ASSESSMENT OF BONE GRAFT STABILITY IN A FEMORAL OVINE MODEL USING A BIOMECHANICAL AND COMPUTATIONAL APPROACH

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INTRODUCTION: Bone grafts are clinically used for a range of reconstructive orthopaedic surgical applications such as bone repair, osteochondral grafting, and ligament reconstruction procedures [1]. Graft stability contributes to effective tissue regeneration between the host and graft bone [2]. This study used experimental and computational methods to evaluate graft stability as an indication of the risk of graft subsidence.

METHODS: *Experimental:* The mechanical stability of various bone-only grafts at different stages after implantation, compared to native bone, were assessed using a push-out test, which measured the force required to displace grafts below congruency [3]. Push-out tests were performed on the bone-only portion of skeletally mature, distal ovine femurs. From 9 femurs, a total of 33 sites were tested. “Post-osseointegration” samples had been implanted *in vivo* with either decellularised porcine xenografts (N=6) or ovine allografts (N=6) and allowed to integrate for 12 weeks (approved by the NAMSA ethical committee on 04.01.2016). “Post-implantation” samples were implanted *in vitro* with autografts (N=9) (harvested from the medial side of the femur and implanted in the lateral side of the same specimen). “Native (control)” samples had nothing implanted (N=12). All grafts were 6.5 mm diameter, 10 mm length. The autografts were implanted with an Acufex™ Mosaicplasty surgical toolkit (Smith and Nephew, MA, USA). The specimens were prepared for testing by segmenting the femurs at 10 mm from the test surface to expose the grafts from below. The graft or test site was uniaxially loaded at a rate of 1 mm/min, using a materials testing machine (3365 with a 5 kN load cell, Instron, UK) until a displacement of 10 mm below congruency or a maximum load of 2.5 kN (Fig. 1). Maximum reaction forces (N) and resistance to motion (kN/mm) were derived for each test. For each specimen, the bone density (ratio of bone volume to total volume), segment thickness at each test site, and angle of graft implantation of the post-implantation group, were measured from CT scans. Differences between groups were assessed with Kruskal Wallis and Wilcoxon post hoc tests, after the non-normality of the data and homogeneity of variance were verified with Shapiro Wilk and Brown Forsythe tests respectively (significance was set at 0.05). *Computational:* The CT scans were segmented and meshed using Simpleware ScanIP (2019.09, Synopsis, USA) to develop computational models that replicated the push-out tests. Finite element models, developed using Abaqus (2022, Dassault Systemes, France), featured image-based element-specific material properties with a constant Poisson’s ratio of 0.3 and heterogeneous Young’s modulus values based on voxel brightness (linear relationship derived using previous methods [4]). The bone was modelled with linear tetrahedral elements and elastic material properties. Models assessed graft stability immediately post-implantation, comparing maximum reaction force against a base model (whole bone segment, 6.5 mm diameter, axially loaded, friction coefficient of 0.6 between the host and graft). The effect of graft-host interaction was investigated by varying the friction coefficient (N=4), and bone relaxation by reducing the host site diameter (N=2). The effect of the bone surrounding the graft site was studied by removing concentric bone rings with increasing proximity to the graft site (N=6; thickness of rings equal to the radius of the host site). The influence of additional graft sites was examined by varying their presence and proximity (N=4; 7.5 mm and 10 mm centre-to-centre). The angle of implantation was investigated using non-axial loading via a displacement boundary condition with increasing angle (N=4).

RESULTS: *Experimental:* A general correlation between the maximum force and resistance to motion was observed (Fig. 2). The maximum force was largest for the post-osseointegration samples (mean value F=1.50 ± 0.18 kN for the porcine xenografts; F=2.11 ± 0.17 kN for the ovine allografts), then the native controls (F=1.19 ± 0.39 kN), and lastly the post-implantation samples (F=0.34 ± 0.11 kN) (Fig. 2). The segment thickness and bone density of all samples, and angle of implantation of the post-implantation group, which had some experimental variability (10.91 ± 2.45 mm, 55.7 ± 11.2 %, and 8.9 ± 3.5°), did not appear to correlate to the maximum forces observed. The statistical analysis showed differences between the resistance to motion of all groups except between the two post-osseointegration groups (p=0.66). *Computational:* The base computational model produced a maximum reaction force of 0.23 kN. The results of further testing showed, of the characteristics tested, the maximum reaction force of the model was most sensitive to the host site size, in which a diameter reduction of 0.2 mm increased the maximum reaction force by 0.41 kN (+78%) (Fig. 3).

DISCUSSION: The experimental outcomes demonstrate that osseointegration resulted in an increase in the force required to displace bone-only femoral grafts, while immediately post-implantation, grafts were susceptible to subsidence at low loads. The base computational model underpredicted the maximum reaction force with respect to the post-implantation experimental results (-110 N) due to inherent idealisation but allowed controlled comparisons of the difference scenarios. The model showed, immediately post-implantation, stability increases with angle of implantation, but is most affected by host site size, an effect of bone relaxation. This increased stability could potentially be engineered clinically by oversizing the graft in comparison to the host site, which also has histological benefits [5]. The model also shows minor differences in outcomes with material changes at 3 or more rings away from the graft site (9.75 mm), indicating other graft sites did not interfere with experimental test results.

SIGNIFICANCE/CLINICAL RELEVANCE: Grafts are shown to have a short-term risk of subsidence post-implantation, at low loads, while stability increases following osseointegration. Immediately post-implantation, models show the greatest sensitivity to angle of implantation and graft site diameter.

REFERENCES: [1] Khan et al, 13(1):77-86, 2005. [2] Bowland et al, J Biomech, 77:91–98, 2018. [3] Bowland et al, J Biomech, 234(2):163–170, 2020. [4] Day et al, J Mech Behav Biomed Mater, 134:105411, 2022. [5] Makino et al, J Arthro, 20(8): 837-840, 2004.

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IMAGES AND TABLES:

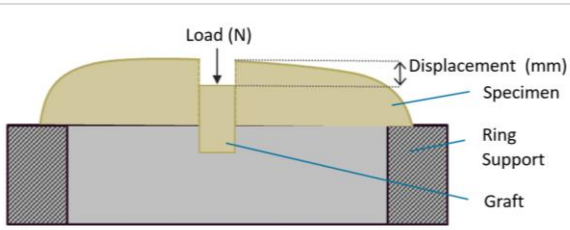

Fig.1: Push-Out Test Setup

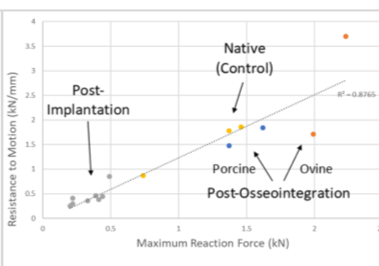

Fig.2: – Experimental Results: Maximum Reaction Force against Resistance of the Grafts to Motion

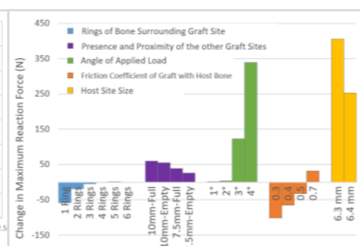

Fig.3: Computational Results – Influence of Individual Features on Maximum Reaction Force Compared to a Baseline Model (Whole Bone Segment, Host Diameter 6.5mm, Axially Loaded Graft, 0 Degrees, Friction Coefficient 0.6)