

The role of implant surfaces in fracture fixation

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The development of a stable bone/implant interface (though not necessarily direct osseointegration) for partial or complete stability of an implant device is critical for the success of osteosynthesis implants, such as screws, pins and nails. Bony integration is increased on implant surfaces with increased roughness, though really this is only within a range of 200nm to 2 μ m. We believe osteoblast cells do not react to roughnesses outside this range. The majority of research for surfaces throughout the world has been towards increasing bony integration. This trend is probably inappropriate for internal fracture fixation (IFF), apart from in special areas such as in spine fusion and long term or permanent CMF implants.

IFF devices are often removed to avoid: growth disturbances in paediatrics, allergic reactions, soft tissue irritation (prevention of tendon gliding within hands), implant protrusion/intrusion (e.g. into a joint), pain experienced by the patient or being cosmetically disturbing (protrusion under skin or even optically disturbing), implant migration/breakage, build up of fretting particles in unrelated organs (from loose multi-component implants), in cases where infection of the device or adjacent tissue has occurred as well as due to cold intolerance of the patient. There are difficulties in removing a device. These include increased operative time due to difficult removal of strongly integrated bone to screw threads, screw heads and even the plate itself, screw stripping and breakage. This has caused industry to have developed special removal devices to retrieve these parts. These problems also have associated risks such as increased blood loss and debris contamination.

In temporary implants such as plates and nails with the use of screws or the application of external fixators, minimal direct bone bonding to implants is desirable for the least traumatic device explantation. Strong bony integration is a disadvantage when the device may later need removal. Surface microtopography is the major determinant of bony integration for current clinically used metals.

Surface polishing reduces microdiscontinuities (Ra 0.2 to 2 μ m) that can be 'seen' by the cells producing surfaces of low roughness (Ra less than 0.2 μ m). Our *in vitro* work with osteoblasts has shown that polishing acts on a cellular level (as it does with fibroblasts). Implant surface topography influences osteoblast differentiation, reducing expression and function of genes specific for osteoblast phenotype, compared to standard micro-rough counterparts. Polishing had a strong effect on one gene osteocalcin, significantly reducing its expression. This surface induced cell behaviour change is achieved initially due to the surface altering the cell shape/cytoskeletal organisation.

Our *in vivo* study in rabbits in the late 90's showed that increasing the surface roughness of EPSS (electropolished stainless steel) internal fixation plates when roughened (Ra 0.2 to 2 μ m) induced more bone formation towards the implant surface without fibrous tissue formation in between, compared to plates outside this range. These results support the hypothesis that bony integration is increased on implant surfaces with higher amounts of protruding microdiscontinuities that the cell can 'see'. More recent *in vivo* work within the group assessed the effect of surface topography of TAN and cpTi screws with different surface topographies (polished and microrough) in a sheep cortical (tibial) and cancellous (rib) bone model over three time periods of 6, 12, and 18 weeks. The effect of implant topography on bone adherence was evaluated mechanically by measurement of the peak torque removal force and histological assessment of the amount of bone present at the surface of the implant. The results demonstrated that polishing both cpTi, and TAN resulted in lower removal torque than standard microrough screws when placed into cancellous and cortical bone.

In a more recent *in vivo* study we compared the pull out forces required for the removal of standard TAN (NS), and EPSS IM nails, and for the removal of NS and paste polished TAN (PP-TAN) IM nails, from bilateral, non-fracture sheep tibia model, after a 12 month implantation. This novel study successfully demonstrated the effect of implant surface

polishing on reducing pullout force for intramedullary nails. Since TAN is preferred over SS for IM nailing due to its better biocompatibility and mechanical properties, we believe these findings could be used to recommend changes to current surface technologies of IM nails, to reduce complications seen with nail removal, especially in rapidly growing bone in paediatrics.

For bone fixation plates such as the LCP and LISS, we have identified excessive bony on-growth to the plates and in-growth within the screw holes as a major contributor to removal failure. Some studies suggest early removal once a fracture has healed, in an attempt to circumvent this problem, however, by the time fracture healing has occurred, encasement of the implant by bone, may also have occurred. Additionally, premature removal of an implant can jeopardise the healing of a fracture. Therefore in another *in vivo* study we reduced the surface micro-topography of clinically available LCP's, with locking screws. Our findings showed that surface polishing significantly reduced the force required for removal of TAN cortical screws compared to standard micro-rough counterparts. Furthermore, there was a trend for lower percentage of bone contact on the polished samples compared to micro-rough screws; however, this was always significantly higher than that observed for EPSS screws. Moreover, the significant reduction in time required for tissue removal from polished devices, will directly reduce the surgical time associated with implant removal, thus improving, not only the economic burden associated with surgical procedures, but also the surgical related complications with regards to the patient, which are both principal deciding factors for implant removal. Consequently, we suggest that surface polishing is a promising technique for fixation devices destined for removal which would positively influence the prevalence of implant removal-related complications.

On the other side, implant loosening is an unresolved complication associated with prosthetics such as spine cages, where osseointegration is essential to their success.

Anodic Plasma-chemical (APC) treatment binds calcium and phosphate direct into the metal surface to produce superior adhesive strength than a coating, thus offering great

potential for enhancing integration into surrounding hard tissue, while negating adhesion issues associated with conventional HA coatings. We showed APC to be both cytocompatible *in vitro* and biocompatible and osteoconductive *in vivo*. The APC treated samples had similar biological performance to HA coated screws, though they had superior binding strength compared to standard HA coatings.

Polyetheretherketone (PEEK) has due to its radiolucent properties come into the spotlight as a replacement for metals in devices such as spine cages and craniomaxillofacial (CMF) implants. However, cellular attachment to PEEK is restricted due to its low surface energy, which can lead to fibrous encapsulation. To aid tissue integration the surface energy has been increased by plasma surface treatment incorporating oxygen into the surface. Surface treatment of PEEK has led to higher levels of nodule formation indicating that these treated surfaces are likely to improve bony integration to implants, though more detailed work is being undertaken.

In situations with either hard or soft tissue interactions with biocompatible bulk materials, the 'implant biocompatibility' is determined more by the design and surface characteristics. Without surface modification an implant may be biocompatible in one anatomical situation, (e.g. a spine cage surface increasing osseointegration) yet not in another (the same surface would be deleterious to free gliding of tendons). There is no 'generic wonder surface' for all applications and surfaces even on one implant interacting with different tissues need to be considered as separate entities.

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