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The Use of a Novel Laser Sintered Porous Collar in Optimising Osteointegration of Endoprostheses

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Background
Aseptic loosening of massive segmental bone tumour implants is problematic. We have shown that extracortical bony bridging adjacent to the transection site improves fixation but occurs in only 75% of patients. Osteointegration at this site only occurs when a hydroxyapatite (HA) coating is used. Osteointegration of extracortical bone is thought to result in more beneficial stress transfer at the shoulder of the implant, reducing high stresses within the intramedullary stem fixation. New bone formation onto the shoulder of the implant and its integration with the implant is unreliable. Selective laser sintering (SLS) can produce novel titanium components with varying pore sizes and degrees of structural stiffness. The inner pores can be electrochemically coated with hydroxyapatite (ECHA), whereas line of sight plasma spraying only coats the outer surface. This structure could be used more reliably to replace the solid implant shaft allowing bone regeneration and implant integration.

Questions
1. What level of osteointegration is required to reduce stresses along the intramedullary stem?
2. Compared with conventional coatings can a novel porous shaft manufactured using selective laser sintering (SLS) enhance integration and osteointegration of cortical bone?
3. Can the osteointegration of an inner porous structure on a SLS shaft be improved by using an electrodeposited HA coating?

Materials and methods
Finite element analysis (FEA) was used to determine the amount of osteointegration required to offload the intramedullary stem at the shoulder of the implant. HA coated large pore (Ø750µm, LP), small pore (Ø500µm, SP) and grooved (G) collars were tested in vivo as part of a diaphyseal implant in an ovine model that remained in situ for 6 months. In order to investigate if a HA coating could be applied to the inner porous structure roughened TiAl6V4 discs were coated using current densities 5, 10 and 20mA/cm^2 over 5, 10 and 15mins. Surface topography and coating thickness was examined using electron microscopy. The porous structures were used in an ovine diaphyseal midshaft tibial model and bone integration was assessed radiographically and histologically. The extracortical bone (EC) growth was quantified (length, thickness, surface area, % surface contact) between the 3 groups (LP, SP and G) and underwent Mann-Whitney U statistical analysis.

Results
FEA suggests only 25% of collar osteointegration is required to reduce stresses along the intramedullary stem. Greater current densities and longer coating times produced different topographies and thicker (p=0.000) layers of HA respectively. Higher current densities produced 'flares' of HA crystals of greater frequency. Radiographic analysis of retrieved specimens reveal significantly greater length of EC bone growth in G Vs LP (p=0.01) and SP (p=0.004) groups. Greater thickness of EC growth was seen in G Vs LP (p=0.000) and SP (p=0.000). Greater surface area of EC growth in G Vs SP (p=0.000) and LP Vs SP (p=0.031) was found. Both the G (p=0.000) and LP (p=0.031) groups performed significantly better than SP regarding surface integration of EC bone growth. EC bone ingrowth with direct attachment to the HA coated surface of the non porous collars was demonstrated and was similar to that seen clinically. Using electrochemical deposition in the SLS collars we showed that HA could be deposited uniformly within the inner porous structure. This porous HA structure induced greater bone formation and more bone growth from the cortex at the transection site through the implant structure leading to a much more integrated prostheses. In a number of examples this growth was blocked by a cement layer between the shoulder of the implant and the cortical bone

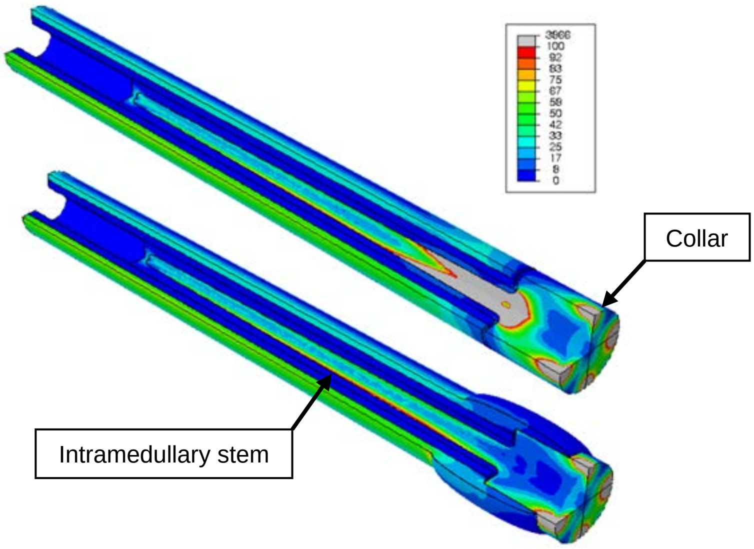

Figure 1: (top) Von mises stresses with 0% osteointegration (bottom) Von mises stresses with 75% of the collar integrated

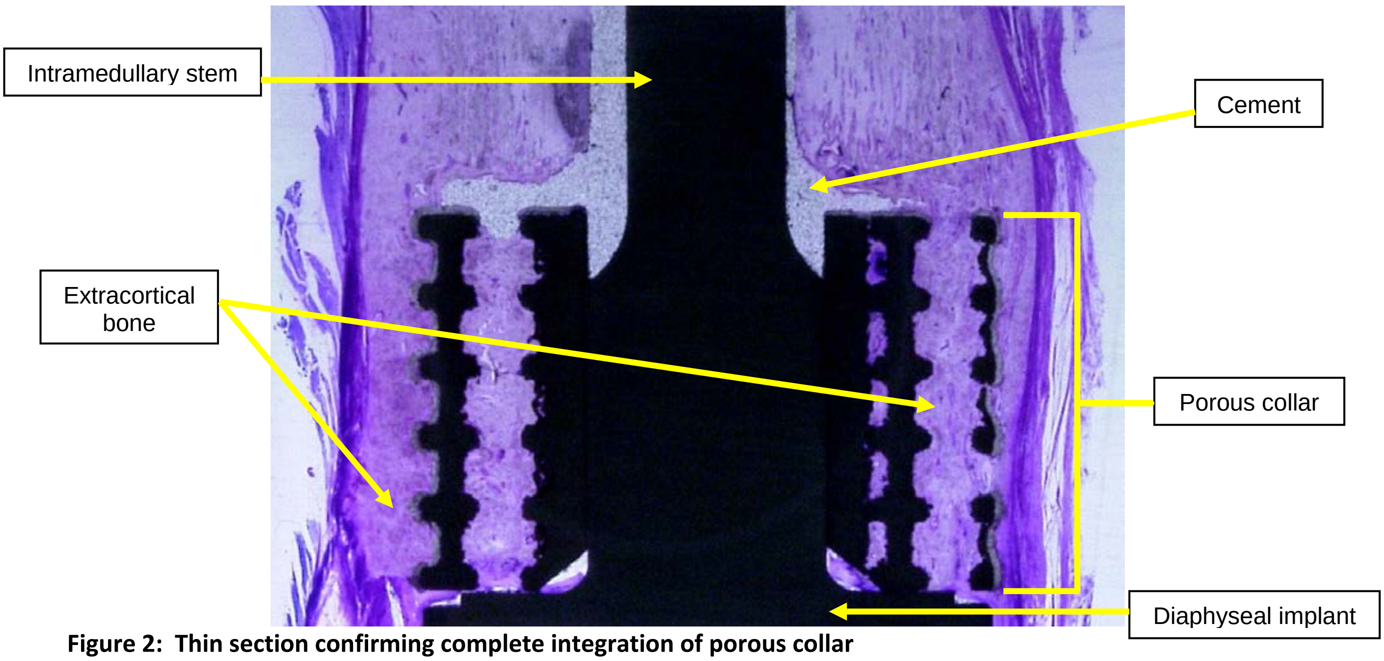

Figure 2: Thin section confirming complete integration of porous collar

Discussion

Lower current densities produce even coatings compared to high current densities where HA crystal ‘flares’ are seen which are thought to be weak under shear forces. Grooved collars utilise bony ‘overgrowth’ to become integrated. SLS collars combined with ECHA utilise bony ‘ingrowth’ with less perceived EC bone on radiography. Ingrowth was seen throughout the porous structure and the implants were better osteointegrated with the bone.

Conclusion

A fully integrated collar is not required to offload stresses through an implant. Porous collars enhance fixation of massive implants via ingrowth with less extracortical growth. This novel design provides improved osteointegration and theoretically a reduced rate of implant failure.