# Muscle mechanics and modelling

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## INTRODUCTION

*Our primary interest within the Bioengineering area lies in the skeleto-muscular mechanics. Our current work deals with muscles primarily on the organ and system level, where we are studying how muscular properties affect (human) movement and load carrying capacities. At present, our applications are dealing with human gait, but also with some investigations of the clinical outcomes of certain types of surgery, e.g., tendon transfer for patients with paralysis. In gait analysis, our efforts are directed towards spasticity and the relaxation of it through medication. We also study muscular effects on eye accommodation.*

In parallel to the studies of muscular effects on human body and body parts, we are involved in some work on proper and improved models for numerical simulations of muscular behaviour. The basis is a cooperation with KI on experiments, with a special emphasis on tests which can be used for development and verification of general numerical modelling. This demands tests set up in a different way than the common, purely physiologically oriented, experiments. The key question in our context is the produced muscular force under arbitrary variations of activation and fibre length.

The latter area also points to another interesting area, namely the cooperation between the normally redundant muscles in the human system. For almost all kinds of movements, there are alternative muscular activation patterns, producing the same results. Simulations of how desired movements can be produced, from the action of redundant forces, needs considerably improved models, allowing the optimization of dynamic motions.

## Muscle modelling

The action of the muscles is very complex, but is physiologically rather well-known. The key concepts are an activation of the muscle, governed by the neural system, but also a strong dependence of the created force in the muscle on the current muscle length and its time differential. Although the neural activation, the chemical supplies to the muscle, the fatigue from extensive usage, and the complex description of anatomical geometry, make accurate simulation of musculoskeletal systems difficult, important qualitative information can be obtained with simpler models, yielding the optimal distribution of forces in a redundant system, and optimal dynamic movements. When referring to a biological system the used optimality criteria can, however, be questioned, as adaptation and learning can affect the actions for common and for extreme situations.

As commonly used 'Hill-type' muscular models are known to have their main shortcomings for such cases, we are particularly interested in the response from the muscles when activated in eccentric situations, i.e., situations of externally induced lengthening of the muscles during activation. These situations are typical for all kinds of impact-like loadings: extreme cases are the take-off for world-class high jump athletes and in car crashes.

## To be prepared, or not to be...

The modelling of muscles is of very high importance for many classes of movements. We are particularly interested in extreme situations, which are often impact-like, and subject the muscles to eccentric contractions, i.e., a lengthening while they are trying to contract.

*Philipp Hunger* has, in a student project, studied the effects of preparedness in a simplified car crash. He used very simplified assumptions on loading and damage criteria. One conclusion, for a specific case, was that similar damages occur at $\approx 25$km/h if neck muscles are un-prepared for their restring action, as with $> 40$km/h, if the muscles are pre-activated.

Understanding the force production in the muscles in such situations —and reliably simulating them— is a goal for our work.

## Experiments on muscles

The objective of an ongoing project is to develop a numerical model for muscle behavior, in particularly eccentric contractions and in relation to pre-activation of the muscles. The aim of this model is in the simulation of externally induced, impact-like, skeleton-muscular movements. A set of experiments were performed on mouse soleus and extensor digitorum longus ('EDL') muscles. The experiments defined both length and activation patterns, and recorded the resulting forces in the muscles.

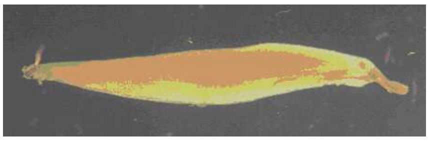

Fig. 1. Mouse EDL muscle tested. Length $\approx 10$ mm, max.force $\approx 0.2$ N.

To avoid effects from tendon elasticity, small stainless steel loops were tied, using thin nylon thread, to the tendons very close to the isolated muscle. The muscle was then mounted between force transducer, Dual-Mode Muscle Lever System. The specimens were mounted in a chamber containing a physiological solution, and stimulated electrically through the electrodes. The muscles were stimulated with a constant voltage stimulus, but activation was introduced through variable frequency.

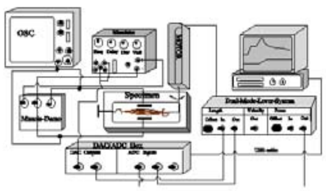


Fig. 2. Experimental setup.

Several combinations of pre-activation times and stretch/shortening velocities were tested. Force enhancement/reduction due to the length change velocity were measured and evaluated during and after length change. In the figure, the pre-activation was 0.3 s. and the stretch velocities were 2.5 – 5.1 mm/s. During the first 0.3 seconds of activation, the muscle develops a force isometrically. The muscle is then forced to stretch, with a constant stretch velocity, and is then held isometrically again.

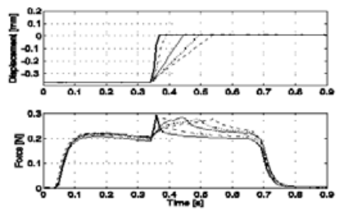


Fig. 3. Typical results from pre-activated eccentrically contracting EDL muscle.

An ongoing further investigation, with essentially the same experimental setup, will focus on the increase or decrease in produced muscular force, due to non-isometric conditions. These data will be important in the model development.

## Eye accommodation mechanics

Accommodation, i.e. the ability of the eye to focus on objects at varying distances from itself, is a keystone to our vision. A more complete understanding of this mechanism becomes increasingly important as new types of lens implants and surgical procedures for the correction of accommodative loss are being explored. Present study aims to contribute to the fundamental knowledge about accommodative process of a human eye by investigating and progressively developing a numerical model, which simulates its optical and mechanical behavior.

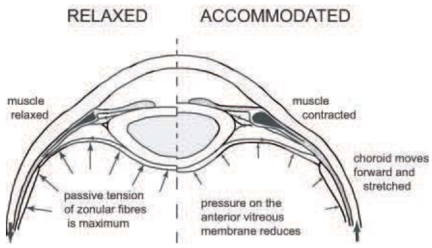


Fig. 4. Biomechanics of human eye accommodation. Modern conception.

The clinical and experimental knowledge was used as a platform for establishing relevant modelling procedures, which were based on finite element (FE) representation.

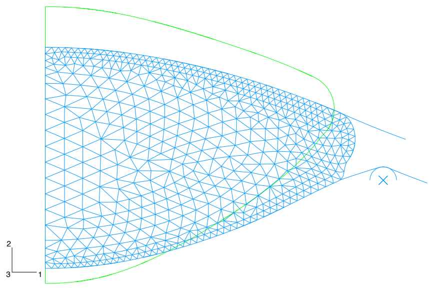

Fig. 5. Deformed lens meshes together with reference surfaces. No vitreous support is shown.

Non-linear axi-symmetric analyses were performed and additional forces supplied by vitreous support were taken into account. The inverse methodology was developed to estimate unknown quantities. By appropriate adjustments of parameters, different model configurations could be achieved.

The results of the research is broadly in agreement with published observations. The model behavior is consistent with classical theory. It was shown that the modelling captures at least some physiological aspects of accommodation. The obtained results can be used to draw some recommendations in pursuit of the clinical imperatives of ophthalmologists.

## Acknowledgments

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