Plasma Polymer – High-Porosity Silver Composite Coating for Infection Prophylaxis in Intramedullary Nailing

V. Alt, M. Wagener, D. Salz, T. Bechert, P. Steinrücke, R. Schnettler

Introduction

Infection after intramedullary nailing of fractures is one of the most devastating situations in trauma surgery and can lead to septic non-union and chronic osteomyelitis [1, 2]. Infections can occur in closed fracture treatment [3] but open fractures in particular have a high risk of infection [4]. There has been a long controversial discussion whether open long bone fractures should be treated by a reamed or by an unreamed nail. The theoretical advantage of unreamed nails is the preservation of endosteal blood supply with a lower infection risk and better healing results [5]. However, reduction of infection rates by unreamed nailing could never be proven and a recent systematic literature review showed that there were no differences in infection rates between unreamed and reamed nailing [6]. In contrast to initial hypotheses, several authors found that reamed nailing exhibited lower rates of non-unions, shorter fracture consolidation time and lower incidence of hardware failure [6–8] and advocated reamed nailing also for grade IIIB open fractures [9].

The use of implants for fracture treatment favours infections compared to surgery where no foreign material is implanted into the body [10]. This is mainly related to the adhesion and proliferation of the bacteria on the implant surface [11], often with synthesis of an extracellular polysaccharide matrix called biofilm (Fig. 7.3.1), which has been identified as a crucial step in the pathophysiology of infection and as an important factor of virulence of bacteria [10, 12]. This biofilm formation enables the bacteria to elude host defence and antibiotic treatment [13]. Staphylococci are the most frequent infection-causing strains in bone and joint surgery [14]. Staph. epidermidis is found in up to 90% of all bone infections with indwelling devices (osteosynthesis material, joint prostheses, etc.) [16], which is most likely related to the strong biofilm-building capacity of these bacteria [12]. Also certain strains of Staph. aureus have been found to produce biofilms [16] and bone infections with Staph. aureus are in general more difficult to treat compared to infections with Staph. epidermidis [17]. Once biofilm formation is established, only implant removal promises eradication of the infection [18, 19].

Independently from the technique of intramedullary nailing, adequate prophylaxis is the most efficient way to prevent infection. Besides general pre-requirements such as aseptic operating room conditions, mainly soft-tissue management and the use of systemic antibiotics are crucial parameters to reduce infection rates [20].

Fig. 7.3.1. Scanning electron microscopy of biofilm-producing Staph. aureus. a Biofilm formation of Staph. aureus on the thread of a screw. b Higher magnification reveals the round staphylococci embedded in the biofilm. Magnifications: a ×83, b ×321. Source: Laboratory of Experimental Trauma Surgery, Giessen, Germany
sive overview of intravenous antibiotic prophylaxis for open fractures is given in Chap. 7.1. Furthermore, coating of implants promises prevention of colonisation of the implant's surface with reduction of infection rates. Gentamicin is the most common antibiotic used for loading of bone cements in infection prophylaxis in total joint surgery in Europe [21] due to its good antibacterial activity, excellent biocompatibility, and favourable release kinetics [22]. Recently, gentamicin was used in a poly(D,L-lactide) matrix for coating of osteosynthetic implants in an experimental study [23]. Also metallic silver in the form of high-porosity silver particles was shown to exhibit high antimicrobial activity in bone cements including activity against multiresistant strains, e.g. methicillin-resistant Staph. aureus (MRSA) and methicillin-resistant Staph. epidermidis [24]. Metallic silver can also be used in combination with a SiO₂ plasma polymer for coating of osteosynthetic devices.

**Plasma Polymerisation Coating Technique**

Plasma polymerisation is a versatile technique for the preparation of functional coatings on various materials and devices. Depending on the precursor material and the processing parameters, films with a thickness well below 100 nm can be obtained. In general these films are chemically inert, insoluble, mechanically and thermally stable and are used as membranes or protective coatings, for example [25]. By using hexamethyldisiloxane (HMDSO) as a precursor material, it is possible to obtain highly biocompatible films due to the formation of a coating that basically consists of a SiO₂ plasma polymer.

**Plasma Polymers Containing Metal Particles**

Small metallic silver particles can be embedded into a SiO₂ plasma polymer film in order to achieve an antimicrobial effect with such a coating on orthopaedic implants. Plasma polymer matrices for the embedding of metal clusters were used for the first time by Perrin et al. [26]. The deposition technique developed by these authors is based on the simultaneous deposition of the metal by sputtering and plasma polymerisation. An alternative method is the simultaneous deposition of the metal by evaporation and plasma polymerisation [27–31]. The coatings investigated in this work have been prepared by silver cluster deposition via inert gas evaporation and condensation and subsequent plasma polymerisation. Two different types of coatings have been prepared: for the coating named type A the silver clusters have been directly deposited on the substrate material and were embedded in a plasma polymer film, the coating named type B consists of silver clusters being embedded between two plasma polymer layers so that the silver is not in direct contact with the substrate material (Fig. 7.3.2).

**Type A**

![Type A diagram]

**Type B**

![Type B diagram]

*Fig. 7.3.2. Model of the two different coatings prepared in this work*