Summary

In orthopaedic surgery, implants such as cancellous screws are used in bone fracture treatment to stabilise the fractured bone to assist bone healing. The screws are implanted into the bone with the aid of torque. The bone as a host material provides site for the anchorage of the screw threads. Most mechanical failures experienced in screw fixation occur at the bone-screw construct anchorage due to the collapse of bone structures. The host bone quality therefore plays a pivotal role in determining the success of screw fixation.

In clinics, a patient's bone quality is assessed by measuring areal bone mineral density (aBMD) using dual-energy x-ray absorptiometry (DXA) technology, and aBMD is widely used in the assessment of bone fracture risk. The assessment of bone micro-architecture in clinics is still however limited to peripheral anatomical sites, such as the wrist or ankle using peripheral Quantitative Computed Tomography (pQCT). However, with the current rate of technological developments, it may be possible in the future to assess micro-architecture at other anatomical sites, such as the hip.

During fracture fixation using screws, surgeons rely on their judgement to determine the point at which to stop screw tightening. However, it has been shown that inconsistencies exist among surgeons, leading to overtightening and stripping of the bone around the screw threads. This might be linked to variations in the quality of the host bone among patients.

The overall objective of this thesis was to investigate the respective roles of aBMD and micro-architecture of trabecular bone of human femoral heads on $F_{Pullout}$ and T_{Insert} (including plateau torque or $T_{Plateau}$ — torque at screw head contact) in a laboratory environment. $F_{Pullout}$ is defined as the maximum uniaxial tensile force (Newton) needed to

produce failure in the bone and T_{Insert} refers to the torque applied during cancellous screw insertion.

Fifty-two excised human femoral heads obtained from hip replacement surgery and cadavers were used. Femoral heads were chosen because of their rich trabecular content and the common clinical occurrence of hip fractures particularly in osteoporosis. The aBMD and micro-architecture of each specimen were evaluated using DXA and micro-computed tomography (micro-CT). A partially threaded cancellous screw was inserted in each femoral head specimen using an automated micro-mechanical test device to the point at which the screw head contacted the bone, and the torque at this point was recorded ($T_{Plateau}$). Screw insertion was then continued to a point between screw head contact and failure, after which a pullout test was performed and $F_{Pullout}$ recorded. Micro-CT images were obtained both at head contact and just prior to pullout.

These experiments were used to address three aims:

Aim #1: To determine the relationships between $T_{Plateau}$ and aBMD and micro-architecture. The results indicate that $T_{Plateau}$ exhibited the strongest correlation with the structure model index (SMI, $R = -0.82$, $p < 0.001$), followed by bone volume fraction (BV/TV, $R = 0.80$, $p < 0.01$) and aBMD ($R = 0.76$, $p < 0.01$). Stepwise forward regression analysis showed an increase for the prediction of $T_{Plateau}$ when aBMD was combined with microarchitectural parameters, i.e., aBMD combined with SMI (R^2 increased from 0.58 to 0.72) and aBMD combined with BV/TV and bone surface density (BS/TV) (R^2 increased from 0.58 to 0.74).

Aim #2: To determine the relationships between the $F_{Pullout}$ and insertion torque prior to pullout (T_{Insert}), aBMD and micro-architecture. Results showed that $F_{Pullout}$ exhibited strongest correlations with T_{Insert} ($R = 0.88$, $p < 0.001$), followed by SMI ($R = -0.81$, $p < 0.001$), BV/TV ($R = 0.73$, $p < 0.001$) and aBMD ($R = 0.606$, $p < 0.01$). Combinations of T_{Insert} with microarchitectural parameters and/or aBMD did not improve the prediction of $F_{Pullout}$.

Aim #3: To determine the effect of three different insertion torque levels after head contact on the holding strength of the trabecular bone surrounding the cancellous screw. $F_{Pullout}$ for screws tightened to an average of 80% T_{Max} was significantly greater than for screws tightened to an average of 90% T_{Max} ($F_{Pullout}$ = 2.07 ± 0.28 kN vs. 1.48 ± 0.40 kN, p = 0.019), but was not significantly different to screws tighten to an average of 70% T_{Max} ($F_{Pullout}$ = 1.79 ± 0.31 kN, p = 0.33). $F_{Pullout}$ at 70% T_{Max} was greater than $F_{Pullout}$ at 90% T_{Max} (p = 0.019), but not significantly different (p = 0.27), which could be due to sample size.

In conclusion, $T_{Plateau}$, which has previously been shown to be a strong predictor for insertion failure torque is significantly dependent on bone micro-architecture, particularly SMI and BV/TV, followed by aBMD. Bone with low SMI or that contains a more plate-like trabecular structure, high BV/TV and aBMD, is likely to offer a structural environmental in which the screw threads cut into more material, leading to an increase in $T_{Plateau}$. $F_{Pullout}$ of cancellous screws depends most strongly on the applied T_{Insert}, followed by micro-architecture and aBMD of the host bone. This indicates that for a bone specimen with a given trabecular bone micro-architecture and density, increases in applied T_{Insert} beyond screw head contact within the linear range will increase $F_{Pullout}$ of the screw. However the strength of the construct reduces as insertion levels approach failure torque, probably due to yielding of the bone around the screw threads.