Muscular Posture-Adaption Approach Maintaining Ligamentous Stresses and Strains

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I. INTRODUCTION

Detailed human body models (HBMs) with muscle representation are important tools to analyse injury mechanics in moderate acceleration events, where muscle activity is suspected play an important role. A prominent example is whiplash-associated disorders (WADs) which typically occur more frequently in female occupants and whose injury mechanism is not yet fully understood. Besides the active human behaviour during the excitation phase, the model's initial state is suspected to be extremely important for the injury outcome in cases of non-nominal postures [1-3]. Real human beings use muscle force to change their temporary posture to perform a task, change their view, or feel more comfortable. However, conventional pre-positioning approaches in HBM simulations do not adequately account for changes in the muscles' and ligaments' states that result during the change of posture. Stresses and strains are often not maintained or only reached using external forces [4]. The research questions to be answered are how the postures of HBMs can be naturally adjusted through muscular actuation and how this affects the initial condition after the pre-positioning phase. In this contribution, a novel pre-positioning approach using muscle-level control is presented and demonstrated in a rear-end scenario.

II. METHODS

The detailed ligamentous ViVA OpenHBM head-neck (HN) model [5] was used in the subsequent investigations. The muscles were modelled using the Extended Hill-type muscle model (EHTMM) [6-7]. A non-nominal head posture was modelled with the PIPER tool version 1.0.3. Two different approaches to make the posture available in explicit FE code are compared: A) The posture of the default HN-model was adjusted using discrete elements which apply external forces to the model (PIPER's CNRB approach). The resulting nodal positions were transferred to the HBM used for the separately started scenario simulation; B) In the presented novel muscular posture-adaption (MPA) approach, the pre-positioned PIPER model was exported as an LS-Dyna mesh to obtain the respective muscle part's length in the desired posture λ^i_{MTC}. Then, in each of the 136 muscle parts, an individual PID controller with λ^i_{MTC} as a target length was formulated. This ensures a dynamical motion towards the desired posture with internal muscle forces only, see Fig. 1. Since no external forces were applied, the HBM was in an internal state of mechanical equilibrium. This allowed an extension of the LS-Dyna simulation by a subsequent scenario without a restart. The muscles' control was formulated inside the EHTMM code using the LS-Dyna interface for user-defined material models. The control approach was selected individually for the posture adaption phase and the scenario simulation phase. While the robustness and efficiency were optimised in the posture adaption phase by directly controlling muscle activity q without any delay, the controller in the

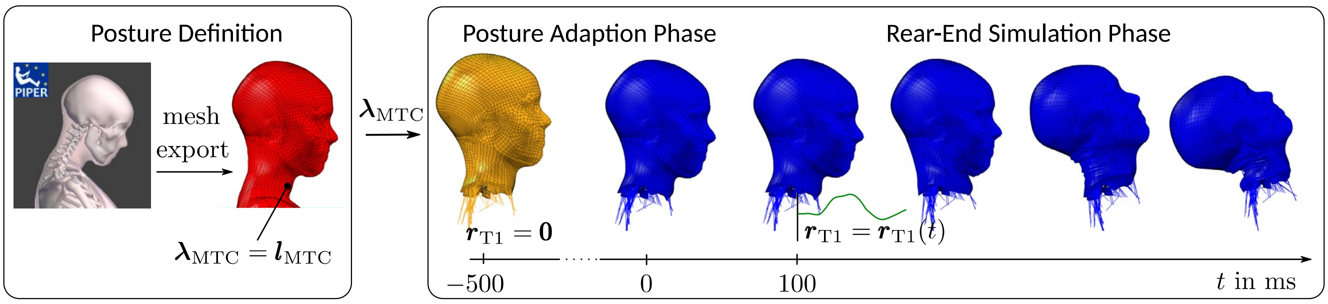

Fig. 1. MPA-approach to simulate HBMs in new postures using muscle-level control with target lengths $\boldsymbol{\lambda}_{MTC}$. The simulation is structured in a posture adaption phase ($t \in [-500, 0]\ ms$), change of controller formulation with initialisation ($t \in [0, 100]\ ms$) and rear-end scenario simulation ($t > 100\ ms$).

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scenario could be defined on a stimulation level $Stim^i = l^i_{\mathrm{CE}}(t-\delta)$, processing delayed information of muscle spindle length l^i_{CE}.

III. INITIAL FINDINGS

The resulting activation values in Fig. 2 show high values at the beginning of the first phase, ensuring fast convergence to the desired steady state reached at $t = 0$ ms. The control approach can be switched to a more biofidelic one, which is required to investigate realistic human behaviour under external excitation. At $t = 0$ ms, the muscles were controlled using neural stimulations, while q results from Hatze activation dynamics [8]. The constant activation values q in $t \in [0,100]$ ms indicate a successful calculation of corresponding stimulation values via the inverse activation dynamics in the transition phase at $t = 0$ ms. The reflex controller working with these constant stimulation values shows the desired activation and deactivation behaviour if surpassing the stretch limit $\Delta\epsilon^i$ referred to the respective muscle spindle length $l^i_{\mathrm{CE},0} = l^i_{\mathrm{CE},t=0}$. In our investigation a stretch limit $\Delta\epsilon = 5\%$ has been used for all muscles. In the comparison of the MPA approach and the PIPER's CNRB approach, differences in the ligament states prior to the application of the scenario pulse could be observed. Longitudinal stress values σ_{xx} were shown exemplarily for the ligaments connecting the cervical vertebrae C6 and C7 (Fig. 3). The posterior ligament, the interspinous ligament (ISL), shows tensile stress values in the dynamic equilibrium at the end of the posture adaption phase of the MPA approach. In contrast, PIPER's CNRB approach resulted in compression stresses due to gravitational loads applied to an already pre-positioned model neglecting the stresses and strains introduced in the adaption phase.

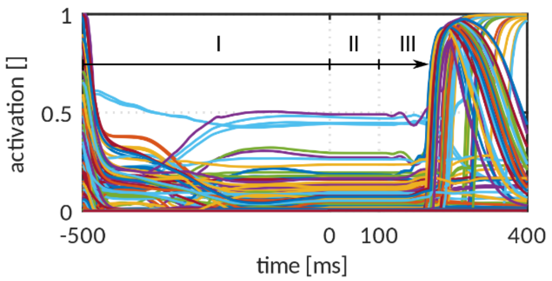

Fig. 2. Muscle activation values of all 136 muscles during direct PID control (I), constant muscle stimulation (II), and reflex control defined on $l^i_{\mathrm{CE}}(t-\delta)$ with activation dynamics and rear-end pulse (III).

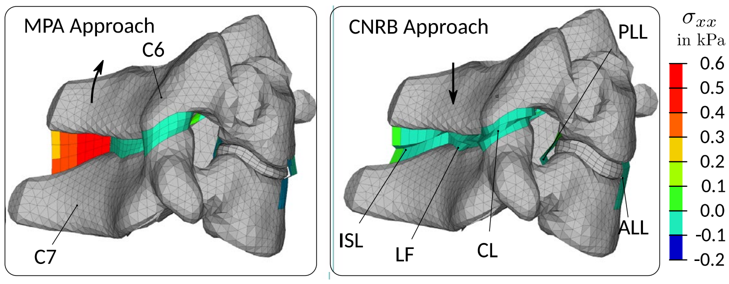

Fig. 3. Longitudinal stress σ_{xx} in the cervical ligaments between C6 and C7 vertebrae before initiating the rear-end crash pulse at $t = 100$ ms. Comparison of the novel MPA approach (left) and PIPER's CNRB approach with remeshing (right) for head posture adjustment.

IV. DISCUSSION

In this contribution, MPA is presented as a novel approach to adjust the posture of HBMs in a user-friendly and more natural way using muscular control. In the successful demonstration with the ligamentous ViVA head-neck model, a more natural initial state of pre-stressed ligaments and muscles was reached prior to the scenario compared to standard pre-positioning approaches. We assume that this more realistic replication of ligaments' and muscles' states is of high importance, especially in evaluating and investigating injury biomechanics accounting for ligament loading. Preliminary results, which are outside the scope of this contribution, support this assumption and show an impact on head kinematics as well as on maximum ligament loads during the rear-end scenario. In future, the MPA approach could be used to evaluate the injury mechanics of WAD for different occupant postures [9], considering not only the altered inertial properties [1-2] in non-nominal postures, but also the resulting pre-stressed ligaments and muscles' states in the neck.

V. REFERENCES

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