

# MBS Model of the Human Head and Neck for Investigating the Effectiveness of Head Protectors in Football

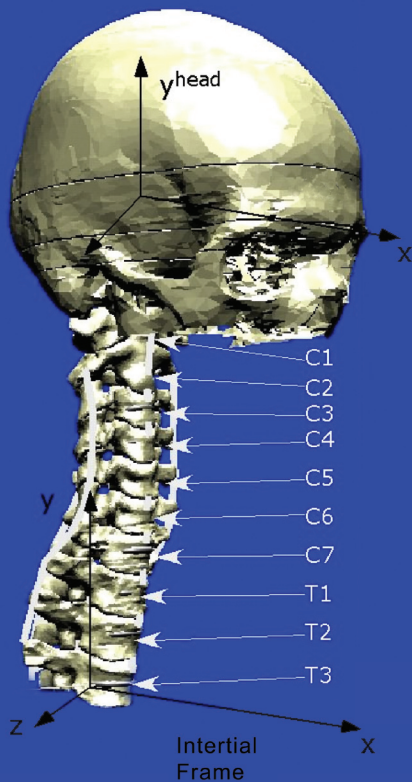


Fig. 1: The anatomical human head neck extremity with definition of the related bodies, the inertial frame and the head frame

Although about 22% of all injuries in football are injuries of the head, head protectors are nearly irrelevant in prophylaxis. So soccer has approximately the same rate of head injuries as American football and Ice Hockey. In the last years with increasing number of elbow tackling in heading duels the acceptance of head protectors was discussed more and more. Furthermore, head injuries are caused by the head hitting a hard surface such as another head, ground, or post. Further reason for concussions are unexpected head impacts of the ball with high velocities or from short distances, when no muscle activities can counteract the impact. Heading is an essential part of football and in normal controlled heading situations the limits that cause symptoms of concussions are not exceeded. Nevertheless, the risk of lasting damages of the neuro-physiological system due to a high number of controlled or uncontrolled heading situations has not been completely investigated.

In this paper, an anatomical detailed human head-neck model including nonlinear vertebra elasticity and ligaments and tendons interactions is derived using multibody system (MBS) modelling techniques. The head-neck muscles are modelled as a control unit to satisfy an input head motion. The impact with an elastic object such as a soccer ball is described by a body and one-side linear viscoelastic contact force element. The parameters of all models are taken from literature, CT-scans, or from specific physical experiments.

## GLOBAL DEFINITIONS

For the investigation of the head injury a detailed head-neck MBS is derived. As shown in Fig. 1, the model contains the rigid bodies of the  
– Vertebra T3, T2, T1, C7 until C1, and  
– the head.

These bodies are attached by joints and force elements as follows:

- Vertebra T3 is inertial fix.
- Between vertebra T3 and T2, T2 and T1 until C3 and C2 a joint of six DOF added by a nonlinear applied force / torque law is used, respectively. The details are given in section 2. 2.
- Between C2 and C1 a revolute joint about the vertical axis (the no-saying axis)
- Between C1 and head a revolute joint about the transversal axis (nodding axis – for flexion and extension) are applied.

The latter joints represent the lower and the upper head joints, respectively.

In addition to the viscoelasticity of the intervertebral discs, ligaments enchain the head – here seven ligaments are considered. Moreover, neck muscles move the head – here 23 muscles are considered within the model, where nine muscles force the flexion and 14 muscles force the extension of the head.

The individual muscle force is modelled as an active control unit distributed from the global net action of the head by the “equal-stress-theorem” using the physiological cross section area (PCSA) and the maximum of the muscle force of each muscle. The muscles are attached at the head body and the inertial frame.

## MODELS OF THE VERTEBRAS AND LIGAMENTS WITH THE DESCRIPTION OF THE VISCOELASTIC MATERIAL BEHAVIOUR

The geometry of the vertebra bodies is taken from CT scans and their mass properties from the literature. The rotations of the vertebrae are limited. The data of the range of motion (RoM) are taken from the literature. For the vertebra viscoelasticity a six-

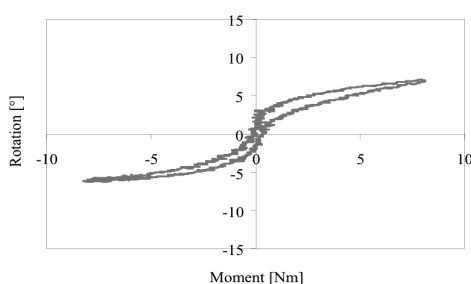


Fig. 2: Hysteresis function of the torque-angle relation

dimensional nonlinear force model is applied. The resulting torques are based on a Kelvin model (a spring with a serial damper is in parallel with an additional spring), where the spring with a torque-angle relation is given by a function as shown in Fig. 2 and is scaled for each specific vertebra by the RoM. The damping behaviour is about 50 % of the stiffness value.

In the longitudinal directions and the transversal plane of the special element, a Kelvin model is also used. The stiffness is obtained as complex function related to the discs parameters.

Carrying out experimental cadaver tests validated the proposed force laws. Special attention was focused on testing the biomechanical behaviour of intervertebral discs. The used experimental set-up applied moments in the three main anatomical planes (frontal, sagittal, transversal) and evaluated motion with an optical 3D analysis system (Fig. 3).

Specific ligaments are considered within the simulation. The applied interaction forces are described by a Kelvin model and their parameters are found from preparations similar to the viscoelasticity of a vertebra.

### MODEL OF THE NECK MUSCLES

The head is moved by a complex set of muscles attached at the head and the bones of neck and shoulder. Herein, 23 muscles are considered where 9 muscles control the flexion and 14 muscles the extension of the head motion.

For this rotation about the z-axis, the absolute head angle  $\vartheta_z^{head}$  is observed for a given goal motion  $\hat{\vartheta}_z^{head}(t)$ . Therefore, the force of a singular muscle  $j$  is found by a cascade control unit and implemented in a special user routine.

The goal function of the control unit

$\hat{\vartheta}_z^{head}(t)$  can be taken from a motion analysis or other input techniques.

### EXPERIMENT AND SIMULATION OF HEAD IMPACT BY A BALL

Referring to this head-neck model, an impact of a soccer ball to the human head is simulated using the general MBS program SIMPACK and validated by an experiment with a test person. From these simulation results a Head Impact Power (HIP) Index developed for evaluation of injury risks when playing American Football is obtained and furthermore, the efficiency of head protections (e.g. commercial headgear) can be found from further simulations.

### THE EXPERIMENT

At first a test person was hit by a soccer ball. The person was prepared by markers for a motion analysis using the VICON Motion Capture System. The person could not see the flying ball and thus could not anticipate the impact.

The ball velocity was 4 m/s. As shown in Fig. 5, after impact of the ball, first the head moved backwards, followed by a muscle-activated return to initial position.

### THE SIMPACK SIMULATIONS

Since the test person tries to bring back the head to the straight initial position and orientation, the goal function for the neck muscles is chosen  $\hat{\vartheta}_z^{head}(t) = 0$ .

Together with the models defined above the MBS simulation leads to the time history of the head angle, which is in good accordance to the experimental results (Fig. 4).

The motion of the ball and the head for some time steps is shown in Fig. 5. With these results the validation to the MBS neck-head model is successfully performed.

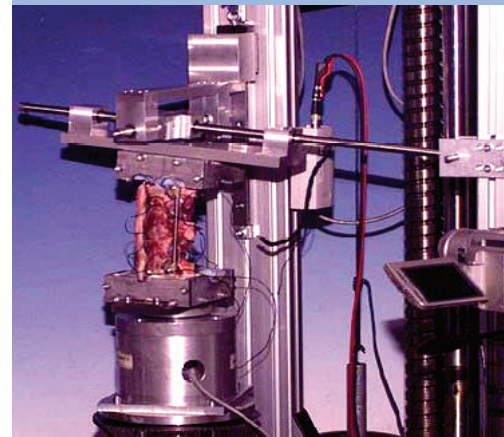


Fig. 3a: Experimental set-up for evaluation of the stiffness of intervertebral joints

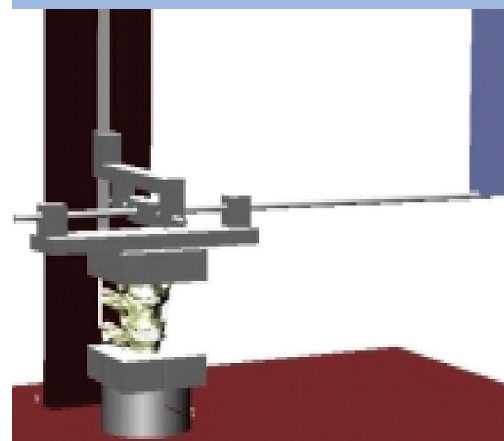


Fig. 3b: MBS of the experimental set-up to validate the developed force elements

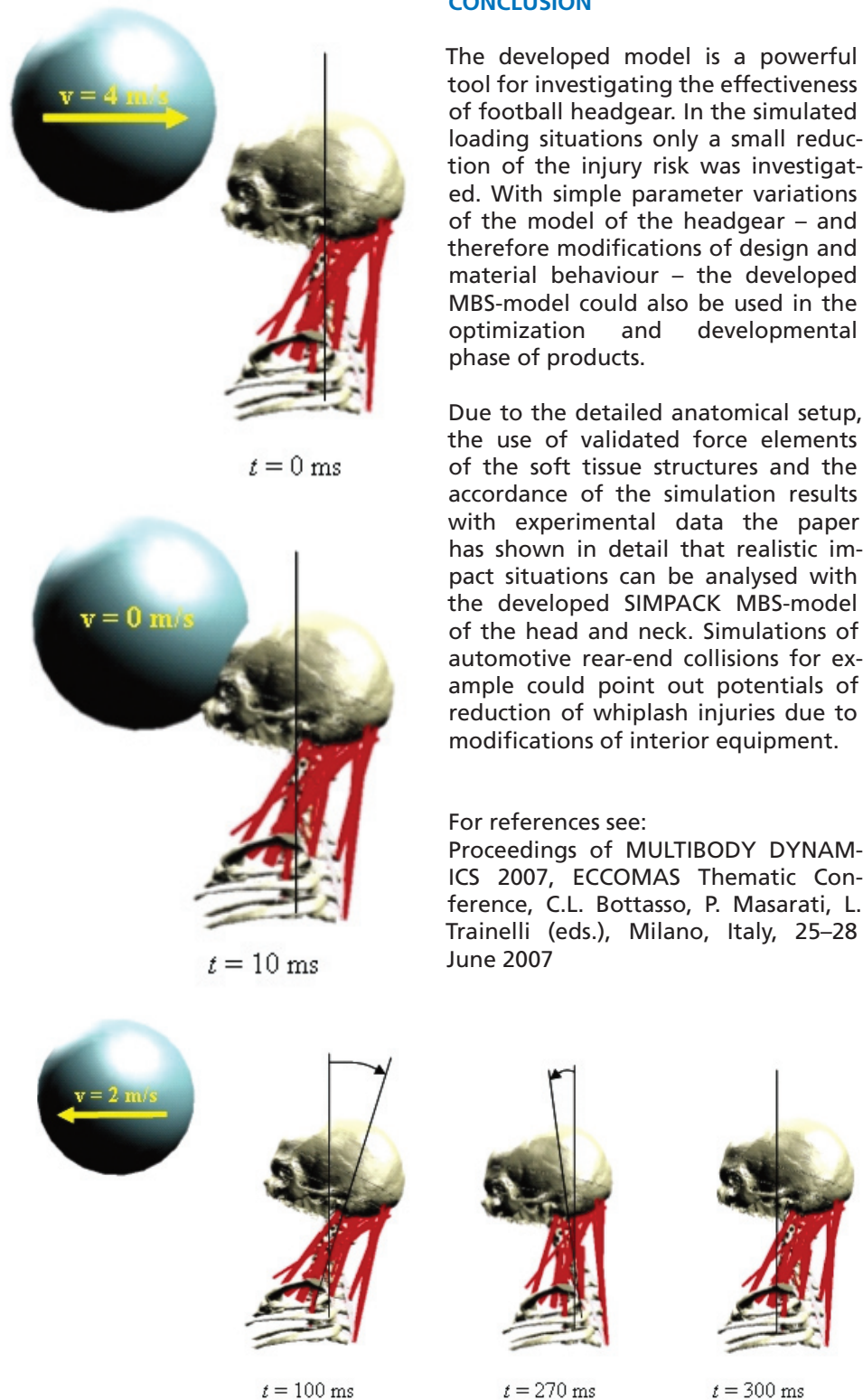


Fig. 5: Simulation of an uncontrolled heading situation: Start of simulation ( $t = 0$  ms), Ball impact ( $t = 10$  ms), max. extension ( $t = 100$  ms), max. flexion ( $t = 270$  ms), end of simulation ( $t = 300$  ms)

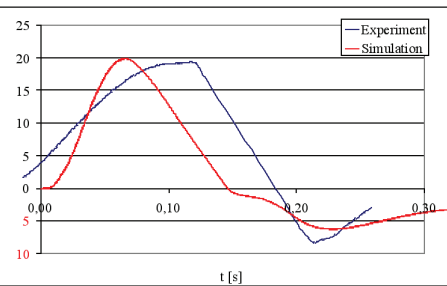


Fig. 4: Time history of the head angle for an impact by a ball at the test person (Full line shows the experiment, bright line the simulation)