Simplified multi-code model for passive muscle tissue under impact

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I. INTRODUCTION

Targeting simulation in multiple Finite Element (FE) software packages with comparable results poses challenges. For example, complex and specific material models are often only available in one or the other code, which becomes evident when comparing the mechanical response of muscle tissue with the existing material models in the FE solvers LS-DYNA and VPS. Consideration of large deformations and a fibre direction dependency would normally require an anisotropic hyperelastic material formulation that is not available in the standard delivery package in both codes. Consequently, a multi-code material modelling implies the usage of the best possible options. Within this short communication, a brief overview on a possible simplified multi-code material for muscle, which has been validated against a drop test setup on the upper arm of volunteers, is given.

II. METHODS

Based on review of existing literature and corresponding data available for the mechanical behaviour of muscles, a dedicated set of experiments was selected to create harmonised multi-code material cards in VPS and LS-DYNA. Here, the focus was on identifying a set of complementary experiments for compressive (transverse the fibre direction) and tensile behaviour (longitudinal) while taking into account strain rate dependency. In order to obtain a meaningful selection of the available data, the following steps have been performed: (1) clustering and analysis of data with respect to origin [1-5]; (2) analytical fit based on 1D Ogden approach (μ,α); (3) selection of suitable curve set (based on μ,α values) for definition of strain rate dependency; (4) calibration of final Ogden parameters (μ,α) and Prony series based on single element testing (tension, compression, shear) and component tests. In Table I the final model parameters are presented, μ differs by a factor of two due to a different implementation of the Ogden model in both codes.

TABLE I
MATERIAL MODEL PARAMETERS FOR SIMPLIFIED MUSCLE MODEL IN LS-DYNA AND VPS

	LS-DYNA	VPS
Used Solver Version	R11.0 – Double Precision	2017.0 – Double Precision
Material Model Type	MATERIAL MAT_77_O (with VFLAG=1)	MATERIAL MODEL TYPE 38 (with IOINF=2, IUFUN=2)
Mass Density	$\rho = 1000.0\ \frac{\text{kg}}{\text{m}^3}$	$\rho = 1000.0\ \frac{\text{kg}}{\text{m}^3}$
Poisson's Ratio	$\nu = 0.495$ [-]	$\nu = 0.495$ [-]
Ogden Parameter	$\mu_1 = 1.08$E-4 MPa	$\mu_1 = 0.54$E-4 MPa
	$\alpha_1 = 13.2$ [-]	$\alpha_1 = 13.2$ [-]
Prony Parameter	$G_1 = 0.29$ [-], $G_2 = 0.30$ [-], $G_3 = 0.19$ [-]	$\gamma_1 = 0.29$ [-], $\gamma_2 = 0.30$ [-], $\gamma_3 = 0.19$ [-]
	$\beta_1 = 2.0$E-1 s^{-1}, $\beta_2 = 1.0$E+2 s^{-1}, $\beta_3 = 1.0$E+6 s^{-1}	$\tau_1 = 5.0$E+0 s, $\tau_2 = 1.0$E-2 s, $\tau_3 = 1.0$E-6 s
Element Formulation	EF = 2 (selective reduced integration)	ISINT = 1 (uniform reduced integr.),ISHG = 0,$Q_3 = 0.01$

The validation load case, based on volunteer experiments, in which an aluminium impactor (0.96 kg mass) was dropped on the relaxed upper arm with two different impact speeds (1.5 m/s, 2.5 m/s), was represented including a FE model of the upper arm [6]. Experimental results for a volunteer whose arm is in a gross match with the FE model were used. The arm model was oriented according to the experiments, positioned onto a rigid wall, taking into account gravity loading. The translational degrees of freedom (DOFs) were constrained for the nodes on the humeral head. To represent the forearm's support in the test, the nodes of the bones of the forearm and hand were fixed for all DOFs.

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The impactor model was positioned according to the experiments and imposed by an initial velocity. Gravity has been introduced for all model parts. Muscle, skin and adipose tissue, as well as the impactor model, were represented by hexahedral elements and cortical bone by shell elements. Bones were modelled as elastic material, the impactor with an elastic-plastic aluminium material. For skin and adipose tissue, material models introduced in the OSCCAR project were applied. The proposed simplified multi-code material model from Table I was assigned to all parts representing muscle tissue.

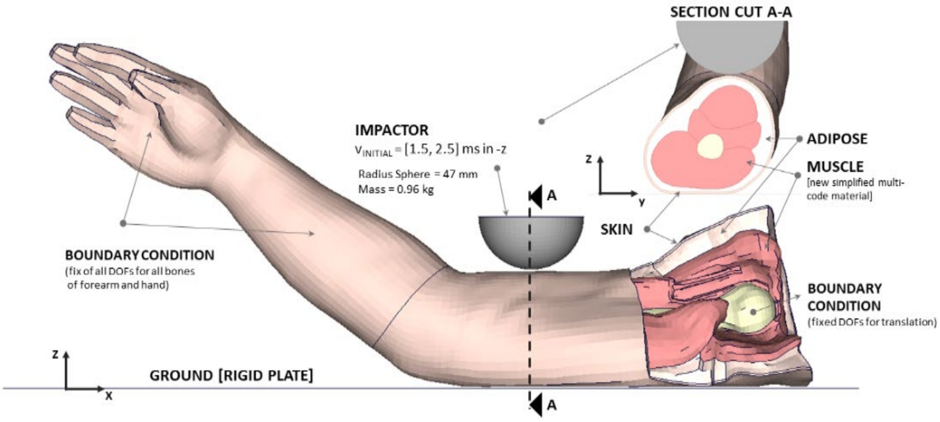

Fig. 1. Arm validation test setup and soft tissue distribution.

III. INITIAL FINDINGS

Impactor acceleration over time for all experiments and simulations is depicted in Fig. 2, with the solid grey lines showing the experimental results, and the solid red and green lines showing the simulation results in VPS and LS-DYNA, respectively. The experiments can be well represented in simulations for the two impactor velocities with respect to impact duration and load level. For the latter, the absolute values are somewhat over-predicted. Furthermore, only minor differences can be seen between the used FE codes.

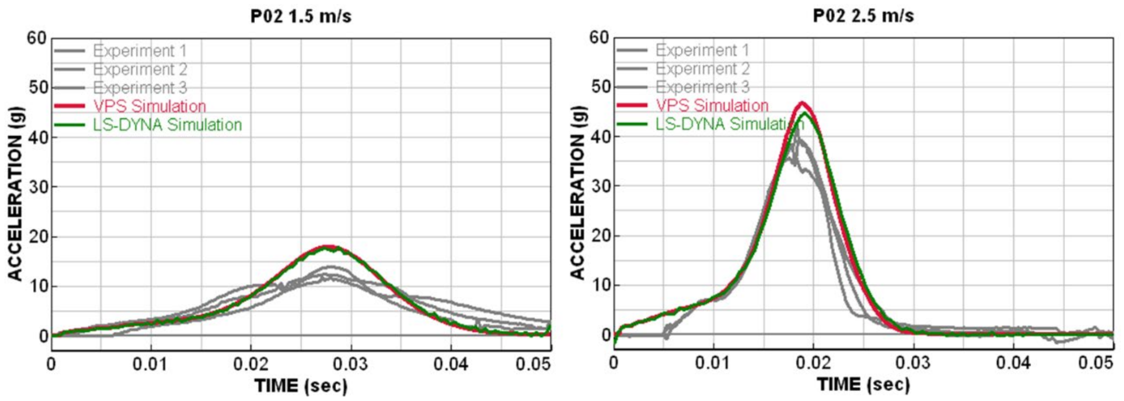

Fig. 2. Impactor acceleration over time for two impact velocities (curves are peak-aligned).

IV. DISCUSSION

Although the model of the experiment contains several soft tissue types and a complex geometry (see cross-section), the differences obtained with the two codes are relatively small. The agreement between simulation and test is seen to be appropriate at this stage. Depending on the intended use cases, further improvements will require a more comprehensive analysis of the individual soft tissue thicknesses. So far, only the gross outer dimensions of the arm were aligned with the model geometry, representing a 50^{th} percentile male. In addition, Prony series can be further adapted to better match experimental results, but this will require a deeper understanding of the contributions of the different tissues to the response, possibly involving re-validation.

V. ACKNOWLEDGEMENTS

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VI. References

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