formation is generally desirable for many areas of the body. Without protein adsorption and cell adhesion, under the presence of micromotion, fibrous capsule formation occurs often surrounding a liquid-filled void at the interface. Under aseptic conditions encapsulation is not problematic but becomes difficult when bacteria are present, since the vascular system is prevented from access to the liquid-filled void, which protects the bacteria. Clinically, this situation is more prevalent with SS implants compared with anodized Ti implants. Increasing micro-discontinuities of SS internal fixation plates prevents formation of liquid-filled fibrous capsules at the soft-tissue interface. Increasing surface micro-discontinuities on the undersurface of SS internal fixation plates also increases bony integration. Unfortunately increasing SS implant micro-roughness with current industrial methods can reduce corrosion resistance of the implant and has also been observed to initiate a macrophage response to the implant. Developments are underway to increase SS implant micro-roughness without reducing corrosion resistance, which could have major benefits for percutaneous implants by allowing soft-tissue integration and vascularization directly at the implant surface which would close a route for bacterial invasion.

In special areas the presence of a plate can produce friction for gliding tissues, such as muscles, and in orbital fixation where the plate is liable to become a site for tissue adhesion and inflammation. In such areas encapsulation may be desired to prevent adhesion to the implant surface and possible inflammation. These applications require the development of surfaces that prevent soft-tissue attachment and resultant irritation, and allow free gliding of the overlying tissues. It is extremely unlikely that a liquid-filled void could arise within the space between a plate and the overlying gliding tendon or muscle due to the large tissue displacements during normal use and these movements would also be too large to allow fibrous encapsulation of the plate to occur. This can be achieved by using either SS implants or Ti with good surface polishing to reduce the presence of micro-discontinuities, while maintaining biocompatibility of the metal, since the surface chemistry should not be altered by the correct method of polishing. Mechanical polishing has been applied with success in hand surgery with the Ti alloy Ti-15Mo to prevent tendon adhesion and subsequent rupture. A general review of the use of Ti and SS in fracture fixation with regards to the above aspects has recently been published by Hayes and Richards.

Currently clinically used micro-rough Ti implants exhibit unique biocompatibility properties which include soft tissue and bone adhesion to their surfaces. Surfaces with many micro-discontinuities support osteoblast differentiation. An advantage of tissue integration at the surface has been the possibility of less bacterial colonization and reduced infection. Recently it has been shown in vivo that for locked implants where minimal periosteal damage occurs, both material and topography were found not to influence susceptibility to infection, with SS and Ti. The same result that both material and topography were found not to influence susceptibility to infection was found with an intramedullary (non-locked) pin model in the rabbit. However, a point to bear in mind is that the in vivo rabbit models included in the studies did not comprise a fracture, nor was there major trauma to the adjacent soft tissues.

Another disadvantage of tissue integration onto Ti and TAN surfaces (alongside prevention of damage to gliding tissues, eg, nerves, tendons, muscles) appears during implant removal. Indications exist to suggest that device retention is not ideal. Studies over the years have shown that, subsequent to fulfilling its function, a device can negatively affect the host by evoking foreign body responses. These can produce complications, such as delayed infections, implant breakage, device migration, hindrance of skeletal maturity and growth, nonunions, nonstable fixations, protrusion/intrusion into joint, cosmetic issues, pain, and discomfort including protrusion under the skin or even optically. Exposure of the implant in the oral cavity also can necessitate removal. In craniomaxillofacial surgery implant removal is sometimes indicated to allow insertion of dental implants and prosthesis. Bone growth through and between the empty spaces of a device, such as into a screw head or between the thread of a screw and a plate, significantly increases the difficulty of implant removal. In children alone, approximately 13% of complications encountered during scheduled osteosynthesis material removal are related to the occurrence of excessive bony overgrowth on the device.

Reduction in surface micro-topography resulting from surface polishing can potentially affect differentiation of osteoblast cells through genotypic regulation. In vitro work assessed the potential of surface polishing of the clinically available materials Ti, TAN, and Ti15Mo for alleviating excessive bony overgrowth. Polishing reduces surface micro-discontinuities that can be "seen" by the cells producing

surfaces of high smoothness (Ra less than 0.2 µm) which thereby reduce expression and function of genes specific for osteoblast differentiation and maturation, compared with standard micro-rough counterparts. Surface polishing appears to target the events relating to terminal differentiation as osteocalcin mRNA levels were markedly reduced for polished Ti and Ti alloy samples. Osteocalcin is to date the only 'osteoblast specific' marker as it is synthesized, secreted, and deposited by differentiated osteoblasts during mineralization. Translation of the in vitro results to the in vivo situation has been observed with surface polishing of TAN and Ti screws reducing removal torque and the percentage of bone contact in cortical and cancellous bone. Ease of polished locked plate removal from cortical bone and of polished nails has also been shown in vivo. These results cause postulation that bone apposition is not negatively affected by surface polishing, but is accelerated by micro-rough surfaces and that polished devices prevent long-term strong bone adherence. Thus, the combination of the reduced strength of matrix adhesion to polished samples with slower rate of remodeling/apposition relative to standard micro-rough devices would directly influence the occurrence of bony overgrowth and ease removal.

4 Summary

For internal fracture fixation metal presently remains the material of choice since it provides strength for bone fragment support, good ductility for presurgical contouring, and it is generally bio-passive. The large use of metal internal fixators has proven successful; however, more challenging applications for metal internal fixators are emerging. For instance, given the large increase in the occurrence of these procedures in children and the different mechanical and biological requirements based on anatomical site, the requirements of metal implants have become more demanding. Therefore, current metal internal fixator–related research is based on defining specific cell and tissue responses to material surfaces both in vitro and in vivo, as well as ways to direct these site-specific tissue responses through implant surface modification.

Upon integration with the surrounding soft and hard tissue, CMF implants have different requirements within different anatomical areas. Permanent implants, such as mandibular joints, need permanent direct osseointegration. External percutaneous fixators should benefit from soft-tissue adhesion to close the entry route for potential microbiological pathogens. It is extremely important that plates in the CMF region should minimize adherence of tissue (nerves, muscles, bone). Fracture fixation implants that are to be removed after fracture healing should prevent direct osseointegration to their surface, since this is not required for their stability. Research is therefore focused on attempting to alleviate the occurrence of removal-related morbidity through surface design. Implant characteristics to control the integration with the surrounding soft or hard tissue include surface roughness, hydrophobicity, and chemistry. Polished surfaces with minimal average roughness of less than 0.2 µm are able to prevent direct osseointegration and reduce extraction torque of screws to ease implant removal. When polishing is performed optimally, it does not change the surface chemistry, hydrophobicity, or biocompatibility. Polishing does not increase susceptibility to infection in mechanically stable osteosynthesis (eg, locked plates).