CHAPTER 3.1

Implant Alloys and Interfacial Engineering

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Introduction

This chapter surveys the different aspects of “state-of-the-art” implant material performance. Today implant failure is less common than bone failure and implant design now focuses upon modifying the interface properties between implant and bone. The text discusses femoral implant design in particular but the principles apply equally to all long bone fracture fixation devices.

The Nature of In Vivo Loading

While there have been many attempts to estimate the nature of loading on human long bones [1], there have been few direct measurements made with which to validate such models. There have been many attempts to measure directly the effects of loading on the long bones but only a few have succeeded in providing any data of value to the implant designer.

Bergmann et al. [2] made an elegant series of measurements on patients in whom an instrumented prosthesis was implanted. The implant (Fig. 3.1.1 a) was calibrated to measure three components of hip force (Fig. 3.1.1 b), and patients then undertook a series of locomotion activities. External force actions and gait kinematics were also measured. The key aspects of the hip joint force components are significant magnitude and variation in direction. The vertical force component is typically 300% of body weight. The anterior–posterior component is significant and in each step taken by a subject alternates between posterior and anterior directions. Reversed torsional loading plays an important role in the mechanical failure of implants. Surgeons have intuitively recognised this, which has led to the addition of cross-locking screws proximally and distally in all intramedullary rod designs. There have been only a few studies in which implants that were indicated for trauma have been instrumented and implanted. Brown et al. [3] developed an instrumented hip nail that revealed for the first time that the “horizontal” component of movement was significant and should be taken into account in the design of devices used for fixation of the hip (Fig. 3.1.2).

The development of instrumented hip nails has continued and fully implantable implant/sensor/telemetry devices have now been developed after Burny et al. [4] (Fig. 3.1.3). Finally, Schneider et al. [5] developed an intramedullary nail (Fig. 3.1.4 a), which was implanted in a patient who had experienced a femoral fracture. The nail loads were transduced as strains and sent via telemetry to a receiver where the force actions were then decoded as shown in Fig. 3.1.4 b. This was a closed-section clover profile nail of 16 mm diameter. While the data are interesting as the only such measurement on record, they do not follow the expected pattern of reducing with time as the fracture heals and the bone takes over the task of load-bearing.

To summarise, the key aspects of loading in the lower limb are that the forces are large, dynamic, and three dimensional in nature, and the design of implants has to take into account the in vivo force environment specific to each implant in its indication range.

General Requirements of Implant Materials

In addition to recognising in vivo loading duty that the implant has to perform, there are other aspects that have to be considered in every implant material:

- Biocompatibility. This is the biological tolerance of the body to an implanted material. At one time it was considered that the ideal material would have no biological impact and result in no adverse body reactions. Now devices are being designed that are intended by surface treatment or some other modification to impact on the local biological environment. Examples are: the addition of hydroxyapatite
coatings designed to promote bony ingrowth; anodisation type II designed to protect titanium implant surfaces and modify the interface between bone and implant. Interfacial bioengineering implants have now become a significant aspect of implant design and will become increasingly important in the future.

- Biomechanical equivalence. An ideal implant should restore physiological loading and result in strains and stresses that are compatible with the requirements of the adjacent bone and soft tissue structures.
- Clinical compliance. The implant should allow all imaging modes, e.g. magnetic resonance imaging (MRI), computed tomography (CT) and ultrasound, with minimum distortion and induction of artefacts.
- Implantation and explantation. The safe and easy implantation and removal of the device must be assured. In general, trauma implants are designed to minimise bony ingrowth to