INTRODUCTION:
Impaction bone grafting (IBG) using morsellised bone graft and cement has been used for over ten years, per and post operative femoral fractures are however still major complications. Per-operative femoral fracture is one of the common problems during reconstruction of the medullary canal and occurs in 12% of revision hip operations [1]. During impaction, a large amount of energy is delivered to the bone graft and is transmitted to the surrounding structures. This is essential to deliver sufficient impaction energy to consolidate the bone graft since the initial stability is vital for osteointegration.

The primary objective of this study was to establish the levels of strain occurring on the medial side of the femur during IBG under different impaction energy. The secondary objective was to investigate the feasibility of using low-force, high-frequency impaction to achieve the same level of bone graft consolidation.

MATERIALS AND METHODS:
Bone graft harvested from porcine femoral heads was used. Soft tissue and articular cartilage were removed and a Norwich bone mill was employed to mill the femoral heads. The graft was inspected to ensure there were no cortical fragments. Graft was stored at −25°C and defrosted thoroughly at room temperature for two hours before use. Third generation composite Sawbone® femora were used.

The Exeter IBG technique was used in conjunction with the Stryker X-change instrumentation [2]. An Impactometer [3] which provides a known impact energy and momentum, was used to standardise the impact process. A 602 g weight dropped from 260 mm, which produced an energy of 1.54 J and a momentum of 1.4 Ns. This represented the typical levels of achieved in the clinical scenario and was defined as the baseline level in this study. Drop heights of 130 mm (0.77 J) and 390 mm (2.31 J) were also used to represent impactation levels of 50% above and below the baseline study.

Four strain gauges were mounted on the medial side of the femur as shown in Figure 1. The distal impaction was broken down into three stages. A fixed volume of 30 cc porcine bone graft was added at each stage and then impacted four times at drop height of 260 mm. Proximal impaction was performed by impacting with a phantom stem. In aforementioned, three different drop heights were used. The numbers of drops were determined by the achievement of the same ultimate level of compaction; and this was determined by a predetermined final position of the proximal impactor. Strains were recorded in both distal and proximal impaction. The number of proximal impactions was also recorded.

![Figure 1: Four strain gauges were mounted from proximally to distally along the medial side of a composite Sawbone® femur.](image)

RESULTS:
Table 1 shows the amount of total accumulated energy required to perform proximal impaction. This was calculated by the number of blows multiplied by the given energy for a specific drop height. The baseline level required approximately 400 J at a drop height of 260 mm for full consolidation. A drop height of 130 mm required a higher total accumulated energy and was still not sufficient to consolidate the graft. A drop height of 390 mm required less total accumulated energy (a lower number of impacts) to achieve the same level of consolidation.

![Figure 2: Strains at different drop heights for the different strain gauge (SG) locations (n=6). The mean and one standard error are shown.](image)

DISCUSSION:
When a drop height of 130 mm was used, there was insufficient energy to impact the stem into the compacted distal graft. Therefore, a larger number of impacts with a ‘low-force’ were shown not to be an appropriate method for proximal graft impaction. In contrast, a drop height of 360 mm gave 50% more energy per impact than the baseline study. This required 37% less accumulated energy in total, but could induce a higher risk of per-operative femoral fractures.

Higher strain levels were expected on the medial side of the femur because of the curvature and the design of the stem. Particular attention should be paid around Gruen zone 6 and 7. Femoral reinforcement with cerclage, meshes, cortical strut grafts or reconstructive plates are essential, especially in massive femoral reconstruction cases [4]. The location of the highest strain levels is dependent on the applied force, the stem geometry, bone quality of the femur and the load transmission ability of graft and cement.

CONCLUSIONS:
It was found that and energy level of 0.77 J was not sufficient to achieve graft compaction. Therefore, a low-force impaction is not an appropriate method for IBG to achieve the same amount of graft consolidation. A high impaction energy (2.31 J) causes higher strains and has a greater potential to cause per-operative fractures. In addition this level of impaction did not achieve improved consolidation over that achieved at the baseline impaction energy level.

REFERENCES: