Short Summary: Countermeasure exercises and bone stress

ESA/ESTEC project 21385/08/NL/PA

A detailed report is available here: www.anybodytech.com

1 Aim of the study

The AnyBody Modeling System is a software system for the simulation of human movement. It can model smaller or larger subsets of the musculoskeletal system (or the entire body) and compute muscle forces, joint reactions, metabolism, mechanical work, efficiency, etc. for given movements.
The aim of this project was to develop and apply (software) models suitable for research in the areas of neuromuscular activity and to assess the capability of the AnyBody Modeling System to enhance bone loss research and countermeasure development.

In detail, this project includes the following tasks:

- Development of a new, more sophisticated lower extremity model
- Validation of the new leg model with respect to individual muscle moment arms and maximal isometric joint moments
- Application of the new leg in a validated gait application. Analysis of the resulting (hip) joint reaction forces and muscle activation patterns
- Development of a treadmill gait application with harness in microgravity
- Analysis of the forces and moments acting on the tibia at one time step during the stance phase in both gait applications (normal walking, 1g, treadmill harness, 0g)
- Development of a computational finite element model of the tibia to evaluate the resulting stresses and strains in both applications.
- Evaluation of the stresses and strains in normal walking and treadmill gait in microgravity.
- Development of a test application to show the feasibility to model countermeasure exercises. A rowing machine is used as test object.

2 Results

Development and validation of a new leg model

A new leg model with 159 individual muscles was developed which allows a very detailed analysis of the muscle activations. The new leg model was validated on different scales. The individual muscles were validated with respect to their moment arms with respect to a certain joint motion of the leg. The maximal isometric strength was analyzed for each individual joint motion. The results showed a good agreement with studies reported in literature.
Additionally, a body model involving the new leg was developed in order to validate the overall performance. The body was applied to a validated gait dataset. This means the motion as well as the ground reaction forces were taken from experimental data and imposed on the model. The resulting quantities joint reaction forces, maximum muscle activity and single muscle activation patterns were analyzed and compared to relevant data from literature. The results suggest that the model behaves realistic in both a qualitative and quantitative manner.

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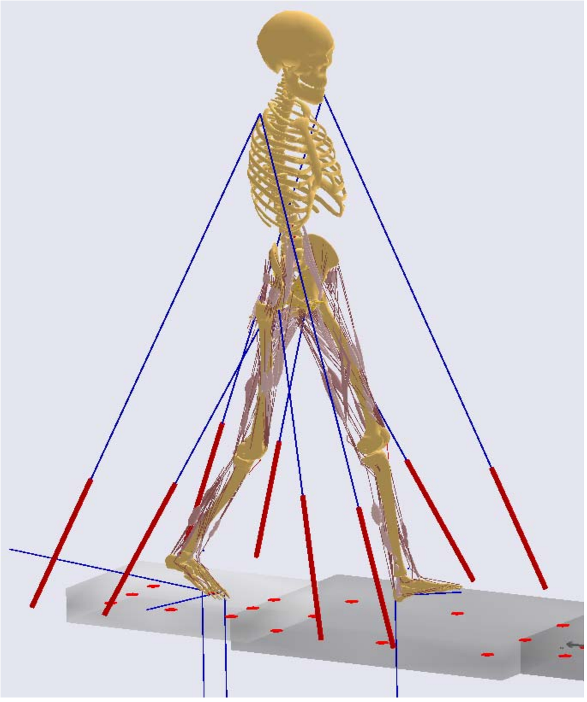

Fig. 1: Gait analysis with harness in microgravity.

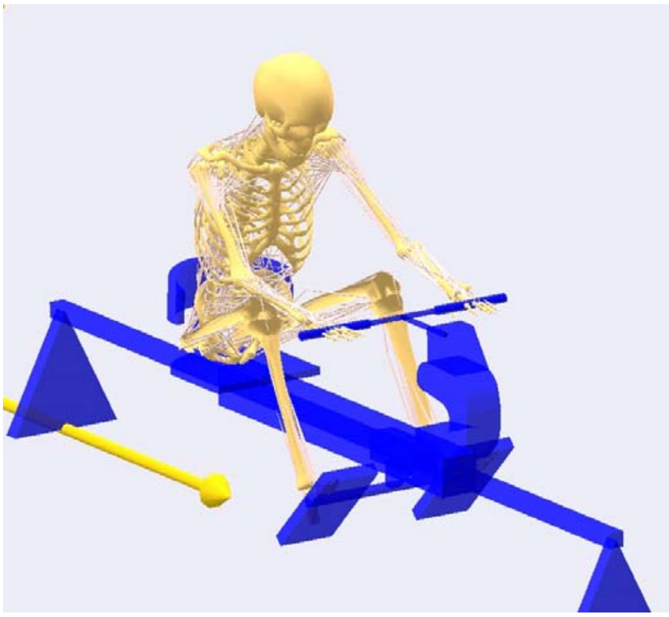

Fig. 2: Simulation of countermeasure exercise – rowing machine.

Evaluation of gait with harness in microgravity

In order to prove the feasibility to analyze countermeasure exercises with the AnyBody Modeling System two gait applications simulating walking (on a treadmill) in microgravity were developed. Both models included a combined shoulder and waist harness (Fig. 1) and differed with respect to the level of pretension in the harness springs. In one scenario, the resultant gravity replacement load was set to 80% of bodyweight, in a second case it was set to 100% bodyweight of the test subject. In these models the same motion was prescribed as in the normal walking of the validation study. Therefore, the cases are directly comparable. The body was constrained by the harness and all necessary forces were computed. Joint reaction forces and muscle activation patterns revealed altered conditions, compared to normal walking.

Development of a finite element model and evaluation of bone tissue stresses and strains

The Anybody Modeling System provides all forces acting on the bone segments of the body like muscle forces and joint reactions. In order to evaluate the influence of these forces on the bone tissue stresses a subsequent Finite Element study is applied. Therefore, all forces acting on the tibia were analyzed at a predetermined time step during the gait cycle for normal walking and the two different configurations of walking in microgravity (harness pretension = 80% bodyweight and 100% bodyweight). These forces were transferred to a Finite Element model in order to evaluate the resulting bone tissue stresses and strains. The model does include the actual geometry of the tibia bone of the AnyBody simulation but was only comprised of a basic description of the material law in this preliminary study.
Stresses were found to differ between the models. The results suggest that even with a harness pretension up to 100% bodyweight significant differences in the bone tissue strains

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can be acting (Fig. 3). These differences may hint to a reduced efficiency of this particular load case to prevent bone loss during spaceflight.

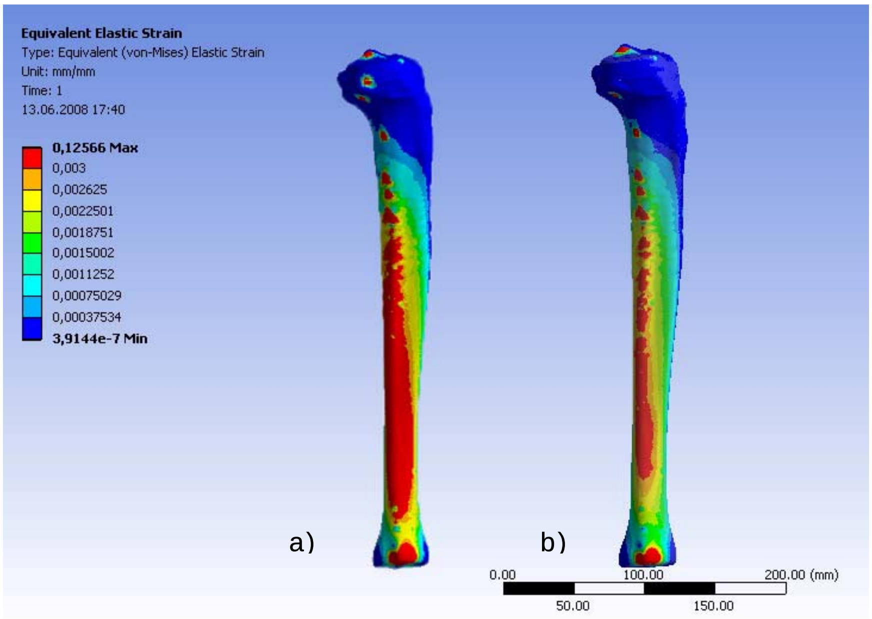

Fig. 3: Bone tissue strains in the tibia during preswing in a) normal walking, b) walking in microgravity with a harness pretension of 100% bodyweight.

Development of a test application – rowing machine

Additionally, a prototype application has been developed which simulated a novel counter exercise machine, the ESE rowing machine, developed for ESTEC by ESE GmbH (Fig. 2). The aim of the rig is to train astronauts during space flights. This first simulation model is capable of evaluating the muscle activities during the exercise and therefore estimating the degree of efficiency of the training based on different configurations of the setup. So it may be used in future to find the best set of forces for optimal training or to optimize the geometry and/or kinematics of the machine. Furthermore, the investigation and development of other countermeasure rigs is a possible field of application.

3 Summary

The developed models illustrate the potential of the AnyBody Modeling System to enhance the research in countermeasure exercises and equipment design. Further improvements may result in essential data on the loading condition and efficiency of countermeasure exercises in microgravity. As a next step, the inclusion of experimental data in terms of motions and forces is important in order to provide more realistic boundary conditions for the simulation. The derived models may be used to investigate and/or develop countermeasure exercises and machines. A more refined Finite Element model of the tibia would give the possibility to evaluate the bone tissue stresses in more detail and may allow a direct correlation to bone density measurements, therefore providing essential data on the acting remodelling processes in microgravity.