Multiscale modeling of the mechanical behavior of the human humerus under low velocity impact

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ABSTRACT

The relevance and biofidelity level of the human numerical models are key issues in car accidents related trauma research. To limit the risk of injury of upper extremities and plan a preventive intervention, the humerus mechanical properties must be correctly assessed. However, the constitutive models used nowadays are still mainly derived from experimental characterizations carried out at the macroscopic scale without taking into account the bone microarchitecture. A multi-scale approach coupled with nanoindentation experiments revealed to be more appropriate when the robustness of computation and accuracy of results are of interest.

In this study, we propose a multi-scale approach for the accurate characterization and modeling of the mechanical behavior of the human humerus under low velocityimpact. The present model is based on the coupling between the Mori-Tanaka homogenization scheme 0 for the estimation of the elastic properties of the humeral cortical bone 00, and an isotropic damage model 0 for the prediction of the bone damage evolution. In order to consider the strain rate effects on the humerus behavior, the standard model of Johnson-Cook is adopted as a preliminary guess0. The obtained model is implemented using a User Material subroutine (UMAT) within the explicit dynamic code LS-DYNA 0. The validity of the resulting finite element model has been validated by comparing numerical predictions with experimental observations at different length-scales.

The outcome of the proposed multi-scale model appears to correctly predict the general trends observed experimentally through the good estimation of the ultimate impact load that a human humerus may encounter before fracture. The fracture patterns predicted by the proposed damage model are consistent with the physical humerus rupture even if this model is limited only to the failure initiation. Further improvements will be performed to the present model to take into account the marrow effects and rupture propagation paths.

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