Bone ingrowth is an effective fixation technique for orthopaedic implants. Successful ingrowth has the advantage that it is maintaining itself, as bone renews its structure via remodelling, avoiding this way damage accumulation. However, lack of mechanical stability can inhibit the ossification process, which leads to fixation failure.

The goal of this thesis is to investigate the effect of macro- and microscopic features of an orthopaedic implant on bone ingrowth and provide a better understanding of the ingrowth process itself.

The two factors that can influence the bone ingrowth process are biological and mechanical environments. However, in this study we consider the ingrowth process as mechanically regulated. Although some biological processes were considered, they were assumed to be controlled by mechanical stimuli.

The main instrument, used in the thesis for reaching the goal, is numerical modelling. Using numerical simulations, we were able to assess the mechanical environment within the ossifying tissues from which we could judge on feasibility of bone ingrowth. Using computational tissue differentiation models, we were able to simulate the bone ingrowth process.

First, using a two-dimensional finite element model of glenoid bone with a component, we study the effect of the component's material and geometric properties on the ingrowth process. Interface bonding and tissue differentiation inside porous component backing are simulated. The bonding is regulated by the magnitude of the relative interface micromotions. The tissue differentiation is simulated using a fracture healing model known from literature. The study shows positive effects of stiff glenoid components and components that provide a uniform distribution of the interface micromotions. It was also concluded that a high friction coefficient is of secondary importance for glenoid components with primary fixation.

In the next study a finite element formulation for simulation of hydrated poroelastic tissues is presented. The goal of this work is development of an effective numerical tool for large-scale nonlinear biomechanical problems. The formulation is implemented as a user element in a commercial FEM package (MSC Marc). This allows easy enhancement of the element with material models already available and usage of such powerful features as parallel computations. The formulation is tested against results obtained with a commercial finite element code, but also results published in literature.

Another study presents a numerical model for tissue differentiation during fracture healing. The model is presented as a system of partial differential equations and allows modelling of such phenomena as cell migration, proliferation, differentiation and replacement, but also production...
and resorption of tissues. The results of the model are compared with results of published animal studies.

Two other studies investigate the influence of micro-features, like implant surface geometry characteristics and interface tissue thickness, on the bone ingrowth process. In both studies, a detailed geometry of a small piece of the interface tissue that penetrates the porous surface of the implant is created. The first study investigates the mechanical environment inside the interface tissue, created by three types of implant surface, namely porous tantalum, sintered spheres coating and a smooth implant surface. Using the geometries obtained in the first study, the second study analyzes the influence of the implant surface characteristics by means of simulating tissue differentiation at the bone-implant interface. The main assumption of the second study is that bone ingrowth processes can be modelled the same way as bone fracture healing. The earlier developed model for bone fracture healing is used to simulate tissue differentiation at the bone-implant interface. In both studies it was concluded that a porous surface favors faster bone ingrowth as compared to a smooth surface. The studies show that a thick interface layer is not less likely to ossify as compared to a thin one. In the second study it is proposed to replace such known parameter as inhibiting micromotions threshold with stress or strain based value. This is explained by the fact that inhibiting micromotions level strongly depends on the interface tissue thickness. The level of inhibiting interface stress or strain is, on the contrary, almost insensitive to the interface thickness variations. It was also demonstrated that under force controlled boundary conditions, the tissue differentiation process is not as sensitive to the variations of the interface thickness as under the displacement controlled boundary conditions. The second study shows that relative performance of an implant surface can vary depending on the interface thickness. This suggests that every surface texture has its optimal interface thickness and, probably, this optimal thickness correlates with shape and size of the surface features. Comparison between the two studies shows that performance of the particular implant surface can be much better evaluated with the full ingrowth simulation, as compared to the estimation of the biophysical stimuli at the interface tissue.