MEASUREMENT OF IMPACTION QUALITY AND CORRELATION WITH STABILITY IN IMPACTION GRAFTING

INTRODUCTION: The surgical technique Impaction Grafting addresses the bone stock loss associated with hip revisions by impacting morcellised human allograft bone chips into the femoral cavity. The compacted graft forms a new medullary canal for the fixation of a new prosthesis. It provides mechanical stability and serves as a biologically active matrix for bone stock regeneration. The successful clinical outcome is influenced by the initial mechanical stability of the graft which strongly correlates with the quality of the impaction of the graft. Too strong an impaction presents risks of fractures in the bone stock and too weak an impaction may result in excessive subsidence leading to failure. The level of impaction may also influence potential for revascularisation of the graft. In the assessment of the impaction quality the surgeon can only rely on “feeling” or experience. This study investigates if the set of the hammer blows can be used as a more objective reference to predict sufficient impaction and stability.

For human allograft suitable for Impaction Grafting has outstripped supply and thus synthetic graft extenders such as calcium-phosphate based ceramics have been successfully tested in-vitro. This study investigates if the clinical use of these synthetic materials in graft mixes affects the impaction feel and the stability associated with a specific impaction level.

MATERIALS AND METHODS: A tube and cone system was used to model the human femur and stem conditions in-vitro. The model consisted of a 25mm diameter metal tube and a metal cone of 120mm length and decreasing diameter from 16mm proximally to 5mm distally. The tube was filled with graft, the graft pre-compact with a flat disk and the cone driven into the tube with a device called the Impactor™. A weight of a preset adjustable height drops along a guide wire onto the disk or cone allowing impaction momentum and energy to be controlled and repeated. The position of the disk and cone was monitored during impaction and the set per hammer was measured.

After impaction the model was mounted in an Instron servo-hydraulic machine and cyclically block-loaded in compression at peak loads increasing from 0.2 to 0.2 kN steps of 5000 cycles each until failure at a maximum subsidence of 6mm. Pre-impaction energy was varied between 3.1J (low), 6.2J (medium), 9.3J (high) and 23.3J (very high) to represent a wide range of total impaction quality. The drop height of the hammer was varied between 65mm, 130mm and 260mm to vary impaction force while keeping the pre-impaction energy constant.

Materials: Pure human morcellised trabecular bone was tested as the gold standard. Ovine graft harvested from sheep humeral heads was tested as an in-vitro experimental graft. Volume mixes of ovine graft and granules of various tricalcium-phosphate/hydroxyapatite ceramics were analysed. Mixing ratios were 2:1, 1:1 and 1:2. For 1:1 bone/ceramic mix the parameters of the synthetic extender were varied in chemical composition (HA:TCP: 100:0, 20:80, 50:50, 80:20), in porosity (0%, 25%, 50%, 67%), particle size (1-2mm, 2-4mm, 4-6.3mm) and sintering temperature (1050°C, 1150°C, 1200°C).

RESULTS: Fig. 1 shows the accumulated set during cone impaction of three characteristic sample groups which recorded distinctively different number of cycles to failure and required significantly different numbers of hammer blows for full cone insertion. However, as with all other graft configurations tested, the set accumulated over the number of hammer blows increased exponentially in all cases as the nearly straight lines against a logarithmic axis show. The slope of the lines and thus the exponent of the functional relationship between accumulated set and number of blows indicate a relationship between impaction set and graft stability for the three extreme graft configurations shown here. However it was not sensitive enough to significantly resolve a correlation for samples of less distinctive properties.

Fig. 2 shows the set of the final hammer blow as a function of stability given as the number of cycles to failure for the total range of graft materials tested. For all pure bone grafts (human and ovine) and for all graft/ceramic mixes there is a clear correlation between the set of the final hammer blow and the mechanical stability against cyclic compression loading. With number of cycles to failure during block loading as a scale for stability there is an exponential relationship between set and stability. With decreasing set the stability increases exponentially. Within the scatter of results this correlation is similar for pure bone grafts and mixes and thus appears to be independent of the graft material. The scatter of values recorded for bone samples appears slightly higher than for the graft/ceramic mixes and this correlates with the scatter of stability values recorded. For different hammer drop heights and thus different impaction peak forces the data points outside the standard trend curve indicate that for different hammer forces the set-stability function must be shifted towards a higher set per final blow for larger drop heights and vice versa.

DISCUSSION: The current subjective surgical assessment of impaction quality as a measure of stability by “manually sensed hammer response” could be objected by replacing a measurement of set per hammer blow. A set measurement sensor could be integrated into the surgical impaction hammer and guide wire system providing the basis of a tool for intra-operative assessment of impaction quality and stability. Absolute values for recommended final set values could be calculated with the help of Sawbone® composite bone model experiments. However as the manual hammer force is not controlled, an average set over a range of the final hammer blows needs to be taken or in the long term, the hammer force needs to be calibrated as well. In this manner some of the variability associated with the surgical impaction process could be significantly reduced leading to a more predictable and reliable outcome. As the set-stability correlation is constant for bone grafts and for graft mixes, surgeons using such an instrumented feedback system may be able to rely on this form of assessment even when ceramic graft extenders are being used. Assuming set per blow as the major component of the manually sensed feedback of a surgeon during impaction, even the use of ceramic graft extenders may not affect this crucial subjective judgment of impaction quality.

REFERENCES:

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