THE POTENTIAL OF CO-SIMULATION IN SPORTS ENGINEERING – A REVIEW ON SPINE SIMULATIONS

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Accidents are part of sports but can only be investigated with great effort because of their risk to human health. Injuries of the spine are most likely to be life-changing due to the severeness they can achieve. [1] Several approaches exist to model and simulate the spine. The most common methods are multibody simulation (MBS) and the finite element method (FEM), which can be combined to a Co-Simulation. This paper will present a review on the recent developments in Co-simulations of the spine and afterwards finish with the potential benefits a nonlinear approach can bring for sports engineering.

When integrating an intervertebral disc FEM model in a MBS model of the spine, two methods exist. One is to calculate the acting forces on the FEM model completely before starting the MBS analysis (unidirectional data flow. The second method considers the acting forces anew in every increment of the ongoing simulation, generating a bidirectional data flow.

Unidirectional Data Flow: Most models found in literature are restricted to an unidirectional data flow. Esat et. al.'s approaches for the cervical spine included the implementation and analysis of an MBS model with real life movement parameters. The forces at the interface points to the intervertebral discs were measured and implemented as boundary conditions in the subsequently set up FEM model. [2, 3] Offline calculations of the intervertebral disc are carried out with the help of FEA by Karajan et. al.. Polynomials, approximating the nonlinear behavior of the intervertebral disc, are found as results of this analysis. The polynomial relationships defined for each spatial direction account only for the purely elastic deformation ranges of the bushing elements representing the intervertebral discs. [4] The results of this simulation are in line with the results of Monteiro et. al. [5], non-linear deformations of the disc are not met.

Bidirectional Data Flow: The only bidirectional Co-Simulation of the spine is realized by Monteiro et. al. by using a Gluing Algorithm for the communication between the MBS and FEM software. [5] The Gluing Algorithm is an adaptation of the 2001 by Tseng et. al. [6] developed algorithm, which in turn was based on the Coordinate Split (CS) technique by Yen et. al. [7]. The goal of their work was to couple together the different subsystems, most likely provided by altering engineering groups, to perform an integrated system solution. The developed algorithm works by separating the dynamic system solution from the constraint

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satisfaction. This approach prevented an excessive intrusion of the multibody subsystem modules and reached a standard of modern, networkdistributed computing environments. Wang et. al. then specified the invented Gluing Algorithm to be suitable for practical application by introducing an interface defined by the reference nodes. It is the only communication platform between the different subsystems and makes the single submodels black boxes. [8] Monteiro et. al.'s calculations have been carried out using a viscoelastic, quasiincompressible intervertebral disc model, a hydrostatic nucleus pulposus and a fiber-drawn anulus fibrosus. For the linkage, Monteiro implemented so-called Co-Simulation elements as reference points of the interface between the MBS and FEM bodies. One master reference point and one slave reference point have been introduced, either on the center of the top side of the disc (slave) or in the center of the bottom side of the disc (master). The validation of the model shows realistic results, confirming the compatibility of the MBS software with the FEM analysis considering the modeling of the spine. [5]

In the biomechanical aspects of sports engineering, bidirectional Co-Simulations offer a great potential. Injuries of the spine, exemplary in cycling and mountainbiking, can be simulated and analyzed in order to optimize the performance of recent back protection systems. But the method is not limited to cycling. Nonlinear deformations of muscles, tendons and ligamets can be investigated. By determining inner stress states, new technologies in sports can be adjusted to the athletes' needs in an optimized way.

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