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► To cite this version:

Marc Gardegaront, Joshua Johnson, Audrey Auvinet, François Bermond, Cyrille B. Confavreux, et al.. Reproducibility of a finite element model of the human femur in torsional load. 48e Congrès de la Société de Biomécanique, Oct 2023, Grenoble (France), France. pp.S86-S88. hal-04289749

HAL Id: hal-04289749

<https://hal.science/hal-04289749v1>

Submitted on 20 Nov 2023

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ABSTRACTS 48th Congress of the Society of Biomechanics

Yohan Payan & Lucie Bailly

To cite this article: Yohan Payan & Lucie Bailly (2023) ABSTRACTS 48th Congress of the Society of Biomechanics, Computer Methods in Biomechanics and Biomedical Engineering, 26:sup1, S1-S341, DOI: [10.1080/10255842.2023.2246304](https://doi.org/10.1080/10255842.2023.2246304)

To link to this article: <https://doi.org/10.1080/10255842.2023.2246304>



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Published online: 24 Oct 2023.



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Reproducibility of a finite element model of the human femur in torsional load

Marc Gardegaront^{a,b}, Joshua Johnson^c, Audrey Auvinet^a, François Bermond^b, Cyrille Confavreux^d, Jean-Baptiste Pialat^d, Aurélie Levillain^b, Benjamin Miller^c, Jessica Goetz^c, David Mitton^b and Hélène Follet^a

^aUniv Claude Bernard Lyon 1, INSERM, LYOS UMR 1033, Univ Lyon, Lyon, France; ^bUniv Eiffel, Univ Claude Bernard Lyon 1, LBMC UMR_T9406, Univ Lyon, Lyon, France; ^cDepartment of Orthopedics and Rehabilitation, University of IA Carver College of Medicine, Iowa City, IA, USA; ^dCentre Hospitalier Lyon Sud, Hospices Civils de Lyon, Lyon, France

1. Introduction

In 2020, there were an estimated 19.3 million new cases of cancer worldwide (Sung 2021), and around 80% of patients with malignant tumors will develop a bone metastasis (Du et al. 2010). Bone metastases affect the strength of bone, which may lead to fractures during daily activities. Accurate fracture risk assessment is crucial to give patients with bone metastases the best treatment. The current clinical gold standard for fracture prediction is the Mirels' score (Mirels 1989). However, this score has been proven to lack specificity (Piccioli et al. 2014). Hence, other failure prediction methods have been evaluated, mostly within the context of femoral metastases. Among these is CT-scan based finite element (FE) analysis, which allows for computation of failure load based on the geometry and bone density of the patient's femur. Most published FE models give good predictive results, though few have endured a reproducibility study (Gardegaront 2022). As FE models may be sensitive to operator-dependent variables and uncertainties in their experimental validation (Taddei et al. 2006; Amini et al. 2023), this study aims to explore the inter-institutional reproducibility of a FE model previously validated for prediction of femoral fracture under torsional load (Johnson et al. 2020).

2. Methods

Irregularly shaped defects were created in a series of eleven *ex vivo*, cadaveric specimens to mimic lytic femoral metastatic lesions. All femurs were scanned using a SOMATOM CT-scanner (Siemens Medical Systems, Forchheim, Germany, 120 kVp, 52 mA, field

of view 11.5 cm, pixel size 0.2246 mm, slice thickness 0.75 mm) together with a calibration phantom to convert Hounsfield units to hydroxyapatite equivalent densities. Femurs were tested to failure in torsion, and a linear FE model with failure criteria was created and cross-validated using these femurs and associated experimental data (Johnson et al. 2020). FE models of these experiments were reproduced by an external lab using the information contained in the paper.

Some changes were made as some software and methods could not be strictly reproduced as mentioned below:

- CT segmentation was performed in different software (3D Slicer vs Mimics).
- Diaphysis constraint was modelled as null displacement for distal femur nodes vs in contact with a constrained distal support.
- Models were loaded with a constraint of nodal load to the nodes of the femoral head vs displacement of femoral head nodes in contact with the loading platen. The rigid rotation of these nodes was not constrained.
- The orientation method was different (diaphysis and neck axes were defined differently).
- The FE software was different (Ansys vs Abaqus).

The results of the original model were then compared to the results of the reproduced model. Furthermore, two different segmentations of each femur from two different operators were used with the reproduced model to quantify the influence of the inter-operator variability of the segmentation.

Agreement between experimental failure loads from each model were evaluated with the coefficient of determination (r^2). Accuracy between model and experimental failure loads was quantified with the mean of differences. Precision between each model (original and reproduced) and experimental failure loads was quantified with the standard deviation of the differences.

3. Results and discussion

There was a strong relationship between the predicted failure loads of the original models and those of the reproduced models ($r^2 > 0.84$, Figure 1 and Table 1). However, both operators of the reproduced model obtained systematically higher failure loads than the original models. There was good agreement in failure loads computed by both operators using the reproduced model ($r^2 = 0.98$, cf. Table 1).

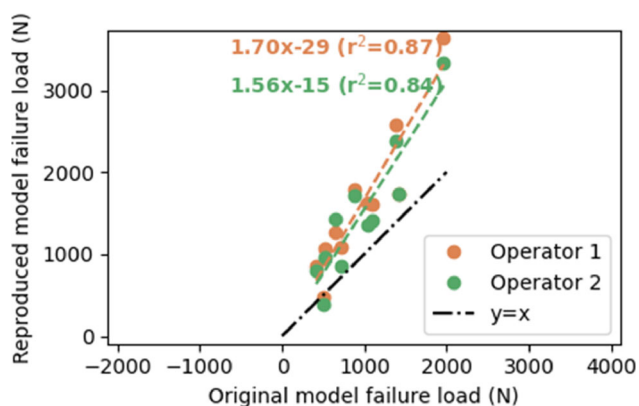


Figure 1. Relationship between original model results and reproduced model results for both operators.

Table 1. Coefficients of determination (r^2) between the experiment (exp.), the models and operators. Orig: Original; rep: Reproduced; Op: Operator.

	Exp.	Orig. Model	Rep. Model Op. 1	Rep. Model Op. 2
Exp.	1	0.88	0.93	0.88
Orig. Model	0.88	1	0.87	0.84
Rep. Model Op. 1	0.93	0.87	1	0.98
Rep. Model Op. 2	0.88	0.84	0.98	1

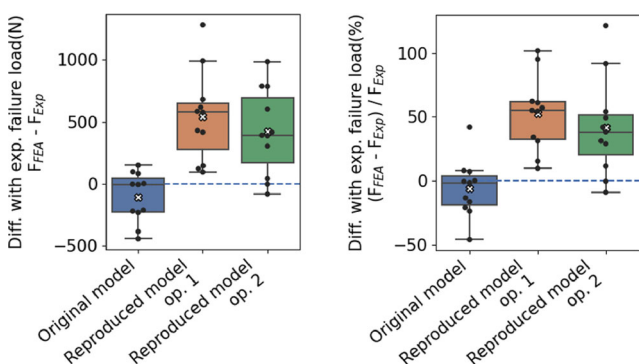


Figure 2. Differences between experimental failure load and predicted failure load for original model and reproduced model (both operators). left: Difference in newtons. Right: Relative difference in % of the experimental failure load.

The accuracy of the original model was -108 N, while for operators 1 and 2 of the reproduced model, it was 539 N and 419 N, respectively. The precision of the original model was 202 N, while for operators 1 and 2 of the reproduced model, it was 366 N and 348 N, respectively (Figure 2).

In a previous study (Gardegaront 2022), a non-linear model of femur failure load was reproduced with strong agreement between the original and reproduced models on the same dataset ($r^2 = 0.95$). The regression slope in that comparison was closer to 1 (slope = 1.07) than for this study (slope > 1.56 , Figure 1). Even if there are methodological

discrepancies between original and reproduced models (orientation, segmentation, etc.) in both studies, the previous study was done in compression and current one in torsion. This suggests that torsional load tests may be more sensitive to segmentation and orientation methods, and boundary conditions.

The results from both operators of the reproduced model suggests an operator dependent segmentation method gives variations on the predicted failure load (there is a difference of 14% between the regression slopes of both operators). However, both operators still obtain systematically higher failure loads than the original model, hinting at a significant contribution of other parameters such as the orientation method or the boundary conditions, on the model predictions.

4. Conclusions

This study aimed to reproduce a linear FE model of the torsional loading of the femur. A relationship between failure load from the original and reproduced model was found, but failure loads of the reproduced model were systematically higher. This suggests that the model may be sensitive to divergent modelling methods of the boundary conditions, segmentation, orientation methods or even the software used. In addition, variations of the predicted failure loads were found when using segmentations from different operators on the reproduced model. A global sensitivity study may explain which variables most affect the predicted failure load of the model, and thus yield information about which variables have to be carefully chosen to avoid inter-institutional reproducibility issues.

References

- Amini M, Reisinger A, Synek A, Hirtler L, Pahr D. 2023. The predictive ability of a QCT-FE model of the proximal femoral stiffness under multiple load cases is strongly influenced by experimental uncertainties. *J Mech Behav Biomed Mater.* 139:105664. doi:10.1016/j.jmbbm.2023.105664.
- Du Z, Zang J, Tang X, Guo W. 2010. Experts' agreement on therapy for bone metastases. *Orthop Surg.* 2(4):241–253. doi:10.1111/j.1757-7861.2010.00095.x.
- Gardegaront M. 2022. ESB 2022. <https://hal.science/hal-03739888>.
- Johnson JE, Brouillette MJ, Permeswaran PT, Miller BJ, Goetz JE. 2020. The effect of coordinate system selection on wrist kinematics. *J Biomech.* 106:109825. doi:10.1016/j.jbiomech.2020.109825.
- Mirels H. 1989. Metastatic disease in long bones a proposed scoring system for diagnosing impending pathologic

- fractures. *Clinical Orthopaedics and Related Research*[®]. 249:256–264. doi:[10.1097/00003086-198912000-00027](https://doi.org/10.1097/00003086-198912000-00027).
- Piccioli A, Spinelli MS, Maccauro G. 2014. Impending fracture: a difficult diagnosis. *Injury*. 45(Suppl 6):S138–S141. doi:[10.1016/j.injury.2014.10.038](https://doi.org/10.1016/j.injury.2014.10.038).
- Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, Bray F. 2021. Global Cancer Statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA Cancer J Clin*. 71(3):209–249. doi:[10.3322/caac.21660](https://doi.org/10.3322/caac.21660).

- Taddei F, Martelli S, Reggiani B, Cristofolini L, Viceconti M. 2006. Finite-element modeling of bones from CT data: sensitivity to geometry and material uncertainties. *IEEE Trans Biomed Eng*. 53(11):2194–2200. doi:[10.1109/TBME.2006.879473](https://doi.org/10.1109/TBME.2006.879473).

KEYWORDS Finite element model; bone; femur; fracture; reproducibility

 helene.follet@univ-lyon1.fr