Popular science summary

The world's population is aging. In elderly, the bone density gradually decreases, and this process is accelerated in women after menopause. Low bone density increases the risk of hip fractures, which means that every year more and more people fracture their hip. To reduce the number of fractures, it is important that people at high risk are identified before the first fracture. Currently, risk is determined by measuring bone density using a 2D radiographic image. The work in this thesis is based on the hypothesis that a better way to assess risk would be to use 3D computer models that calculate the strength of the hip. One of the aims in this thesis is to develop computer models and accurately validate them against experimental mechanical tests that replicate a fall to the side.

When a patient is determined to be at high risk of fracture, they are prescribed pharmacological drugs to reduce further bone loss. These drugs are effective but have a limited ability to promote new bone formation. Orthopaedic surgeons use bone cements to, for example, stabilize implants or reinforce collapsed vertebrae. In the hip, it is thought that bone cements can be used to prevent fractures. Calcium sulphate/hydroxyapatite (CaS/HA) is a bone cement that is similar to bone itself. This cement has already been used for various orthopaedic purposes, which showed that the body is able to degrade and turn the cement into new bone. However, the mechanical properties need to be further characterised in detail. Patients that suffered a hip fracture due to low bone density often receive a total hip replacement. Another option is to fix the fracture with a dynamic hip screw, which is used to connect and stabilize the fractured pieces. These screws loosen easily in patients with low bone density but can be stabilized using bone cement. One of the aims in this thesis is to investigate how hip fractures can be prevented and better repaired with the use of CaS/HA.

The thesis starts with an investigation of the mechanical behaviour of the hip. Bones from human donors were loaded until they fractured in a way replicating a fall to the side. To get accurate measurements of the deformation of the bone, high-speed cameras were used to image the bone. Following the experiments, 3D computer models were created of these bones. Models were either created from clinical CT scans or from micro-CT scans with higher resolution. The

models built from clinical CT scans were able to accurately predict the force at which the bones would fracture and where they would fracture. The deformation was predicted with high accuracy, although the accuracy declined in regions where the surface of the bones was more irregular. With the micro-CT based models, it was possible to model the surface with greater accuracy and include irregularities on the surface. These models showed how the local deformations and resulting cracks are influenced by the irregularities on the surface of the bone.

The thesis continues with an investigation of fracture prevention and repair methods with use of CaS/HA. The ability of CaS/HA to strengthen the neck of the thighbone was shown using 3D computer models. The amount that the bone was strengthened highly depended on the region where bone cement was injected. Additionally, mechanical tests were performed to investigate if an injection of CaS/HA at the tip of a dynamic hip screw could increase stability of the screw. This was tested by inserting screws with and without CaS/HA into synthetic and human bone. By testing the force required to pull the screws out of the bones it was found that the CaS/HA helped stabilize the screw in the synthetic bone. In the human bones the CaS/HA was not able to spread around the screws properly and did not increase the stability of the screw.

To improve our knowledge about the mechanical properties of CaS/HA and bone, a study was conducted using 3D imaging at synchrotron facilities. In this thesis, 3D images of trabecular bone cores and CaS/HA specimens (millimetres) were acquired at high speed (seconds) and high resolution (micrometres), while loading the specimens. The images were used to show how damage initiates and progresses differently in bone and CaS/HA. The specimens with bone and CaS/HA combined revealed that the CaS/HA protects and strengthens the bone.

The computer models presented in this study accurately described the mechanical behaviour of the hip under loading. This can aid further development of this type of models to predict a patient’s risk for a hip fracture. These models have also shown that CaS/HA is a useful bone cement that can increase hip strength, thus helping to prevent fractures. The added knowledge that CaS/HA strengthens and protects the bone from damage can help to find more clinical applications for this material, such as improving fracture fixation with dynamic hip screws.