Titanium Porous-Coated Implant-Bone Interface in Total Joint Arthroplasty

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Introduction

Cementless fixation has been a principal method for fixation of orthopedic implants for decades. Accordingly, different rough and porous surfaces have been developed and applied in clinical use. A variety of these coatings are continuously investigated in order to improve bone–implant integration and enhance osteogenesis at the implant surface. One of the most important elements used in joint arthroplasty is titanium.

History

Titanium is the fourth most common abundant structural metal on earth after iron, aluminum, and magnesium. It does not occur as a pure metal in nature, and it forms compounds with other chemical elements. The most common mineral sources are ilmenite (FeTiO3) and rutile (TiO2), which are widely distributed in the Earth's crust and lithosphere. Titanium was discovered in 1791 by the English clergyman and mineralogist Reverend William Gregor in the village of Manaccan, England. Gregor accidentally discovered a black sand that contained a previous unknown metal and named the metal as manaccanite after the place of the discovery. He reported his findings to the Royal Geological Society of Cornwall and in the German science journal Crell's Annalen [1]. A few years later in 1795 the German Martin Heinrich Klaproth also discovered the same metal in rutile from Hungary and named it as titanium after the Titans of Greek mythology. Initially unaware of Gregor's discovery, when he heard about it he compared manaccanite with his discovery and found that they had discovered the same metal. Gregor was eventually credited the discovery of the metal, though the name of titanium was the one that was used all over the years.

Throughout the years several attempts were made to isolate titanium from its ores. However, this was firstly achieved in the twentieth century with a process developed by Kroll in Luxemburg [2, 3]. This process named as Kroll process involved the reduction of titanium tetrachloride with magnesium and remains the dominant process for titanium production till today.

Titanium Properties

The material properties are of crucial importance not only for the formation of bone around the inserted implant but for the maintenance of this bone as well. The main physical properties of titanium are the high corrosion resistance and the highest strength-to-weight ratio. It is a strong metal with low density that is quite ductile (especially in an oxygen-free environment), lustrous,

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and metallic white in color [4]. The relatively high melting point (more than 1,650 °C or 3,000 °F) makes it useful as a refractory metal. It is paramagnetic and has fairly low electrical and thermal conductivity [4, 5].

One of the most substantial properties of titanium is osseointegration. This phenomenon refers to the formation of a direct interface between an implant and bone, without intervening soft tissue due to the migration of osteoblasts and connective tissue into the pores. The Swedish bioengineer Per-Ingvar Brånemark in 1952 [6] was the first one who used the term "osseointegration" to describe the direct structural and functional connection between living bone and the surface of an implant. Brånemark realized that after implanting titanium cylinders into the femurs of rabbits, he could not extract the titanium without destroying the surrounding bone. The discovery that bone will integrate with titanium components, not rejecting the element as it does with other materials, was the beginning of the study of osseointegration. Due to these properties, titanium materials (both unalloyed and alloyed) have become important materials initially in the aerospace industry in the 1950s and currently not only in industrial applications, but in dental and medical fields as well. Commercially there are four different grades of pure titanium used in clinical practice, but also various alloys. In pure titanium, the concentration of oxygen and iron is gradually increasing in the four different grades, with a consequent change in alloy strength (ultimate tensile strength to failure) ranging from 250 MPa in grade 1 to 680 in grade 4B. Titanium alloys may be classified as either a, near-a, a + β, metastable β, or stable β depending upon their room temperature microstructure [7, 8]. Based on this classification, alloying elements for titanium fall into three categories: a-stabilizers, such as Al, O, N, and C; β-stabilizers, such as Mo, V, Nb, Ta (isomorphous), Fe, W, Cr, Si, Ni, Co, Mn, and H (eutectoid); and neutral, such as Zr [9]. The most common titanium alloy used from the beginning in orthopedic implants is Ti-6Al-4V. This was further developed over the next years and new alloys such as Ti-6Al-7Nb. The permanent application of these alloys has been suggested that may be toxic for the tissues, due to the release of vanadium and aluminum. Therefore, newer implants known as beta titanium alloys that are free of these elements were developed [10, 11]. This new generation of alloys exhibits superior mechanical properties such as lower elasticity, but with adequate strength.

Coating Methods and Types of Titanium Coatings

The biological behavior of a material is influenced to a great extent by its surface properties. The coating of an implant aims to improve implant performance regarding implant fixation, wear, and corrosion, given that it is affecting bone tissue remodeling. Biocompatibility and mechanical stability of the implant are the main factors associated with a successful implantation of an implant in joint arthroplasty. The preparation of titanium surface involves various mechanical, thermal, chemical, electrochemical, and vacuum-based treatments either alone or in combinations [12–17]. At a second stage, the process utilizes the deposition or the addition of foreign materials characterized by the presence of pores to promote the apposition of bone on the implant surface. The pore size seems to play a substantial role for bone ingrowth into the pores [18]. The minimum pore size that is required for weight-bearing implants such as hip and knee prostheses should be approximately 100–150 μm, while most orthopedic implants have coatings with pores measuring from 100 to 400 μm [19]. Several methods have been reported to add bioactivity to titanium implants [20]. Different processes vary in complexity of preparation and also in the type of porous material that they produce. Plasma spraying is the most popular technique widely applied since nowadays, that produces highly porous surfaces with open and interconnected pores, which can vastly improve bone ingrowth characteristics [17, 18, 21, 22]. Moreover, with the plasma spraying method, the compressive modulus of the porous substrate can be produced to match that of cancellous bone, in order to eliminate the problems resulting from stress shielding [18, 23]. Alternative methods include the immersion of titanium into simulated body fluids (SBF) [24], chemical methods [25], laser methods [26], and

sputtering methods [27]. Several types of coatings have been applied to titanium surfaces. Among the large variety of titanium coatings, calcium phosphates mainly hydroxyapatite [28], titanium oxide [29] and nitride [30], zirconium oxide [31], and diamond-like carbon coatings [32] have been used in orthopedic implants. Hydroxyapatite displayed the most promising results and has been extensively studied for over than 20 years. The biological advantages of HA are the enhancement of bone formation, the accelerated bonding between the implant surface and surrounding tissues, and the reduction of potentially harmful metallic ion release [33, 34].

Animal Studies

The period around 1970 was an exceptionally productive period regarding the fabrication and use of porous-coated titanium for orthopedic implants. Hirschhorn et al. in 1971 were the first who described the fabrication and testing of commercially pure (CP) porous titanium as an implant material [35]. They turned from cobalt–chromium alloy to titanium, because of the lower density and modulus of elasticity of the latter. Two years earlier, Lueck et al reported the fabrication and implantation of a porous CP titanium fiber composite material [36]. They proposed the use of fiber–metal composites, which combine strength with porosity, are not brittle, and have a large range of elastic strain, and tear, in contrary to the porous metallic materials fabricated by powder metallurgy techniques that exhibit poor strength characteristics when the degree of porosity is sufficient to permit bone ingrowth [36, 37]. At the same period, Galante et al. [38] and Lembert et al. [39] proposed the use of fiber–titanium composites as a method of fixation of prosthetic implants. Through studies that were conducted in rabbits and dogs, they suggest the use of fiber–metal composites in the form of a thin sleeve surrounding and bonded to a central solid metal core that could provide fixation to bone and uniform stress distribution at the implant-bone interface [38]. Finally, the same period Hahn et al reported favorable outcomes of plasma-sprayed porous titanium hydride coating [40].

In the following years, the main investigations were directed towards the understanding of structural, morphological, and mechanical properties of different types of coatings in titanium porous-coated implants and the comparison of different coating types and the clarification of parameters that play important role in order to establish a successful implantation and an adequate bone ingrowth for implant survival. Turner et al aimed to compare ingrowth of bone into three types of porous-coated titanium prostheses, and to determine the effect of the type of porous coating and the degree of coverage of the stem on the remodeling of bone on the femoral side in cementless canine total hip arthroplasty [41]. Four types of Ti porous-coated femoral prostheses were used: sintered fiber–metal prostheses, prostheses with sintered beads, prostheses with plasma flame spray coating, and femoral components circumferentially coated with plasma-sprayed commercially pure titanium. No significant difference in ingrowth of bone was observed at 1 month, whereas at 6 months there was significantly less ingrowth into the beaded surface than into the fiber–metal surface. In all groups, a proximal-to-distal gradient of loss of cortical bone was observed by 6 months, and the magnitude of bone loss was dependent on the extent (severe loss in circumferential coating) rather than on type of coating. Drastic thinning of the anterior part of the cortex surrounding the titanium fiber–metal-coated intramedullary part of a canine prosthetic replacement of the proximal end of the femur also has been reported [42]. An increase in intracortical porosity throughout the proximal end of the femur and a decrease in the average width of the cortical bone compared with the contralateral femur, which was not operated on, were observed in a canine total hip replacement model of fixation with a femoral component that was coated with titanium fiber metal [43].

During the last 20 years, the vast majority of experimental studies were directed towards hydroxyapatite coatings in titanium implants. The results of these studies have suggested that the coating of hydroxyapatite applied to titanium porous-coated prostheses might have desirable properties for weight-bearing orthopedic implants. Thomas KA et al. in 1987 showed that hydroxyapatite-

coated implants exhibited significantly greater values of maximum interface shear strength and stiffness than the uncoated implants after all time periods [44]. Histologically, all areas coated with the hydroxyapatite material were covered with an osteoid layer after 3 weeks, which was mineralized after 10 weeks. In all cases, longer-term implants demonstrated mineralization of interface bone directly onto the hydroxyapatite coating, and in no case was a fibrous layer observed between the coating and the interface bone. Similar results in animal studies were reported by Cook et al. [45–47], Søballe K et al. [48], Maistrelli GL et al. [49], and Karabatsos et al. [50] in later periods. The benefits of hydroxyapatite coating based on the animal studies include accelerated response of bone to the implant, increased interfacial strength, enhanced filling of the gap, and the lack of a fibrous tissue membrane development. Limited animal studies reported on the effectiveness of hydroxyapatite titanium porous-coated acetabular implants. These results demonstrated that hydroxyapatite porous-coated acetabular components significantly enhanced bone ingrowth in the presence of wear particles, preventing their migration and reducing osteolysis [51]. Different hydroxyapatite coating methods have also been examined in order to improve ingrowth of bone onto the implant surface and increase of mechanical anchoring strength to bone such as surface-induced mineralization techniques [52] or arc-sprayed techniques [53]. Finally, recent experimental studies in animals have been focalized on the enhancement of fixation of titanium porous-coated implants with the use of local bisphosphonate treatment [54, 55], growth factors [56], and bone morphogenetic proteins [57], with encouraging results.

Despite the large amount of experimental studies regarding titanium porous-coated implants in orthopedic surgery, several processes involving the material-bone interface stages are not well understood. The response to titanium implantation seems to be similar to other materials and involves the formation of hematoma, the adhesion of inflammatory cells, the persistence of multinuclear cells, the bone formation, and finally the bone remodeling.

Human Studies

Since the idea of bone ingrowth around synthetic materials was generated in 1909 [58] and since the first experimental application of porous materials 40 years later, it was only in 1970 where the application of porous surface in titanium was described [40, 59]. The introduction and acceptance of titanium as implant was facilitated by reports of poor adaptation and increased erosion over time with the implants used to that point, line stainless steel. The exceptional material compatibility with the human organism as well as the decreased elasticity and density of titanium made it an excellent choice as implant material. Implants inserted in the human body are causing various tissue responses mainly involving the bone tissue around the implant [60]. This reaction to the bone-implant interface is related basically to the material properties and the architecture design of the implant [61]. Implants that are corroded are reported having a severe tissue response compared to those being stable. The most common material used alloys are cobalt–chromium and titanium alloy metals. Titanium seems to minimize the stress shielding in comparison with the stiffer cobalt–chromium alloy implants by having a lower modulus of elasticity and better biocompatibility [62]. Even from the early experience of titanium implants, it was suggested that the tissue response to the implant was not confined to the osseous tissue, but it was expanded to the non-osseous surrounding tissue [61]. Comparing titanium with other metals used in the past as implants, like steel and cobalt, titanium demonstrated lower modulus of elasticity and reduced incidence of stem fracture with no incidence of abnormal wear in the joints [60].

There are several factors that are affecting bone fixation: micromotion of the bone-implant interface, poor biocompatibility, and inadequate contact. Taking into consideration the fact that bone ingrowth does not occur when the distance of the bone is more than 50 μm and that the rate of bone advanced apposition is approximately 1 μm/day, it is easy to realize the precision needed during the operation [63]. In several cases the most common response

Fig. 6.1 Bone ingrowth within the porous-coated surface of a titanium femoral component

finding at the site of the implantation was initially the formation of slender trabeculae of intramembranous bone at the bone-implant interface [64]. The bone ingrowth within the porous coating and the adjacent bone formed a continuum usually at 1 month after the operation, meaning that the femoral component exhibited certain degree of stability relatively early after the implantation that promoted early rehabilitation of these patients [64]. In order for the implant to achieve its initial bone ingrowth, it usually takes up to 3–6 months, while during the next period of the next 1 or 2 years bone ingrowth is progressing appositionally towards the porous coating depth (Fig. 6.1).

Total Hip Arthroplasty

Femoral Component

The use of orthopedic implants from titanium and its alloys started in the United Kingdom in 1970s. At that time, the problems encountered with the use of cobalt–chromium prostheses, mainly their early fatigue and failure as well as atrophy and reaction of the surrounding bone, facilitated the search for a new material with improved structural properties. The first used alloy was the Ti-6Al4V, which apart of the excellent biocompatibility demonstrated significant strength and fatigue resistance [65]. The replacement of vanadium by iron formed the Ti-5Al-2.5Fe that was used for implants that they were able to bend. The biocompatibility of the titanium is related etiologically to its ability to cause chemisorption of superoxide due to its effective passivation. Passivation is the process of forming a titanium oxide at the surface of the implant when titanium or its alloys are exposed to the body tissue [65, 66].

Nowadays, there are two widely accepted methods of implant fixation, cemented and uncemented. The cemented fixation provides a static result, meaning that it does not allow remodeling of microfractures that can occur at the interface of bone implant [67, 68]. On the other hand, cementless fixation has the advantage to be biological that allows bone ingrowth to the implant surface [67, 68]. However, the use of cemented implants was proven problematic especially in young patients where there was observed a high number of loosening cases [69]. Cementless arthroplasty proved to be a feasible alternative to cemented implantation for total hip replacement. The aseptic loosening as well as the difficulties in stem revision when cement was used was bypassed by the use of cementless arthroplasty [70, 71]. The first results of the use of uncemented fixation were discouraging with patients suffering from thigh pain, aseptic loosening, and proximal osteolysis [72, 73].

Over time, the design of the femoral component was continually changing in order to address problems reported and to improve the features of the fixation. It was suggested that the osteolysis

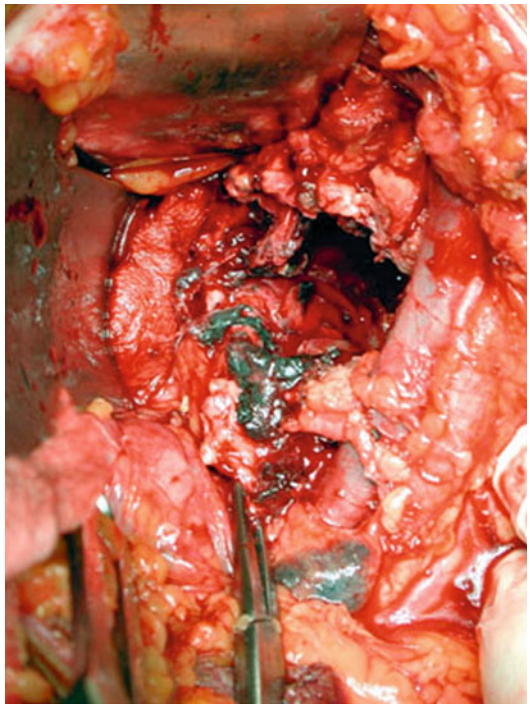

Fig. 6.2 Black deposits in the periprosthetic tissue from the wear of a titanium porous-coated THA implant

found in several cases was related to the stem design that involved stress-shielding effect at the component [74]. The results of THA using titanium alloys continued to be very good at an intermediate follow-up period. This is probably the result of the excellent adaptation performed at the bone-implant interface [75]. One problem noted with the use of titanium, is the extensive osteolysis and polyethylene wear, when metal on polyethylene articulation was the configuration used. These considerations led to the development and study of designs as ceramic-on-ceramic, metal-on-metal, and crossed-linked polyethylene. The behavior of Ti-6AI-4V when used against polyethylene in a cemented prosthesis was catastrophic. Early reports suggested the presence of black deposits and significant wear of the polyethylene and titanium damage when titanium alloys were used as a bearing surface (Fig. 6.2). Thus, the use of a ball head from CoCrMo or Al2O3 that could be the bearing surface replacing titanium in this area was proposed [76].

The introduction of porous-coated implants that was localized only to the proximal part of the femoral stem improved significantly the outcome (Fig. 6.3). Midterm results of porous-coated femoral stems showed minor loosening, and subsequently very few revisions were performed [75]. Although the coating should be limited to the proximal portion of the stem, at the same time it must be extended enough in order to provide adequate support and resistance to the load sustained. This is crucial especially in young and active patients [77]. The use of a plasma-sprayed porous-coated titanium alloy femoral stem showed very good results even at 10 years after primary arthroplasty, with minor loosening and revision rates reported [78].

The development of hydroxyapatite-coated implant improved the survival of the implants in clinical setting due to the proposed extremely strong bond to the host bone (Fig. 6.4). Remarkable bone apposition around the component with more rigid fixation and at the same time its ability to allow gradual replacement of the coating with living bone at an acceptable rate are the proposed advantages of the hydroxyapatite. Questions have risen from the potential strength of the bonding at the bone-implant interface and the brittleness of the material [79]. Gradually, new bone grows into the prosthesis at a rate comparable to the healing rate of a fracture [79]. Randomized trials proved the superiority of the hydroxyapatite–tricalcium phosphate-coated stems confirming that they had significantly less femoral bone loss [80, 81]. Primary reports suggested that the addition of hydroxyapatite coating dramatically improved the relatively poor results of earlier cementless press-fit stems facilitating initial and long-lasting mechanical stability [82] and led to a more rapid clinical improvement after THA [83]. However, these findings were not confirmed in several randomized controlled studies that showed comparable outcome with and without the use of hydroxyapatite coating [84, 85] with a survival rate being 100 % for the stem and 89 % for the cup after 16 years regardless the use of hydroxyapatite coating or not [85].

There are two different ways of hydroxyapatite coatings, plasma sprayed and electrochemically deposited (EDHA). Although plasma sprayed

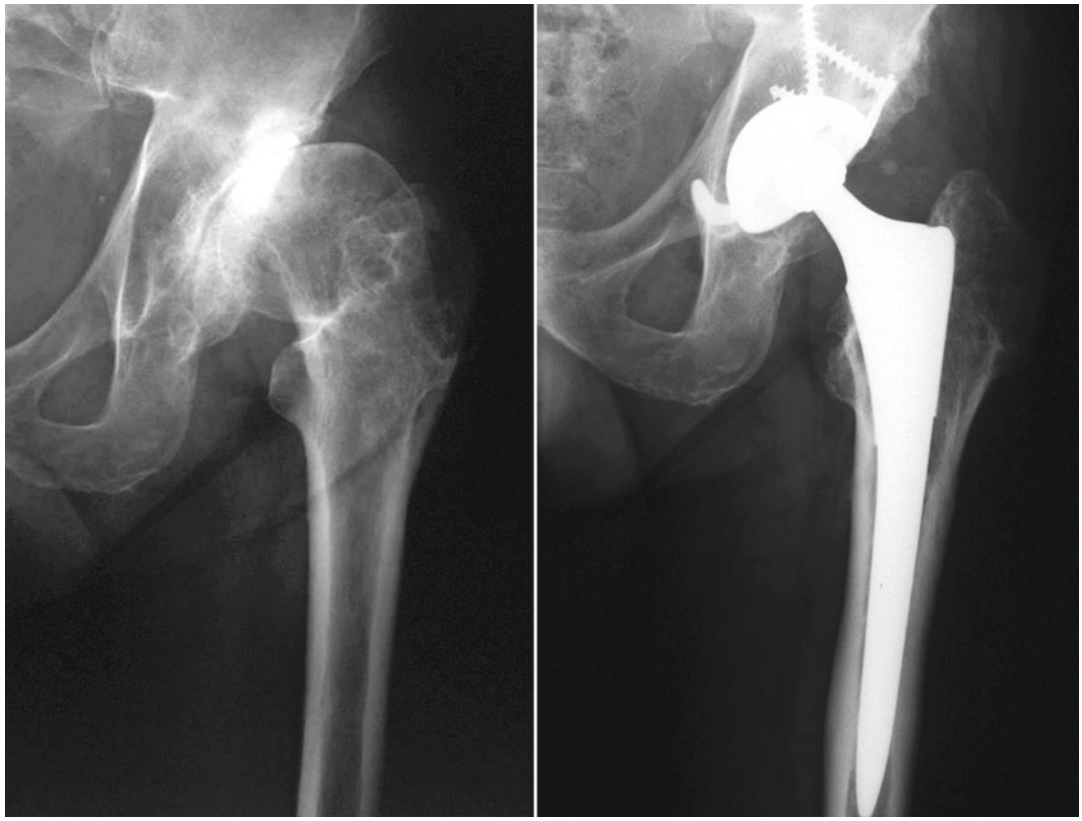

Fig. 6.3 Pre- and postoperative x-ray of a cementless THA with the use of a proximally porous-coated titanium femoral stem (Synergy stem, Smith & Nephew)

exhibits good results regarding prosthesis survival, the EDHA allows various biological substances like antibiotics or adhesives without considerable increase in implant thickness. Both groups showed similar clinical results and no difference in stem migration. However, there is evidence of less bone resorption in zone Gruen 1 with EDHA [86]. Despite the fact that titanium implants coated with hydroxyapatite have shown a survival rate of nearly 98 % in 10 years, other metals may exhibit an enhanced antimicrobial activity and a favored response to osteoprotegerin/receptor activator of nuclear factor K ligand (RANKL) ratio in cellular level studies [87]. However, the addition of other metals to hydroxyapatite coating needs to demonstrate its potential effect in clinical trials. Alterations in taper design have showed comparable results to cemented implants, in patients younger than 75 years old with funnel-shaped proximal femoral medullary canals [88]. Other advances in femoral stem design aimed to reduce stress shielding and proximal bone loss [89], with the use of circumferential porous-coated design and the use of titanium, which is more biocompatible being the most important [77, 90]. Further studies provided adequate data in order to improve anatomic orientation of the hip joint and more completely seal the proximal femoral canal to reduce particle-related osteolysis [91–94]. Advances in our knowledge about biological reaction and the confirmation of the pathogenetic mechanism of wear in total hip replacement by the acceptance of stem migration within the effective joint space have also led to improvements in implant design [92]. New implant designs with extensive porous titanium fiber–metal fixation surface, a mixture of CoCrMo in the core, and a layer from polymer have found to achieve stable fixation and reduced stress shielding at 10 year follow-up

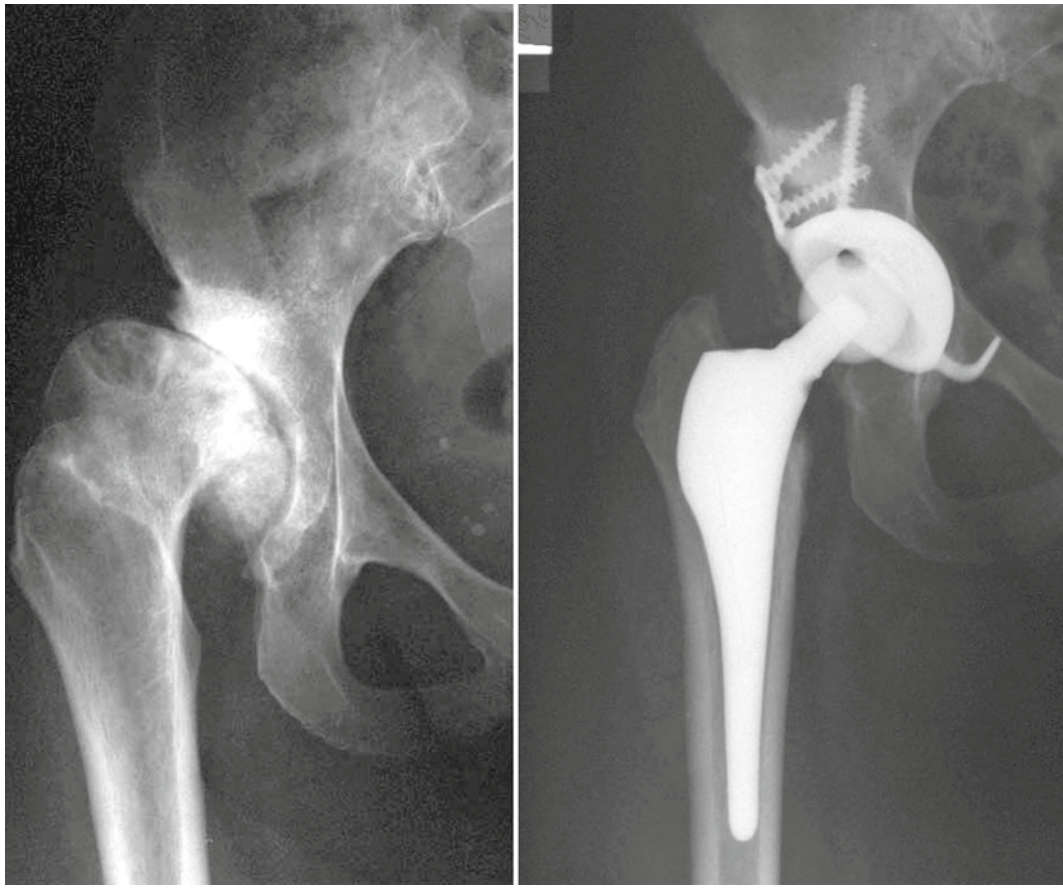

Fig. 6.4 Custom-made cementless THA with a titanium porous-coated femoral implant covered with hydroxyapatite at the proximal part (pre- and postoperative x-ray)

[95]. In this level I therapeutic study, the 10-year survival of the implant was 100 %, with cortical bone apposition along the distal stem that was judged complete in 92 % of the cases. No revision was performed, and there was no radiographic evidence of loosening or failure [95]. The adaption of a circumferential coating was found to have favored outcome and decreased the possibility of osteolysis and loosening possibly due to its ability to prevent the access and migration of particles wear [75]. Recently, long-term survival of titanium porous plasma-sprayed femoral implants was found to be extremely high [96]. Specifically, the cumulative survival was 98.6 % at 5 years, 98.4 % at 10 years, 97.1 % at 15 years, and 95.5 % at 20 years when any stem revision was used as the end point [96]. Interestingly, this outcome was not influenced by factors such as age or femoral anatomy or pathology, and it could be used with similar results in older patients or patients suffering from osteoporosis [96]. When aseptic revision for failure of ingrowth was determined as the end point, then stem survival was reported to be as high as 99 % [96]. In an attempt to produce a hip replacement system that could reduce stress shielding and minimize other complications such as thigh pain, systems like Buechel–Pappas THA have developed [97]. Its improvements include a 30°-angled loading collar without porous coating at the medial part of the proximal component and a thin-film ceramic surface coating. The clinical and radiographic evaluation demonstrated very good survival of these prostheses [97]. A recent study evaluating osseointegration in stem revision with actual radiographic signs has shown that although

reduced, there is still an increased incidence of stress shielding due to the higher stiffness that the stem demonstrates beyond 18 mm of diameter [98]. A new design that combines cementless, metal-backed alumina bearings showed promising early clinical and radiographic results with regard to wear-related problems [99].

Acetabulum

Titanium implants of acetabular component of the hip joint replacement were compared with the recently developed tantalum cups for revision surgery. Early findings suggest that bone deficiency can determine the implant of choice. Tantalum exhibited better results with fewer failures in major deficiency grades. In cases where there was no bone deficiency both titanium and tantalum implants demonstrated comparable outcome [100]. In the condition of acetabular bone defects in total hip replacement, the use of cemented polyethylene cup together with impaction of allograft bone has considered for years a successful technique. On the contrary, the usage of uncemented cup stabilized with screws has proven unsafe and problematic. There are promising results with the use of press-fit tri-spike cup, which is composed of a porous surface from titanium alloy that allows secure fixation without the use of screws. Recently, there are reports that favored the use of a porous acetabular component which may allow a greater number of surgical options for reconstruction [101, 102]. The survivorship for the tri-spike acetabular component was 100 % for cup loosening/revision and 97.8 % for radiolucency at 9 years follow-up [102]. The presence of osteoporotic bone may impair the bone ingrowth in prostheses that are inserted using uncemented technique. Therefore it is common to use cement for these patients. However, titanium alloy stems implanted cementless in patients with osteoporotic bone demonstrated similar results compared to non-osteoporotic bone [103]. Stem survival was found 100 % at 5, 10, and 15 years for aseptic loosening in all types of bone classes (A, B, C) [103]. The reliability demonstrated by cementless fixation of a tapered femoral component in total hip arthroplasty has been questioned by the fact that the patients introduced first were young with good bone quality. However, studies conducted in patients with low bone quality confirmed the satisfactory results of this fixation even in these patients [104].

The failure mode of the acetabular component varies among the different cup designs. In a study comparing the different cup fixation methods in relation to revision, it was suggested that all methods provide comparable fixation. However, when the results were analyzed separately depending on the cause of the revision, it was found that aseptic loosening among the spiked cups was increased, while recurrent dislocation revision cases were equal among the different groups [105]. Hemispheric titanium acetabular components that have the advantage of not using screws for fixation, have demonstrated comparable results to other implants [106].

Cemented Fixation

The usage of cemented titanium implants is infrequent. Several studies suggested that the cemented fixation of titanium alloys resulted in poor outcome [107, 108]. Recently, the clinical and radiographic outcome of the use of cemented double-tapered femoral stem made from titanium was reported to be excellent [109]. A minor vertical subsiding, radiolucency without osteolysis at the bone-cement interface and a cortical hypertrophy were found in a small number of hips at 5 years, with no clinical effect [110]. The role of cemented fixation when titanium alloys implants are used remains controversial [110, 111].

In summary, the evolution of cementless total joint replacement was based on the late failure of the prostheses that use cement, involving particularly the acetabular component of hip replacements. The porous-coated prostheses were introduced as a need to alter the features of the bone-metal interface and increase strength against shearing forces that produced implant failure. The porous-coated surface allows adequate bone ingrowth, meaning that pores are created in order to allow the growth of bone into the metal surface. Certain characteristics of the pores

are affecting the properties of the bone-metal interface and therefore are related to loosening or failure of the implant device. Several properties of the pores have been proposed to alter bone-implant interface mechanics like porosity, pore depth, and pore gaps. Porous coating is nowadays usually constricted to the proximal part of the prostheses. This allows more homogeneous bone loading and minor stress shielding.

Total Knee Arthroplasty

Overall, a small number of components for total knee arthroplasty (TKA) are made from titanium alloys (Fig. 6.5). Their introduction started because of the mechanical advantages of titanium that potentially could improve outcome in cementless implants. One of the major problems in knee replacement is migration of the implant and consequent aseptic loosening of the components. The use of titanium alloys was introduced because of the advantages of titanium regarding its biocompatibility, its strength, and elasticity. However, the concern about excess wear of the polyethylene against titanium implants has risen early [112]. In vitro there was no any additional wear of the polyethylene because of the use of titanium [113]. Furthermore, early results from the use of titanium alloys in TKA have shown comparable results in short-term survival of these implants [114]. Titanium implants used for TKA have demonstrated an increased rate of wear debris production compared to cobalt–chromium metallic components. Also, TKA using titanium failed earlier and was associated with a prompt failure at the patellofemoral region [115]. The excessive wear debris with titanium implants have led to elevated serum titanium levels. These could serve as a marker of component failure in total knee replacements with titanium alloy bearings, especially if this is localized to the patellar component [116].

In uncemented total knee replacement, porous coating is used in order to achieve biological fixation of bone-implant interface. The superiority of the uncemented fixation is questionable. Regarding fixation, it seems that hydroxyapatite augmentation offers better outcome compared to simple coated implants but with no obvious advantage compared to cemented fixation. Radiostereometric analysis (RSA) provides a very good predictive value for TKA migration [117]. Several studies have highlighted the poor bone ingrowth in to porous coating surfaces, especially in the tibia. For this reason, iliac grafting has been used to promote bone growth with promising results [118, 119].

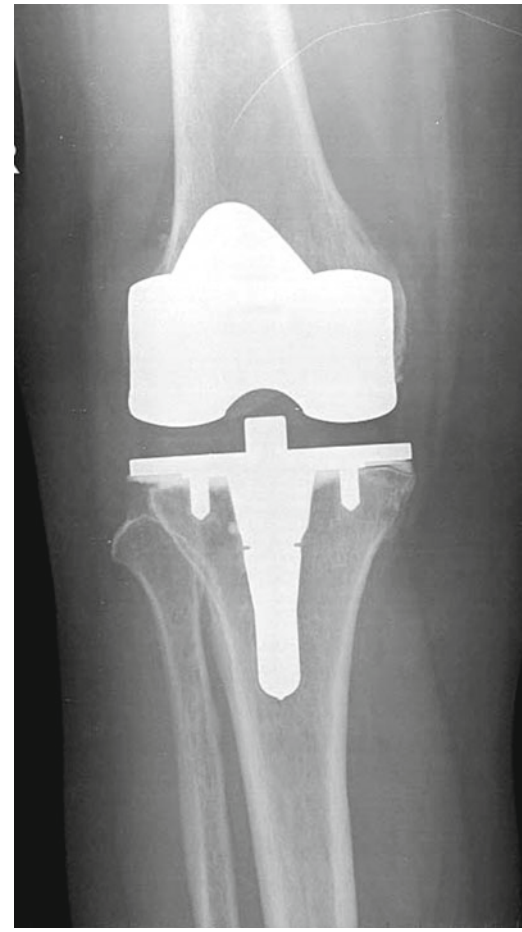

Fig. 6.5 Titanium porous-coated TKA

Other Joint Arthroplasties

Apart from the use of cementless prostheses in the hip and knee joint, titanium alloy implants have been used in elbow total replacement

surgeries with relative success [120]. Though, the problems of tissue metallosis and wear are present also in the elbow, despite the fact it is considered a non-weight-bearing joint [120].

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