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Innovation Intelligence®

CARMA

Prevention of a skiing injury situation with an innovative protective gear

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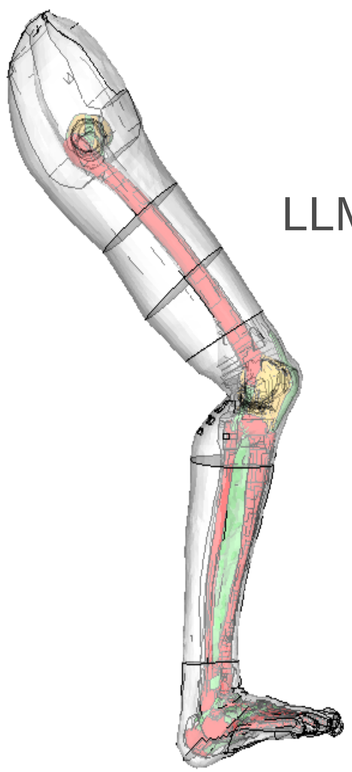
This study was done in collaboration with the Altair Engineering France by their R&D department known as Altair ProductDesign. For contact information: Marcelo FONSECA BARBOSA.

Model Presentation

Modeling Hypothesis

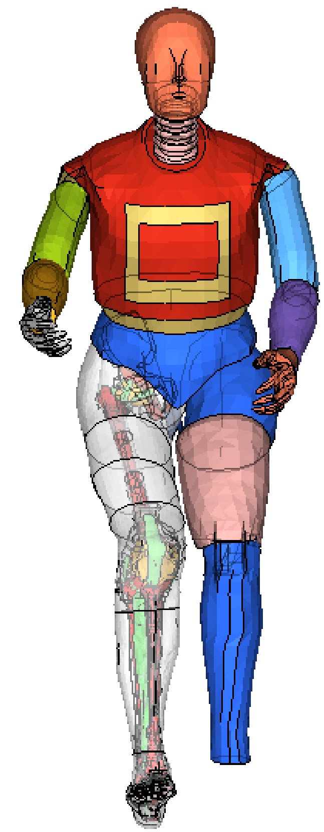
LLMS and Dummy Models

- **Right leg is modeled with LLMS model (Lower Limb Model for Safety). The LLMS model has been designed in order to set an injury model based on an accurate description of all anatomical parts of the lower limb. This model was built in collaboration with Anatomist Researcher of the Laboratory of Biomechanics Applied of Marseille (UMR INRETS-Univ. Med) the Wayne state University USA.**
- **LLMS model is interfaced with an anthropomorphic HYBRID III dummy in normal straight skiing position.**



LLMS Model

Dummy model



LLMS Model

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- **General presentation**

- model developed for RADIOSS V11h and mainly consists of :
  - deformable components
  - Articulated bones
  - Ligaments and tendons
  - Muscle (passive)
  - Skin (mainly around the knee)

- model includes :
  - Nodes : 24945
  - Elements : 25030
  - Properties : 161
  - Materials : 101
  - Interfaces : 138
  - Functions : 33
  - Rigid bodies : 16
  - Skews : 5

- model main limitation for KneeMax :
  - Muscle contraction
  - Bone / flesh interface

General specifications

The LLMS model is an advanced human model which reflects the up-to-date experimental knowledge on lower limb behavior under crash conditions. It is based on the leg of a 50th percentile volunteer human male. It includes the whole lower limb from hip to toes with emphasis on knee and foot & ankle articulations modeling.

The LLMS can be used alone, but it is also compatible with Hybrid III and HUMOS models in order to use it in a global context and still get a standard analysis and a high level of details in the lower limb area.

The model validation was done by using existing data for the main modes of solicitations. It includes:

- A full leg validation (for the interaction with the vehicle) using sled test type with gross kinematics, impact forces and similar other global measurements.
- A knee validation with detailed 3D kinematics of tibia, patella and femur in flexion, axial impact on patella, axial impact on tibia (involved in tibial plateau fractures) and antero-posterior motion of tibia (involved in ligament tears).
- A foot and ankle validation including all the solicitation modes involved in injury causation i.e. inversion / eversion, dorsiflexion and axial loading

Knee joint Model

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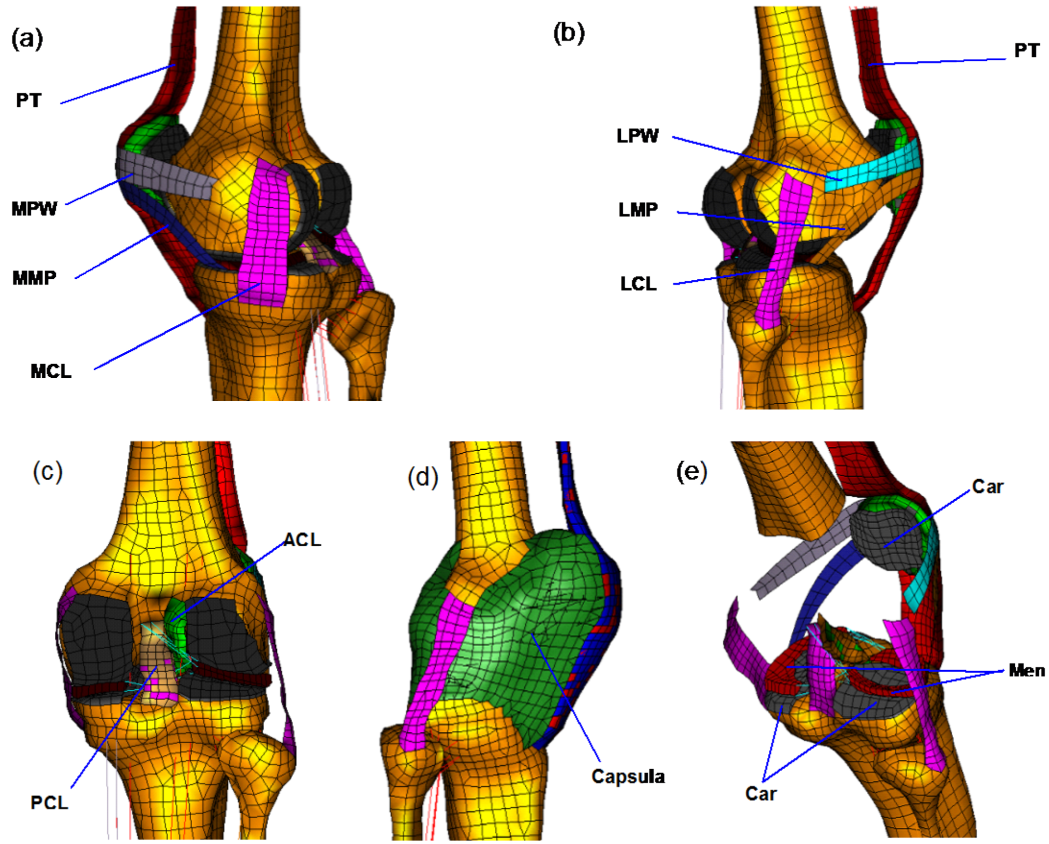
Knee soft tissues were modeled using brick, shell and spring elements depending on the dimension of corresponding tissues. Cruciate ligaments and patellar tendon were described using both solid and shell elements to model membranes around the structure.
Lateral ligaments and patellar wings were described using shell elements. Lastly, fibular-tibial ligaments and meniscus ligaments were described using spring elements.

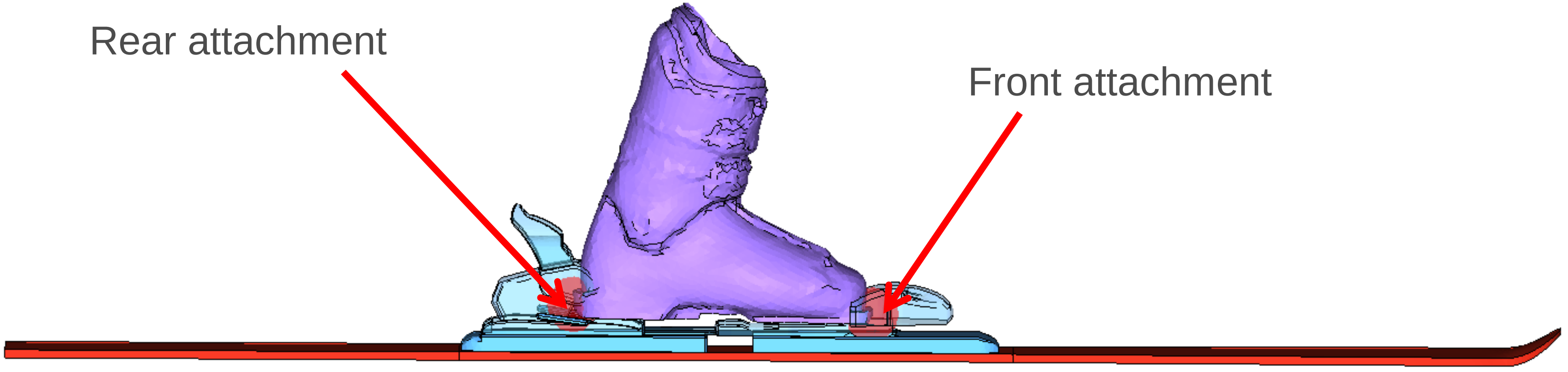
Ligaments and tendons of the knee were modeled with a generalized viscoelastic Kelvin Voigt material law (law 35) or using elastic or viscoelastic spring elements. The choice of sets of parameters was based on the work of Johnson, Noyes, Pioletti, Arnoux and Attarian.



Medial (a), tibial (b), posterior (c), with capsula (d) and opened view (e) of the knee model.

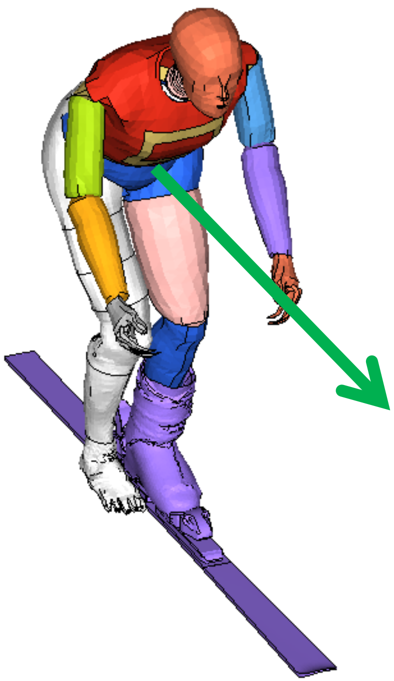
Ski and Ski Boots models

- **Ski boots meshing is based on a tomography 3d reconstruction.**
  - Density: $1200\ kg.m^{-3}$
  - Young Modulus: $1500MPa$
- **Skis are considered to be rigid.**
- **Ski-boot bindings are modeled with springs which do not allow translational or rotational movements.**

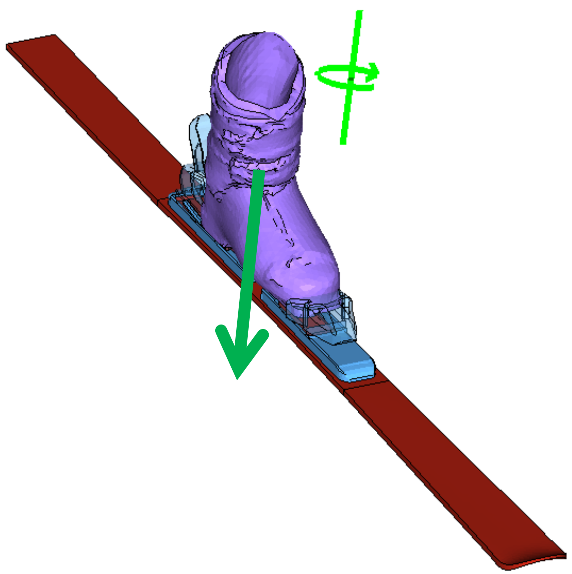


Scenario Modeling

- **Objective : model valgus and external rotation**

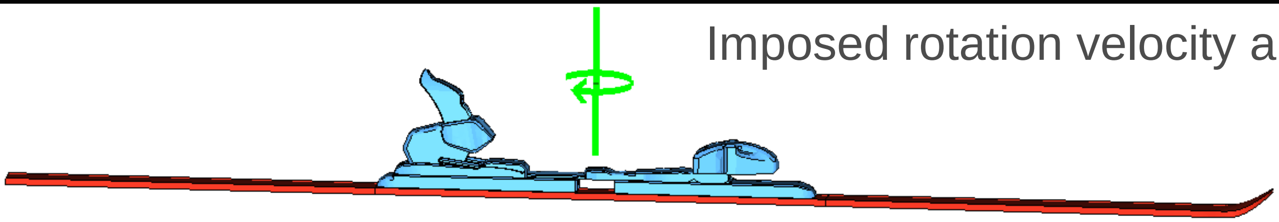


Initial velocity of $5 m.s^{-1}$ in 0°



Initial velocity of $7{,}07 m.s^{-1}$ in 45°
Initial rotation velocity around z axis of $0{,}01 rad.ms^{-1}$

Imposed rotation velocity around z axis of $0{,}01 rad.ms^{-1}$



Shell Modeling (1): Material properties

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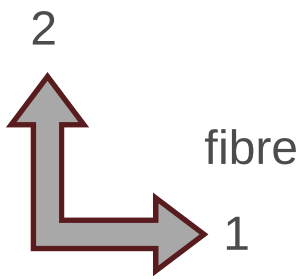
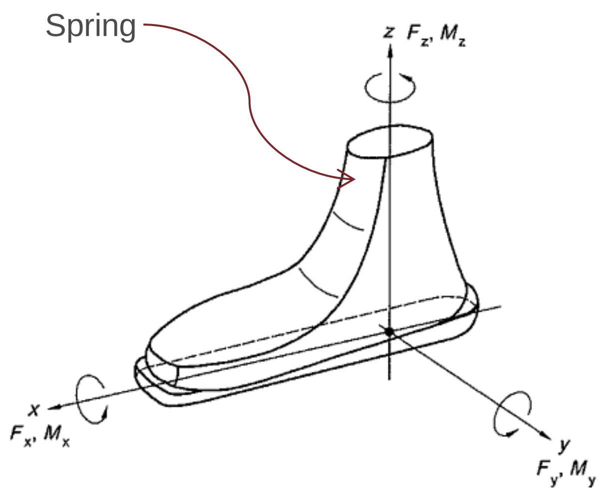
- **Orthotropic material :**
  - High modulus carbon fibre reinforced epoxy composite material
  - Density: 1560 kg/m^3
  - Young modulus:
    - 250GPa in fiber direction (1)
    - 25GPa in other directions (2&3)
  - Shear modulus:
    - 100GPa in directions 12 & 13
    - 10GPa in direction 23
  - Poisson coefficient: 0,25
- **Thickness: 5 mm**



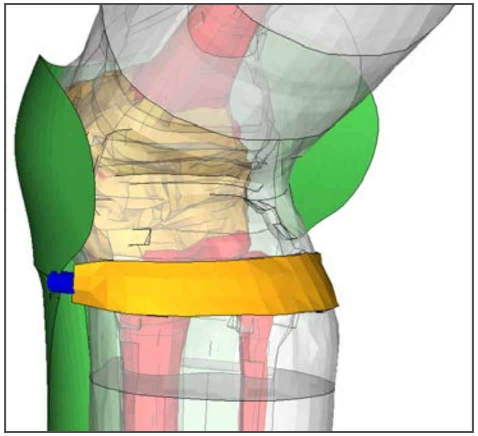
Shell Modeling (2): Anchorage to boot



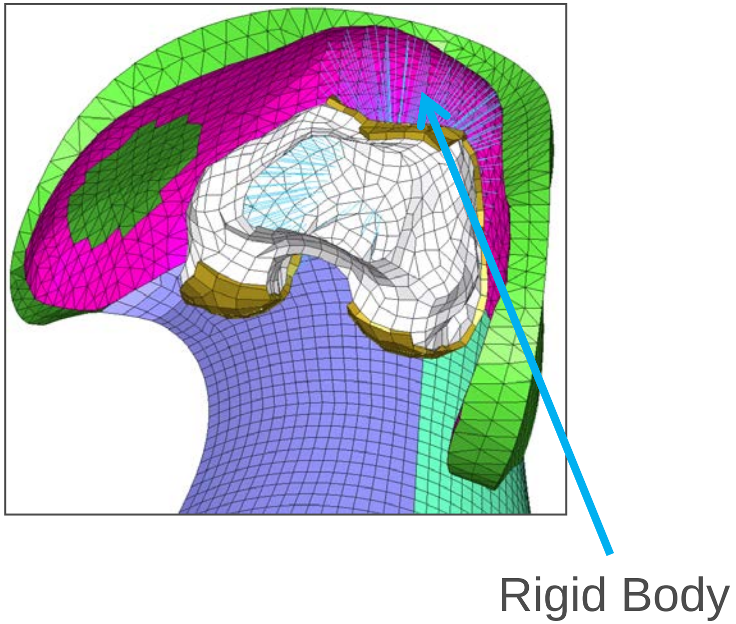
- **A spring is used to model anchorage between boot and shell**
- **Degree of freedom:**
  - Translation:
    - X: Fixed
    - Y: Possible elongation of $\pm 2mm$
    - Z: Possible elongation of $\pm 7{,}5mm$
  - Rotation:
    - X: Allowed until contact with boot
    - Y: Allowed until contact with boot
    - Z: Fixed

Shell Modeling (3): Anchorage to leg

- **The shell is attached to rear of the leg with a strap. This attachment is modeled with glue to prevent the strap from sliding along the Z axis.**

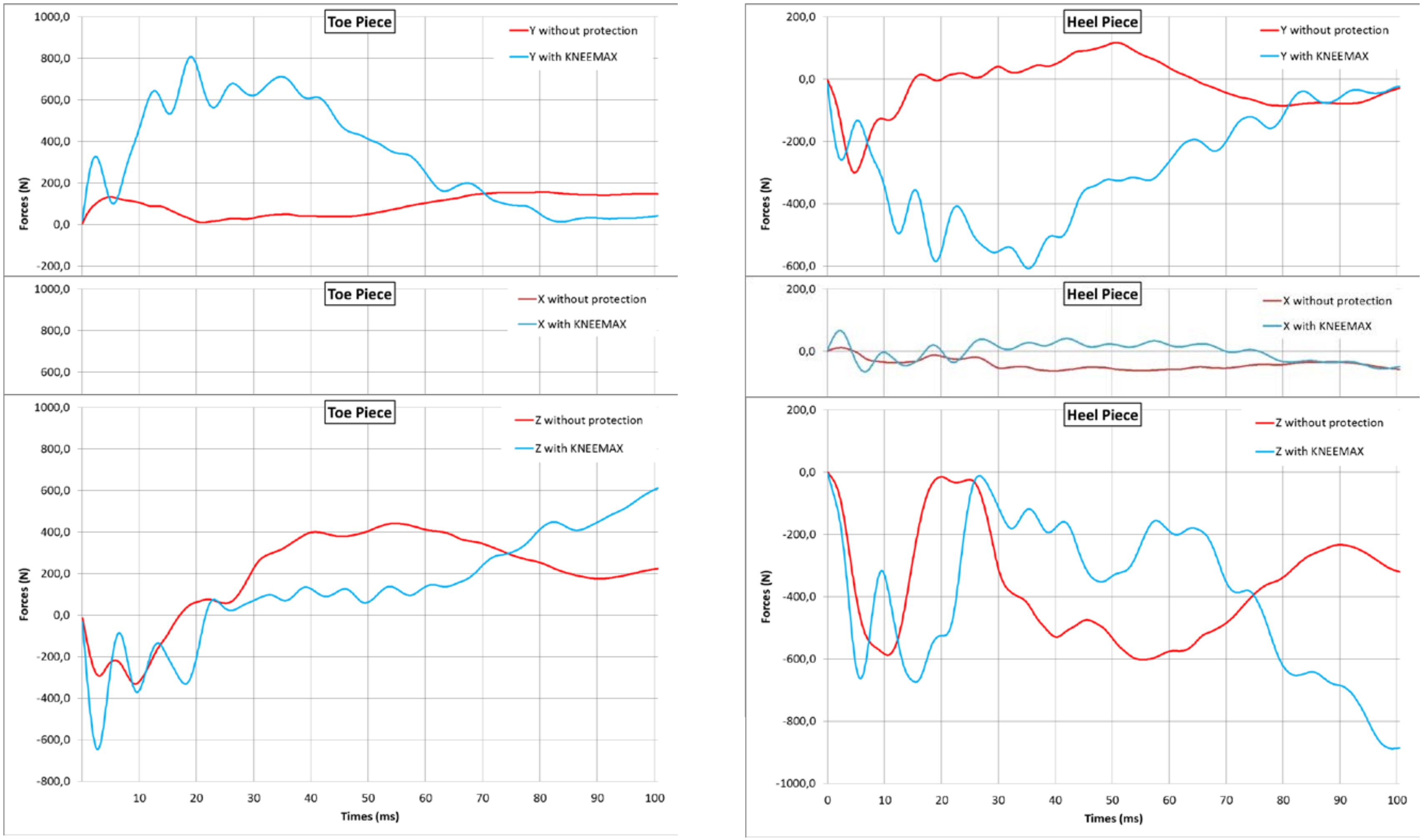


- **Due to imperfect bone / flesh interaction in the knee area of the model, the shell has been directly attached to the femur bone by a rigid body. This is idealistic but permits a better evaluation of the shell concept.**



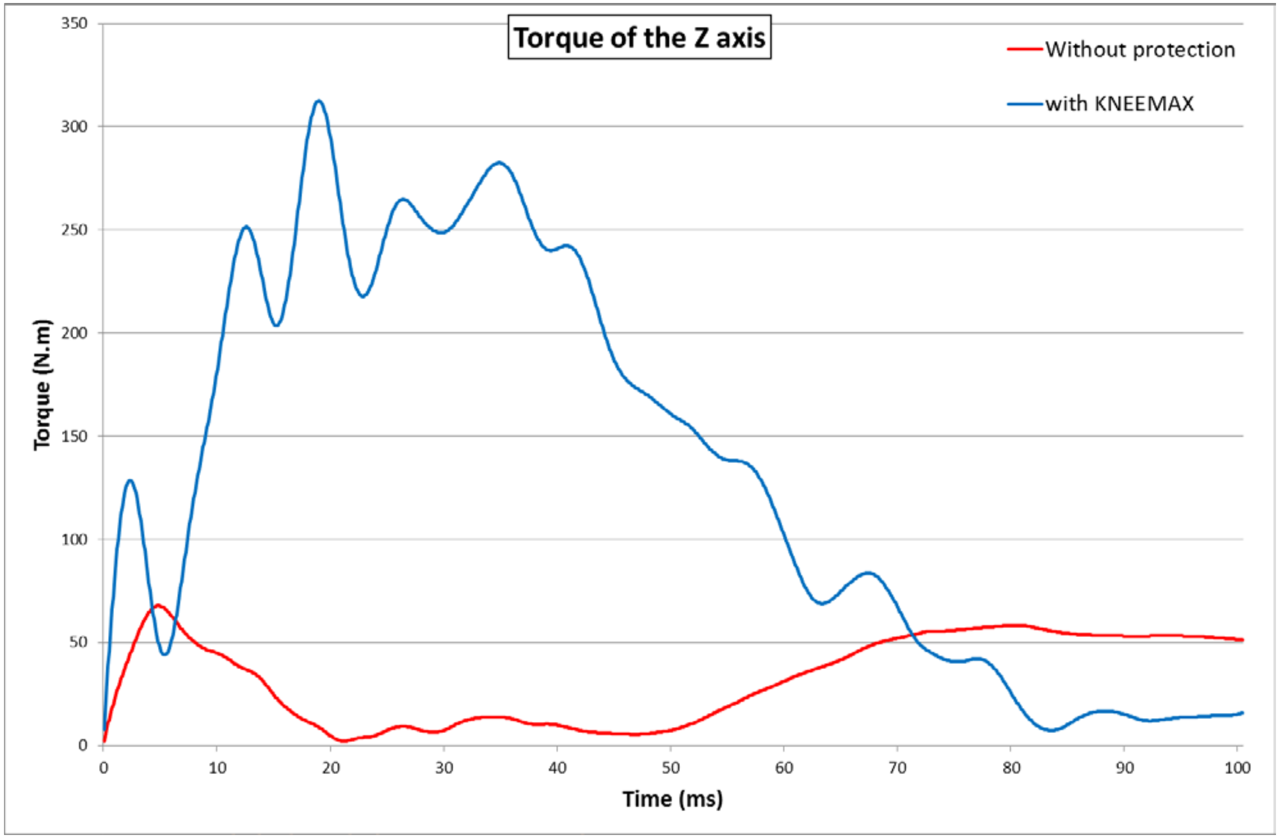
Force and Torque in ski bindings, comparisons with KNEEMAX® and without.

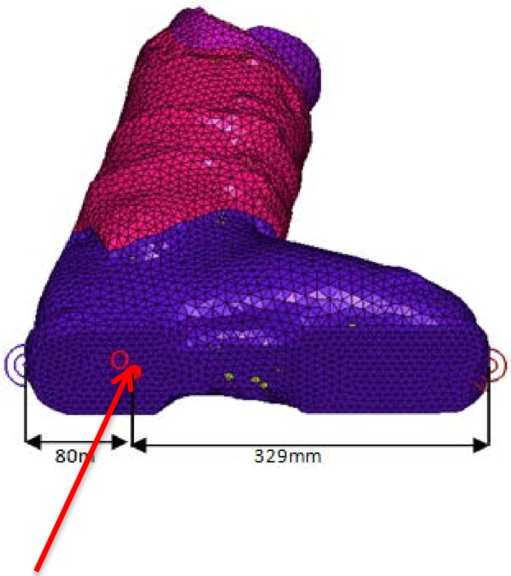
Ski bindings Force, axes Y, X, Z



KNEEMAX® improves the efficiency of the ski bindings by creating a stronger signal (according to Y axis) from the lower limb to the ski binding.

Torque

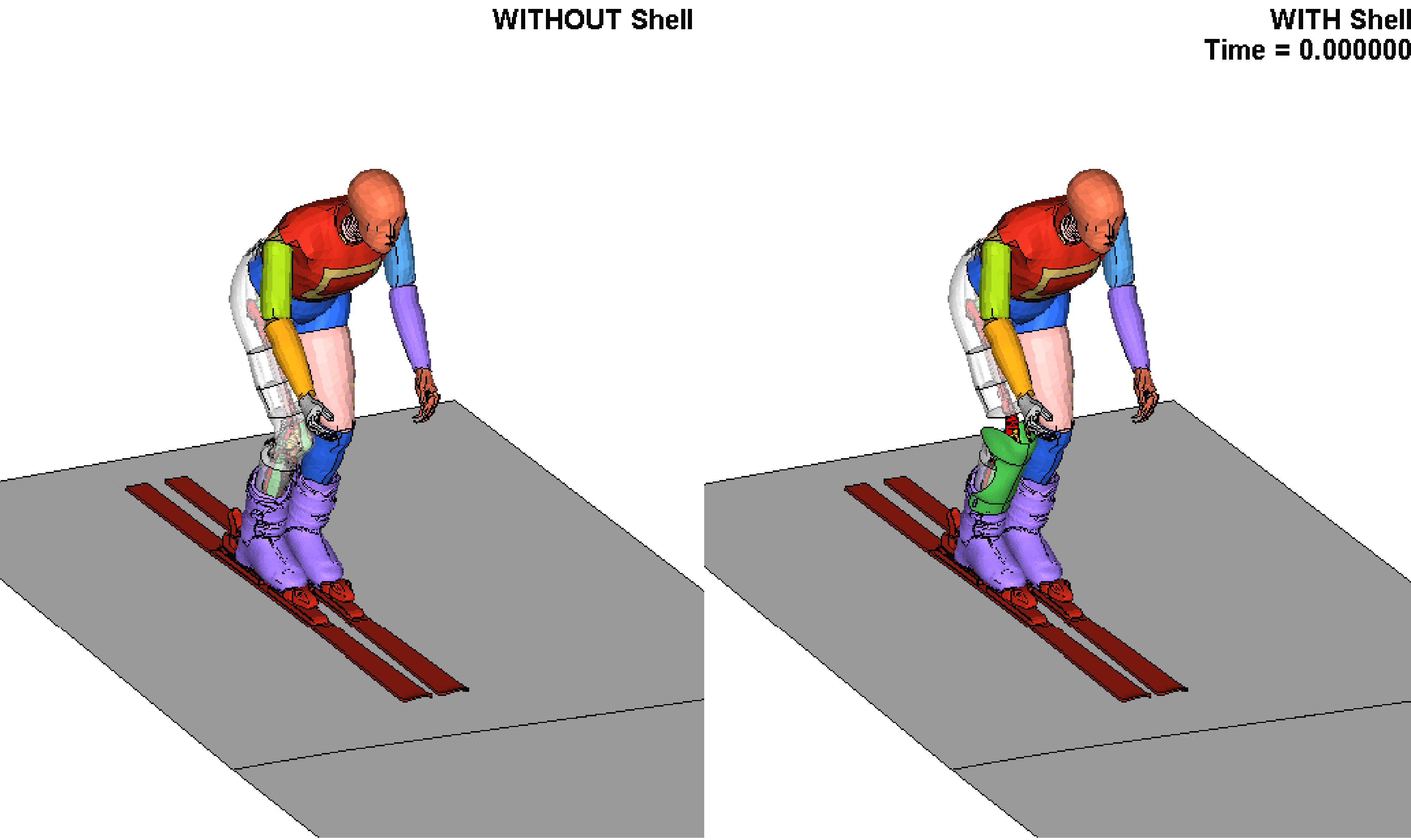




Torque center axis

- **Solid blue line KNEEMAX® shows a growth of the release's torque of the ski bindings during a non physiological movement.**

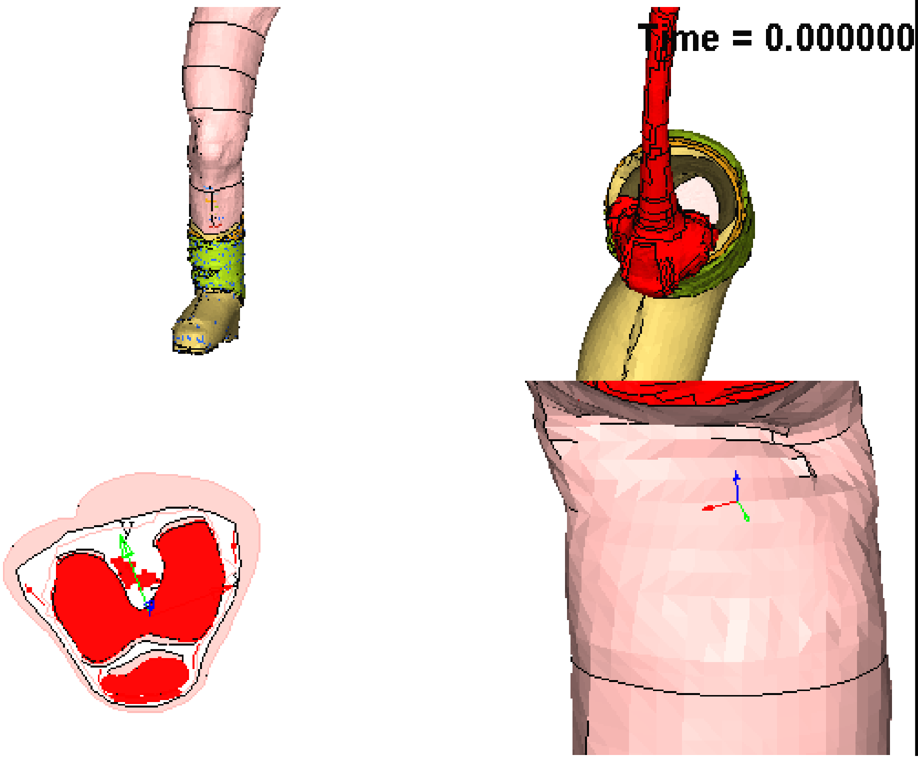
Kinematics (1)



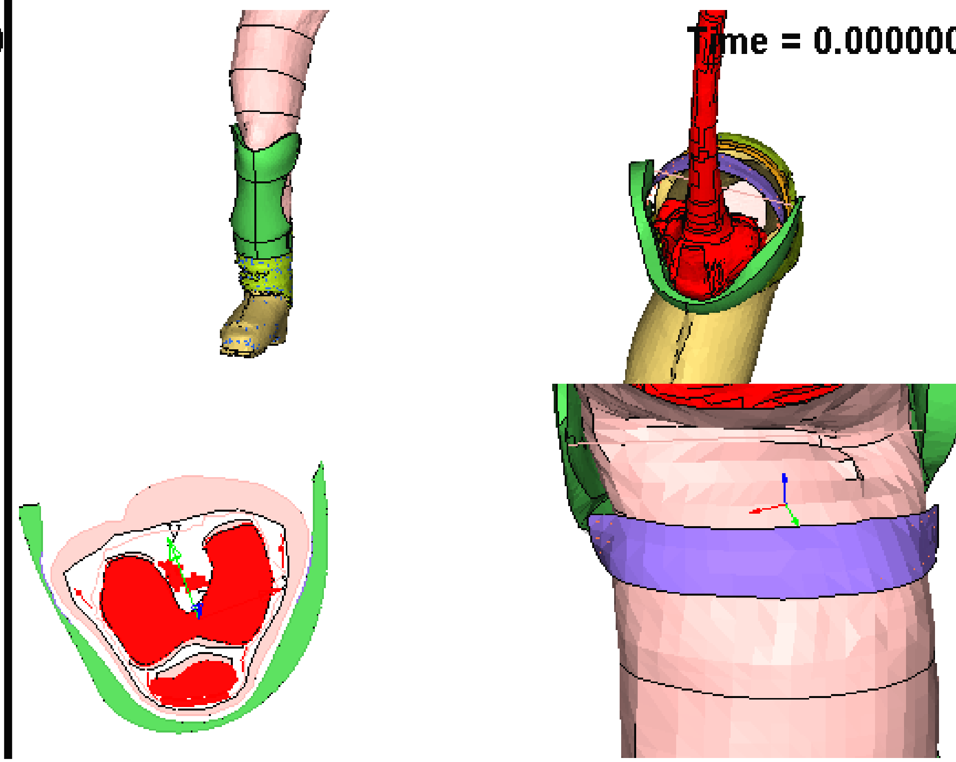
Animated gif

Kinematics (2)

WITHOUT Shell



WITH Shell



Observation of the KNEEMAX'S influence on the lower limb during an injury situation.

Animated gif

Kinematics results

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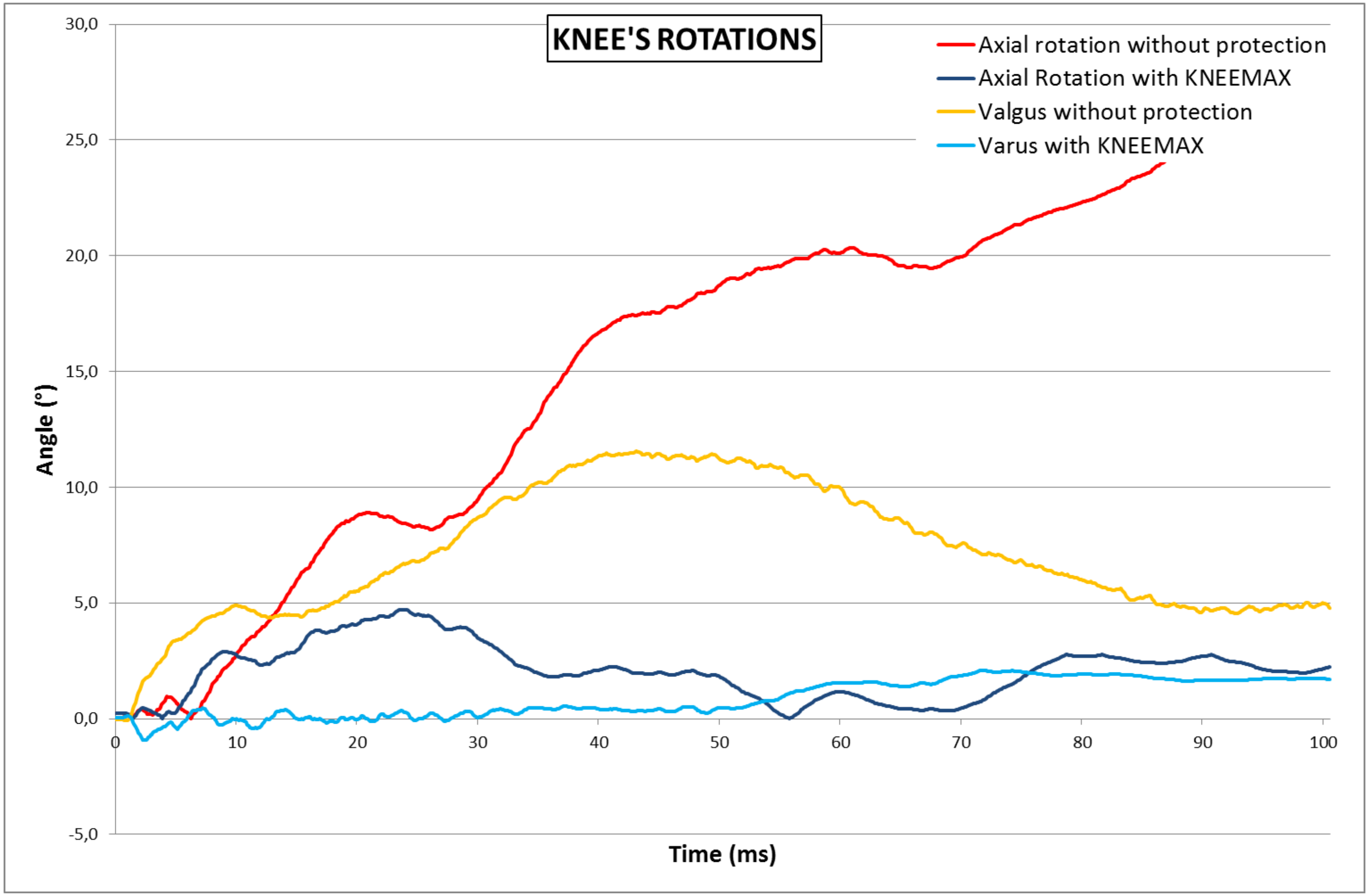
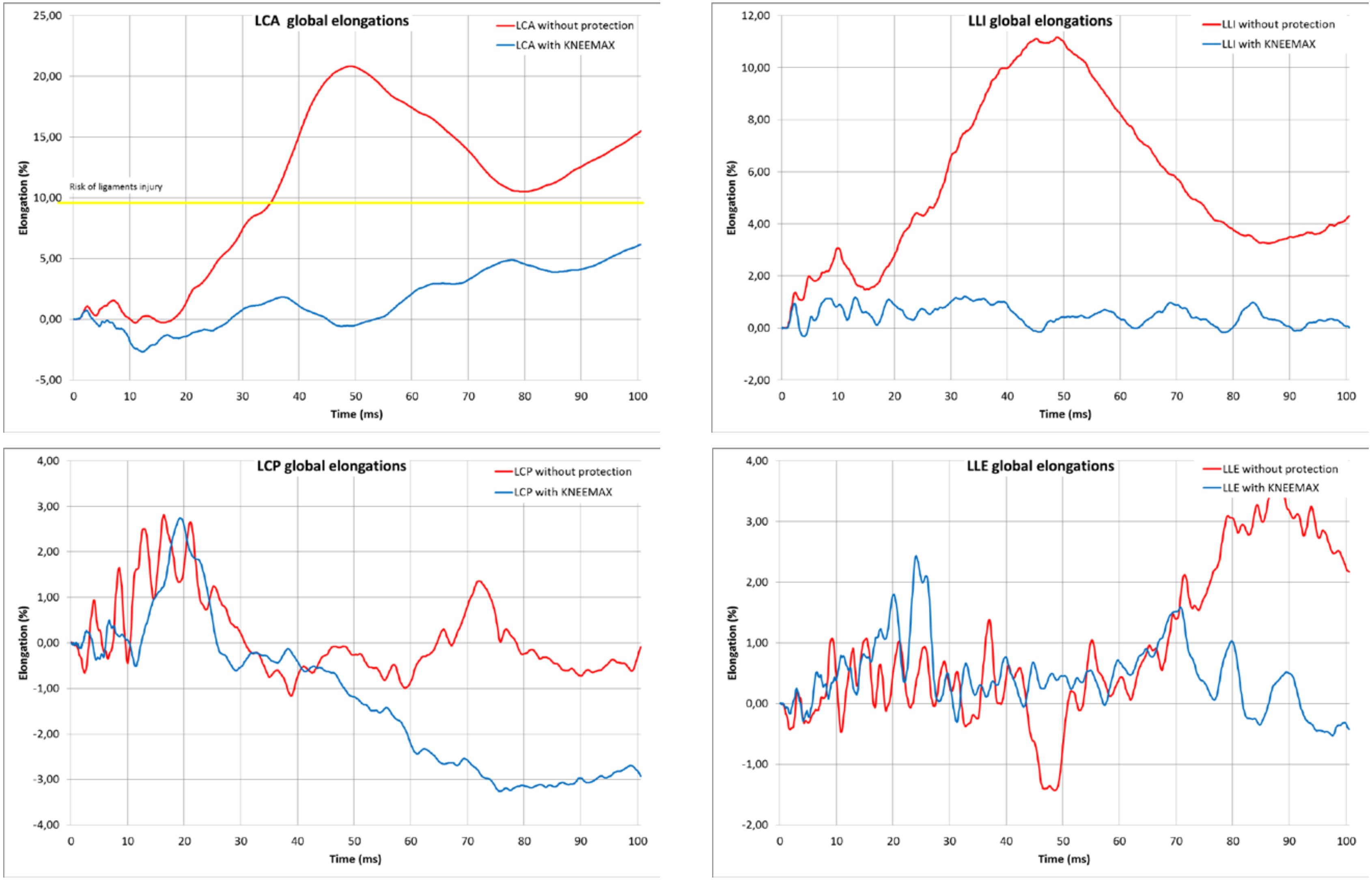


- **KNEEMAX® limits the tibia's rotation versus tight bone.**
- **No valgus is observed.**

Ligaments Elongations



- **KNEEMAX® limits ligaments elongations.**

Tibia Momentums (at t=40ms)

(N.m)	Max WITHOUT Shell	Max WITH Shell	Thresold Value
Torsional Momentum	6,9	4,1	70-100
Flexural Momentum	28	5,7	190-260

- **Tibia momentums are lowered thanks to KNEEMAX® Shell.**

Discussion and conclusion

- **The objective of the study is to simulate and evaluate valgus and external knee rotation in an injury situation with KNEEMAX®.**
- **Due to an imperfect bone / flesh interaction in the knee area of the LLMS model, the following assumption has been made: the shell is directly linked with the tight bone in order to bypass bone / flesh interaction.**
- **During a non physiological movement the shell distributes the effort along the lower limb instead of being concentrated mainly on the ligaments, and adds a new link between the tight bone and the ski bindings.**
- **Ligament elongation is lowered.**
- **Bones should not suffer lesions.**
- **Ski bindings are released before a ligament injury can occur.**

Further work

- **Further experimental studies using cadaver knee specimens are necessary to validate the degree of knee protection.**