were processed using Materialize Mimics (v23.0) to segment bone and callus in the defect zone (A). The models were virtually realigned and cropped to the ROI (B). A quadratic tetrahedral finite element (FE) mesh with maximum edge length of 1 mm was used.



### VIRTUAL TORSION TESTS

Virtual torsion tests were performed using ANSYS (2020 R2) by rigidly fixing the distal end of the tibia and applying a 1° rotation through the bone's long axis on its proximal end. Torsional rigidities for the physical tests (GJ) were determined by dividing each torsional stiffness by its corresponding gauge length.



$$VTR = \frac{ML}{\Phi} \quad [Nm^2/°]$$

*With M = moment reaction,*
*L = = the working length of the bone segment,*
*Φ = angle of twist*

### MATERIAL ASSIGNMENT

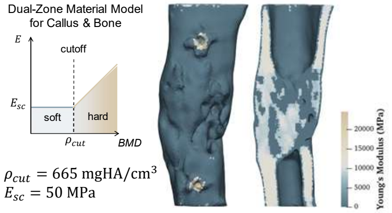
A phantom calibration was used to calculate bone mineral density ($\rho_{QCT}$) from the voxel Hounsfield Units (HU) of each scan:

$$\rho_{QCT} = 0.597 \times HU + 4.146 \qquad (1)$$

Elementwise material properties in the FE models were defined using a piecewise function, according to our previously-validated **dual soft-hard model** for mineralized and non-mineralize tissue[2]:

$$\rho_{QCT} > \rho_{cut} \rightarrow E = 10225\rho_{QCT} \qquad (2)$$

$$\rho_{QCT} < \rho_{cut} \rightarrow E = 50\ MPa \qquad (3)$$

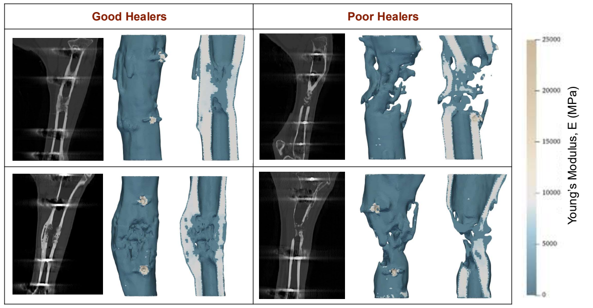


Dual-Zone Material Model for Callus & Bone

$\rho_{cut} = 665$ mgHA/cm$^3$
$E_{sc} = 50$ MPa

[2] Inglis et al, *Sci Rep.* **12**(1), 2492. (2022)

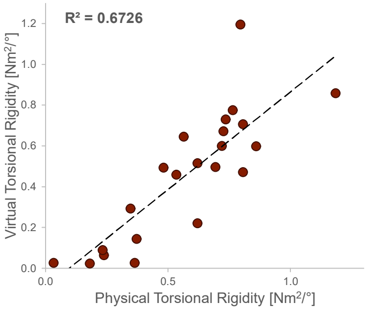
## RESULTS AND DISCUSSION



Representative slice views demonstrate a wide range of healing in the dataset as seen by the range of values of *E*, indicative of callus development throughout healed tibiae.

Virtual torsional rigidity (VTR) and torsional rigidity determined from physical tests (GJ) had no significant difference between means (p = 0.350). VTR and GJ were strongly and significantly correlated, and the linear slope approached unity (slope = 1.014) indicating high absolute agreement.

| Pearson's Correlation for Torsional Rigidity Results | |
|---|---|
| $R^2$ | p |
| 0.673 | < 0.001 |



The results were additionally evaluated for absolute agreement by comparing the root mean squared error (RMSE) between VTR and GJ to the standard deviation of the datum set*. We concluded good absolute agreement as RSME = 0.171 < $\sigma_{biomech}$ = 0.266.

| Descriptive Statistics for Torsional Rigidity Results | | |
|---|---|---|
| | Mean [Nm²/°] | Standard Deviation [Nm²/°] |
| Biomechanical | 0.576 | 0.266* |
| Virtual | 0.457 | 0.354 |

## CONCLUSIONS

The results of this study demonstrate that the virtual torsion test is a robust methodology that is adept at evaluating the healing progress of a bone regardless of surgical techniques, sample types, and other experimental characteristics. Compared to the previous validation study, the dataset utilized in this investigation had lower resolution scans and had larger defects. Despite these differences, strong agreement was observed between physical and virtual torsional rigidities. This suggests that **virtual mechanical testing is a valid and reliable surrogate for physical mechanical tests** and can be used to expand the available data.

## MORE INFO

**Acknowledgements:**
Special Thanks to:
- Madeline Boyes and Thomas P. Schaer (PennVet)
- David and Lorraine Freed Undergraduate Research Symposium, Lehigh University
- Clare Boothe Luce Research Scholar Program, Lehigh University
- Department of Mechanical Engineering, Lehigh University