The Use of Selective Laser Sintered Components in Enhancing Osteointegration of Endoprostheses: A FEA and Histological Study

Aadil Mumith¹, Melanie Coathup¹, Anand Shah¹, Paul Fromme², William Aston¹, Tim Briggs³, Mukai Chimu tengwende-Gordon¹, Gordon Blunn¹
¹Institute of Orthopaedics and Musculoskeletal Science, University College London, Royal National Orthopaedic Hospital, Stanmore, UK
²Mechanical Engineering, University College London, UK
³Bone Tissue Engineering, University College London, UK

Disclosures: Aadil Mumith (N), Melanie Coathup (N), Anand Shah (N), Paul Fromme (N), William Aston(N), Tim Briggs(N), Mukai Chimu tengwende-Gordon(N), Gordon Blunn (N)

Introduction: Aseptic loosening of the intramedullary stem in massive segmental bone tumour implants is problematic. We have shown that osteointegration of extracortical bone to a grooved hydroxyapatite (HA) coated collar located adjacent to the transection site reduced implant failure but integration occurred in only 70% of patients. Reduced loosening may be due to stress transfer at the osteointegrated shoulder of the implant, thereby improving stresses along the intramedullary stem. Selective laser sintering (SLS) can produce novel titanium porous components with varying pore sizes and degrees of structural stiffness. The complete porous structure can be electrochemically coated with hydroxyapatite (ECHA), whereas line of sight plasma spraying only coats the outer surface. We aimed to investigate two novel porous collar designs manufactured using SLS augmented with ECHA. We hypothesised that ECHA coated SLS manufactured collars of a large and small pore design, would enhance osteointegration in an in vivo ovine model compared to the current plasma sprayed HA coated grooved design. Finite element analysis (FEA) techniques were used to investigate the effect of different levels of osteointegration at the shoulder and stresses adjacent to the intramedullary stem are reduced with increasing osteointegration within the collar.

Methods: HA coated large pore (Ø750μm, LP), small pore (Ø500μm) and grooved (G) collars were investigated in vivo as part of a diaphyseal mid-shaft tibial implant in an ovine model that remained in situ for 6 months (Fig. 1A). Integration was assessed radiographically and histologically. Extracortical bone (EC) growth was quantified (length, thickness, surface area, % surface contact) between the 3 groups (LP, SP and G) using radiographs. Samples were processed for undecalcified histology and thin sections (<80 μm) prepared through the centre of each collar (Fig. 1B). Using light microscopy, osteointegration of collars was quantified as the proportion of the exposed collar surface that had direct mineralised bony attachment. A Mann-Whitney U test was used to statistically compare data between groups where p values < 0.05 were considered significant. For the FEA, a cylindrical axis was defined for the model and transverse isotropic material properties were used for cortical bone. 4-node, linear tetrahedral elements were used to represent the geometry of all parts in the model. A mesh element size of 0.75mm was assigned to the cement layer. The final model consisted of 136626 elements. The FE model was fixed beyond the end of the intramedullary stem with maximum forces recorded during a gait cycle applied to the implant shaft (Fig. 1C). Stress distribution within the bone and implant were investigated at five different growth stages where (i) 0% (ii) 25%, (iii) 50%, (iv) 75% and (v) 100% of the collar was osteointegrated.

Results: Radiographic analysis of retrieved specimens showed a significantly greater EC bone length in G (7.7±4.4mm) Vs LP (4.9±6.5mm, p<0.01) and SP (4.9±6.3mm, p=0.004). Greater thickness of EC growth was seen in G (3.2±1.3mm) Vs LP (1.5±1.7mm, p<0.01) and SP (1.8±2mm, p<0.01). Greater surface area of EC growth in G (15.7±16mm) Vs SP (11.2±18.2mm, p<0.031) and VS LP (10.2±17.4, p<0.031) was found. Both the G (36.4±27.2% ±0.01) and LP (23.7±31.5%, p=0.031) groups performed significantly better than SP (11.3±28.7%) regarding surface integration of EC bone growth as seen on radiographs. EC bone ingrowth with direct attachment to the HA coated surface of the porous collars was confirmed histologically. Thin sections of in vitro specimens showed that the surface available for integration was significantly greater in SP (225.5±24.7mm) Vs LP (121.7±48mm, p=0.01) and G (37.2±7.9mm, p=0.01) groups. The LP design was also found to have a greater surface available for integration than G (p<0.01). The proportion of surface with direct bony attachment expressed as a % of the total surface available was not statistically different between SP (35.2±24.8%), LP (37.8±36.4%) and G (36.3±27.1%). In a number of examples this growth was blocked by a cement layer between the shoulder of the implant and the cortical bone. At 6 months and unlike the plasma HA coated grooved collars, the ECHA coating could no longer be observed on the implant surface. FEA results indicated that the least amount of integration (25%) caused a reduction in stress of the order of approximately 800 MPa removing the risk of implant fracture, yield or fatigue. Loads transmitted within adjacent bone were also reduced in the models where the implant was osteointegrated.

Discussion: Novel porous SLS collar designs combined with ECHA augmented bone growth within the porous structure. Although significantly greater integration was not seen with the SLS collars compared with grooved collars, it is possible that bone ingrowth within pores will produce a stronger mechanism of integration as bone is permeated throughout the collar and not just located on the implant surface. Further work is required to optimise the pore size and ECHA coating. FEA showed that with relatively small amounts of osteointegration may be advantageous in reducing high stresses along the intramedullary stem.

Significance: Porous collars may provide an alternative method of fixation of massive implants via ingrowth and improved fusion between the collar and extracortical bone growth. This may potentially provide improved osteointegration and a reduced rate of implant failure.

Acknowledgments: Orthopaedic Research UK, Skeletal Cancer Action Trust, Royal College of Surgeons of England

Fig 1: (A) Porous collars in situ indicated by red arrows. (B) Integration of grooved Vs large pore collar designs (C) Von mises stresses with 0% osteointegration (top) Vs reduced Von mises stresses with 75% of the collar integrated (bottom)

ORS 2016 Annual Meeting Poster No. 2127