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Long-term bone remodelling around 'legendary' cementless femoral stems

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- Bone remodelling around a stem is an unavoidable long-term physiological process highly related to implant design. For some predisposed patients, it can lead to periprosthetic bone loss secondary to severe stress-shielding, which is thought to be detrimental by contributing to late loosening, late periprosthetic fracture, and thus rendering revision surgery more complicated.
- However, these concerns remain theoretical, since late loosening has yet to be documented among bone ingrowth cementless stems demonstrating periprosthetic bone loss associated with stress-shielding.
- Because none of the stems replicate the physiological load pattern on the proximal femur, each stem design is associated with a specific load pattern leading to specific adaptive periprosthetic bone remodelling. In their daily practice, orthopaedic surgeons need to differentiate physiological long-term bone remodelling patterns from pathological conditions such as loosening, sepsis or osteolysis.
- To aid in that process, we decided to clarify the behaviour of the five most used femoral stems. In order to provide translational knowledge, we decided to gather the designers' and experts' knowledge and experience related to the design rationale and the long-term bone remodelling of the following femoral stems we deemed 'legendary' and still commonly used: Corail (Depuy); Taperloc (Biomet); AML (Depuy); Alloclassic (Zimmer); and CLS-Spotorno (Zimmer).

Keywords: bone remodelling; legendary stems

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Introduction and brief history of cementless stems

Cementless total hip arthroplasty (THA), described in the 1950s by McKee and Watson-Farrar, had fair to good reported clinical results.[1] Initial fixation was obtained by press-fitting an oversized smooth surface implant which did not allow secondary fixation, leading to aseptic loosening a few years after surgery.[2] In 1981, the work of Albrektsson et al on the principles of 'osteointegration',[3] coupled with advancements in materials engineering, paved the way for the development of stem surfaces and coatings allowing osteointegration (ongrowth or ingrowth) that achieved better long-term results.

Various cementless implant designs with different fixation methods were developed.[4,5] In the United States, one of the first cementless stems to be approved in 1985 was the fully coated cylindrical collared CoCr alloy stem, namely the Anatomic Medullary Locking stem (AML®), designed for distal diaphyseal fixation. Despite the excellent long-term track-record, undesirable thigh pain and proximal femoral bone loss secondary to stress-shielding were observed.[5-7] Other designs targeted more proximal metaphyseal fixation, with proximal porous-coated tapered titanium alloy stems. The tapers were either mediolateral (ML) or dual ML and anteroposterior (AP) tapers. The latter aims to fill the metaphysis in both the ML and AP planes, defining the 'fit and fill' concept. This enables the stem to get a strong rotational stability but, in cases of anatomical variability, sizing the stem may be very difficult. Conversely, ML tapered stems (Taperloc® stem being the first design) increase in size only in the coronal dimension, eliminating potential AP/ML mismatch, but theoretically providing less rotational stability. Both of these stem designs have an exceptional long-term track-record of survivorship and minimal thigh pain.[8-13]

At the time of the AML release in the USA in the 1980s, western European countries were developing two cementless designs. The first design was a fully grit-blasted tapered quadrangular section straight titanium alloy stem allowing fixation at the metaphyso-diaphyseal junction, the most popular designs being CLS-Spotorno® and Alloclassic® stems. The second design was a fully hydroxyapatite (HA)-coated, proximally flared with distally tapered quadrangular section collared straight titanium alloy stem, which is implanted after compaction broaching – the original and most popular being the Corail® stem. Those designs are still in use nowadays and have shown excellent long-term outcomes.[14-18] Interestingly, the Corail® stem is the most commonly used uncemented stem in the Australian (AOA 2014), England and Wales (NJR 2014) and Swedish (SHAR 2013) registries.

Once implanted, joint load transfer is modified and bone remodelling around a stem is a long and unavoidable physiological process. The related tissue modifications are related to implant design, which may render the long-term radiograph assessment of different femoral stems difficult. Nowadays, young orthopaedic surgeons frequently have to assess implanted stems in their third decade. In order to provide translational knowledge, we decided to gather the designers' standpoints related to the design rationale and the long-term bone remodelling of five 'legendary' stems still commonly used: Corail (Depuy); Taperloc (Biomet); AML (Depuy); Alloclassic (Zimmer); and CLS-Spotorno (Zimmer).

Basic science of bone remodelling around femoral stem

Bone tissues undergo routine turnover cycles and normal bone structure is maintained by a balance between the activity of osteoclastic bone resorption and osteoblastic bone formation.[19,20] Mechanical load forces continually expose the bone to a remodelling process according to Wolf's law.[21,22] Increased load leads to a gain in bone mass, and reduced load results in its loss. Osteocytes play a role in the mechanical regulation of bone by receiving mechanical input signals and transmitting these stimuli to osteoclast and osteoblast cells.[23]

The physiological load pattern provides a eutrophic bone, whereas atrophy and hypertrophy result from non-physiological bone loads. The loading pattern of the proximal native femur shows the calcar region withstanding greater compressive loads than the distal diaphyseal regions of the femur.[24] An ideal prosthesis should restore a physiological load transfer through the remaining bone. Unfortunately, following the implantation of all designs of THA, the femoral loading pattern is modified and results in a proximal unloading and a transfer of the majority of the compressive loads to the distal part.[24] Thus, the bone's local response to stem implantation is basically expressed by proximal metaphyseal bone resorption, seen with calcar and proximal cortical bone atrophy, and distal diaphyseal bone formation, seen with distal cortical hypertrophy. This adaptive response is found in varying degrees regardless of the femoral stem design, and it is more apparent with bigger and stiffer femoral stems.[6,25-28] Nevertheless, each stem design leads to a specific load pattern change which leads to a specific adaptive periprosthetic bone remodelling.[25,26,29-31] This remodelling process is thought to be potentially detrimental for patients by favouring late loosening and late periprosthetic bone fracture, rendering revision surgery more complicated.[32-34] Nevertheless, there is, so far, no evidence that clinical outcomes are related to bone remodelling regardless of the stem design assessed.[35,36]

Bone remodelling around the stem is affected by a physiological remodelling process defined as 'aging of the bone' with typical endosteal resorption causing widening of the medullary canal (age-related bone changes) coupled with an iatrogenic remodelling process related to the THA implantation (implant-related bone changes). Whereas the former process can only be influenced by medications influencing bone turnover, the latter depends on the surgical technique, the stem design and the activity level during recovery time. In studies comparing the implanted side with the contralateral non-operated side, the bone mineral density (BMD) in the proximal femur has been shown to lower in both sides but more in the operated side. Although the BMD in the non-operated side fully recovers at one year of follow-up,[25] BMD in the operated side remains lower in all Gruen zones at ten years of follow-up.[35] Conversely, the cortical thickness in the proximal femur at 15 years of follow-up was found to decrease in both sides but more on the non-operated side. This could possibly indicate a preservation of cortical thickness through stress transfer on the implant side.[37]

Stress-shielding is defined radiographically by the onset of proximal femoral bone loss or bone resorption, most commonly in the calcar area, but also the cortices in more severe cases.[6,25-28] The radiographic appearance of stress-shielding is graded according to Engh's classification.[27] Multiple studies support the fact that severe stress-shielding can often develop at mid- to long-term follow-up, and document the difficulty differentiating between age-related and implant-related bone changes.[37,38] On dual energy X-ray absorption measurements (DEXA), significant changes have been observed in the proximal femur (Gruen zones 1, 2, 6 and 7) for many years after implantation. Post-implantation of a stem, the BMD tends to decrease in all Gruen zones and most prominently in the proximal region, reaching the lowest values at two years. The reduction of BMD in the first two years after implantation is calculated to be around 10% to 40%.[25,35,39] In the period following that, a steady increase in BMD was noted, reaching at ten years' post-implantation a value similar to the post-operative baseline value.[25]

Implant-related bone remodelling is also characterized by excessive bone turnover during the post-operative period that can last for more than three years.[40] It depends on the new stress distribution imposed by the femoral stem on the proximal femur. The location and magnitude of stress transfer from the femoral component to the bone varies depending on many mechanical and biological factors. The former is related to the implant and the latter is related to the stiffness of the patient's bone. Factors promoting proximal femur bone resorption secondary to stress-shielding include: when the osteointegration area is distal (stem length, extended coating); stiff femoral stems (which is determined by their size and composition);[4,27-30,32,38] and low density proximal femoral bone (elderly patient, large and straight femoral canals, female sex).[32,37,38,41] Postmenopausal alteration of bone turnover predisposing to osteoporosis may explain why females are affected more by stress-shielding than males.[41]

Material and methods

When the femoral stems were initially designed, long-term bone remodelling around them was difficult to predict. The aim of this paper is to relay the long-term experience of expert clinicians and designers who are renowned for having a long-term world class experience with femoral stems we deemed legendary. Selected femoral stems had to be first implanted before the year 1990 and still be widely used in clinical practice. In addition, the stem's designer or expert user (since its early days) had to be available to participate in the current review. Selected stems were: Corail (Depuy); Taperloc (Biomet); AML (Depuy); Alloclassic (Zimmer); and CLS-Spotorno (Zimmer). We asked the experts to present their femoral stem design rationale. Second, we asked them to describe bone remodelling seen on standard radiographs over the years of implantation, especially the 'normal' and 'abnormal' radiographic signs. This knowledge prevents misinterpretation of normal radiographic appearances specific to each stem and supplies some insight into what to expect after a femoral stem has been implanted.

Designers'/ Experts' points of view

Corail® stem

Design rationale: The Corail® stem, made of forged titanium alloy (TiAl6V4), is a straight implant with a quadrangular cross-section. The proximal part has horizontal grooves and is flared in both sagittal and coronal planes. The distal portion has longitudinal grooves and a tapered design. In the absence of the formal theoretical argument, the Corail stem was available in two versions, with and without collar support. An extensive HA coating, with a 150-µm thickness, is applied to the stem using an atmospheric plasma spray process. In addition to the standard stem, three series exist, namely 'coxa vara', 'high offset' and 'short neck'. The ideal implantation technique is done by bone compaction broaching. The design rationale for this stem is to obtain initial mechanical stability by press-fitting the compacted cancellous bone all around the stem, with the collar acting to augment the stability by preventing its subsidence. The surgeon should avoid close cortical contact between the stem and the diaphysis, and thus it is normal for the stem to look slightly under-sized on an immediate post-operative radiograph. This low volume rectangular stem design with a compaction broaching technique aims to preserve both the bone stock and the endosteal blood supply, enabling the stem to fit a variety of bone shapes. The different neck options address different extramedullary morphotypes.

Long-term bone remodelling: The biological fixation starts during the first week and early migration over 3 mm is rare. Radiological signs of osteointegration (spot welds) appear as early as the third month; they are present all along the stem, but especially visible distally in the diaphyseal area. They persist throughout the life of the prosthesis. Radiolucent lines are almost never observed, as well as cortical diaphyseal reactions (atrophy or hypertrophy). Bone remodelling is very limited; nonetheless, calcar atrophy and some non-progressive radiolucent lines in Gruen zone 1 can be observed. In the vast majority of cases, radiological 'silence' is the rule with no significant changes in the periprosthetic bone trophicity observed even after more than 20 years of follow-up. The positioning of the stem in the canal (varus or valgus) has no significant influence on the periprosthetic bone pattern. Wear-related osteolysis progresses slowly and is only visible in the proximal femur (Gruen zones 1 and 7). In contrast, failure of bony ingrowth is characterized by the development of progressive radiolucent lines adjacent to the porous coating, calcar hypertrophy and distal bone pedestal formation (both are signs of load transfer to bone) and finally stem migration (Fig. 1).

Taperloc® stem

Design rationale: The Taperloc® femoral stem is a forged titanium alloy stem with a circumferential porous coating of the same titanium alloy that is applied using a plasma-spray technique. This flat, single-tapered stem (frontal plane) includes a reduced distal smooth wedge geometry to address proximal and distal femoral mismatch. Additionally, there is a 3° taper in sagittal plane to improve proximal progressive offloading and provide stability

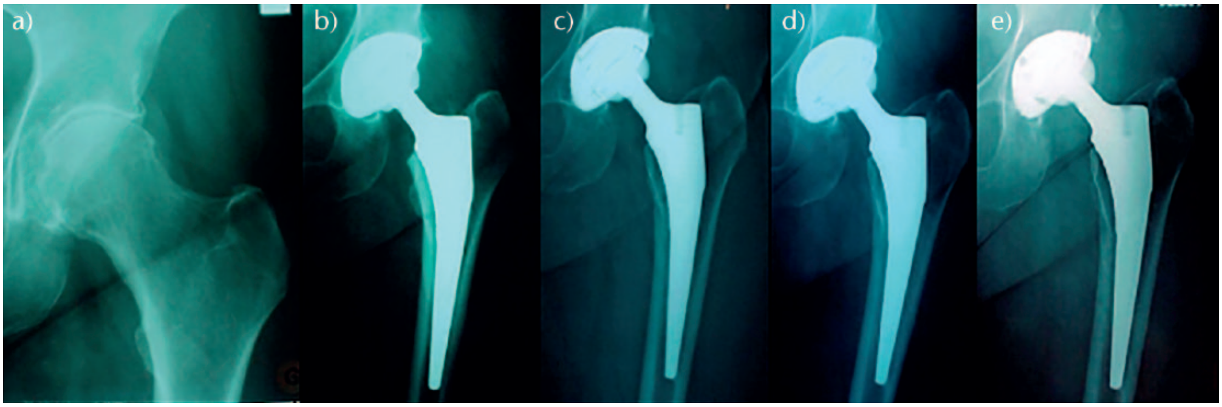

Fig. 1 a) Pre-operative radiographs of a 54-year-old male patient operated in 1988 for osteoarthritis. b) Immediate post-operative control; Corail® stem KA11, ceramic-on-poly bearing was implanted with the stem in a slight varus position but with good reconstruction of the hip anatomy. c, d, e) Successive AP radiographic controls done at five years, 15 years and 20 years, respectively, showing limited resorption in the calcar region. Note the radiological 'silence' with no significant modification of the periprosthetic bone pattern. No osteolysis on both sides, despite significant PE wear.

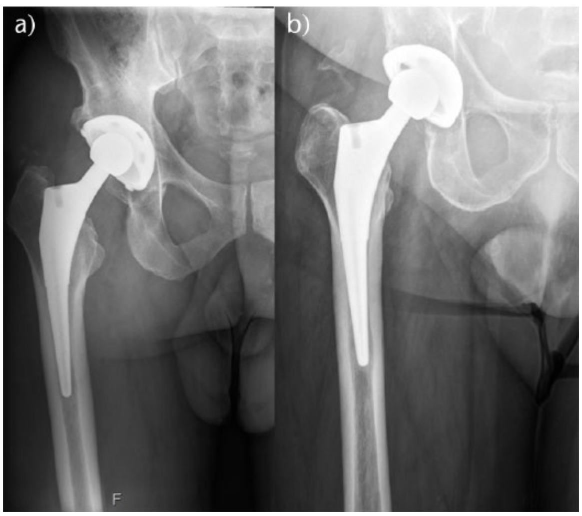

Fig. 2 a) 17-year follow-up on a Taperloc® stem with evidence of distal cortical thickening. b) 12-year follow-up on a Taperloc® stem with evidence of lucent zones.

between the stem and bone interface. Size increments occur only in the ML plane. The design rationale for this stem is to obtain fixation by a ML press-fit within the proximal aspect of the femur, whereas the smooth distal portion of the stem is designed to intentionally prevent distal fixation. This design promotes proximal loading and thus optimizes bone remodelling by reducing stress-shielding. The nearly single taper shape overcomes difficulties related to sizing the stem when facing anatomy variability like mismatch in the sagittal and coronal dimensions of the metaphysis, but theoretically at the cost of less rotational stability.

Long-term bone remodelling: It is common to see cortical thickening around the femoral stem at the distal tapered sections, especially distal to the plasma-sprayed portion (Fig. 2a). At later follow-up, this stem can also demonstrate some radiolucent lines around the tip of the stem (Fig. 2b). The key feature here is that there is evidence of increased radio-opacity around the stem compared with the distal femoral canal, which demonstrates evidence of ingrowth. These zones may be osteopaenic, but the lucent zones around the stem do not indicate stem loosening. Pedestal formation is not common with this implant and evidence of this feature would indicate that the stem may be loose. Long-term results with over 22 years of follow-up utilizing this uncemented stem have demonstrated low revision rates for aseptic loosening and high rates of patient satisfaction.[8-13]

AML® stem

Design rationale: Extensively porous-coated femoral components were first approved for cementless use in the USA in 1985. These cast CoCr alloy femoral components are straight and approximately 15 cm long. The distal portion is cylindrical to match the femoral diaphysis and the proximal portion is triangular to match the metaphysis. There are typically two metaphyseal sizes. Currently the porous coating using sintered beads covers all but the tip of the stem, but prior versions had porous coating over 30% to 80% of the stem's length. The design rationale for this stem is to obtain primary diaphyseal bone ingrowth with the comparatively long cylindrically shaped stem. Distal fixation was chosen because the diaphyseal bone is strong and the diaphysis is easily reamed to match the cylindrical shape of the stem. This is called a 'fit and fill' surgical technique, in which the intramedullary canal is prepared by clearing its contents. Stem stability relies on fitting the diaphyseal canal by achieving a scratch fit. The proximal triangular portion provides additional porous coating for

Fig. 3 Patients with AML stem and good bone quality might develop a spot weld and stress-shielding after a long time. a) Successive AP radiographs at one year, seven years and 15 years post-operatively showing a spot weld developing after seven years on the distal medial aspect of the stem. b) Later views confirm the spot weld formation.

ingrowth and supplements initial rotational and axial fixation of the stem.

Long-term bone remodelling: Findings consistent with ingrowth include spot welding of the bone to the porous coating of the diaphysis, bone resorption secondary to stress-shielding proximal to the spot weld, and calcar atrophy. In contrast, failure of bony ingrowth appears as an absence of these findings combined with radiolucent lines adjacent to the porous coating, calcar hypertrophy, distal bone pedestal formation and stem migration. Radiographic signs of bone ingrowth can take more than two years to appear. Spot welds and bone resorption secondary to stress-shielding are typically first seen on the lateral femoral radiograph. Proximal bone resorption or stress-shielding is always easier to identify among patients with osteopaenia or osteoporosis, who typically require a larger diameter stem. The radiographic findings associated with a bone ingrown stem tend to vary based on the patient's bone quality. For a patient with good bone quality, a spot weld and stress shielding do not appear immediately (Fig. 3). Among patients with osteoporosis, who often require larger diameter stems, a spot weld and stress-shielding are easily seen by three years, especially on the lateral radiograph (Fig. 4). When bone ingrowth does not occur, a stem may become fibrous stable or loose. Instead of a spot weld, a fibrous stable stem will develop parallel radiolucent lines (Fig. 5). Over many years this stem does not migrate, there is no calcar hypertrophy, nor is there a distal pedestal and, most importantly, the patient is asymptomatic. Retrieval analysis in cases like this has demonstrated a dense fibrous attachment between the radiolucent line and the porous coating that stabilizes this stem without bone ingrowth.[27] The hallmark of a loose stem is distal stem migration (Fig. 6). Additional signs of loosening include radiolucent lines and a distal pedestal. By far, the most important clinical sign of a loose stem is thigh pain. Although thigh pain in the first two years could represent a loose

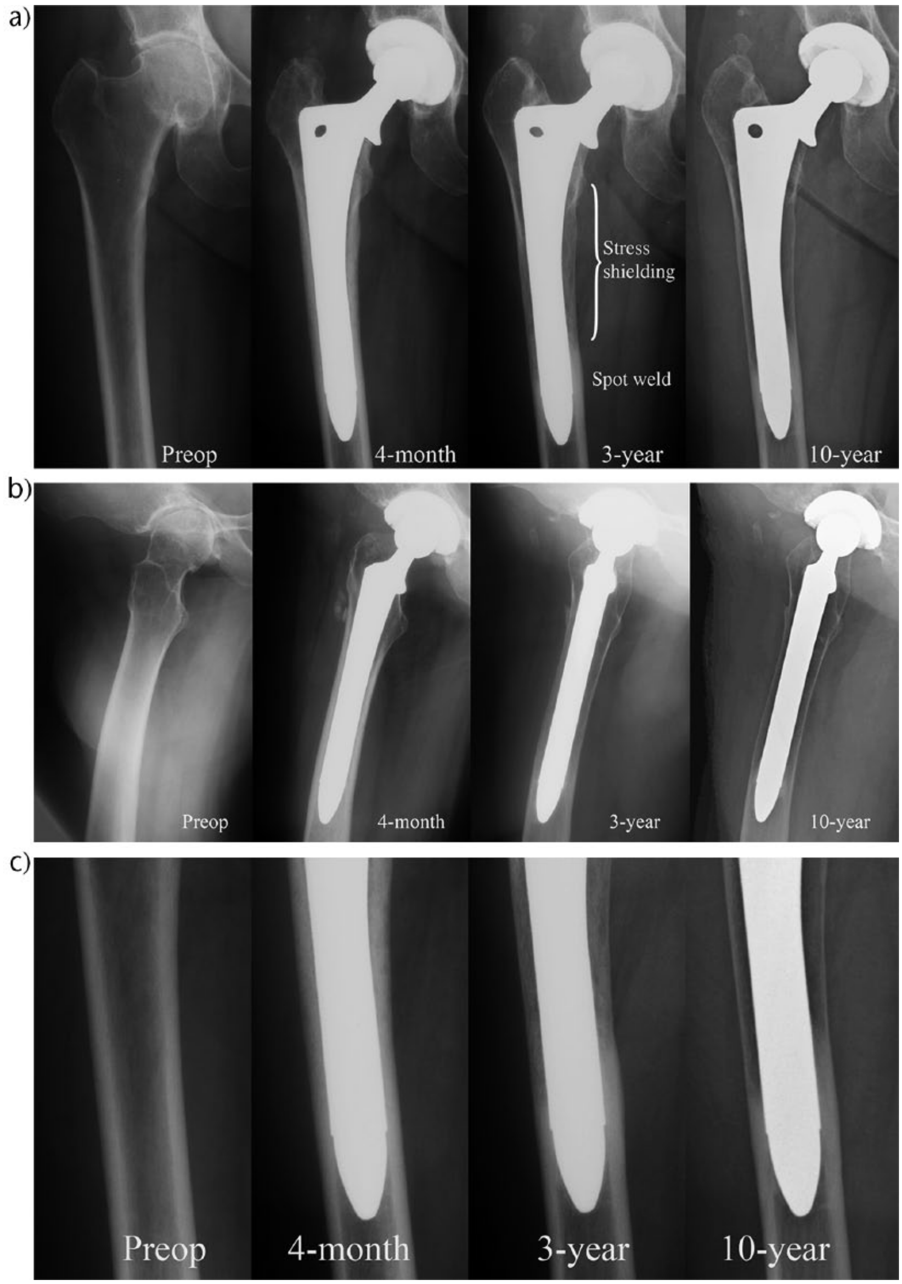

Fig. 4 Osteoporotic patients requiring a larger diameter stem develop a spot weld and stress-shielding earlier. a) Successive AP radiographs of an AML® stem at four months, three years and ten years post-operatively showing the development of a spot weld and stress-shielding which started as early as 3 years. b) Lateral views are more sensitive in detecting these changes. c) A close-up view of the distal stem showing enlarging changes.

stem, alone it is not indicative of stem loosening since 4% to 10% of patients with a bone ingrown stem have thigh pain. Because lucent lines and a pedestal can take more than two years to develop, waiting for these radiographic signs to diagnose a loose stem can be frustrating for both the patient and the surgeon. Luckily, extensively porous coated stems have only a 2% to 3% rate of failed ingrowth and a 95% survivorship after 20 years of follow-up as reported by The Anderson Orthopaedic Research Institute (AORI).[42,43]

Alloclassic SL® stem

Design rationale: The Alloclassic SL® stem was introduced on the market in 1986. The stem is manufactured from TI-6A1-7N alloy (Protasul®-100) and has a rectangular cross-section with a taper shape in both frontal and

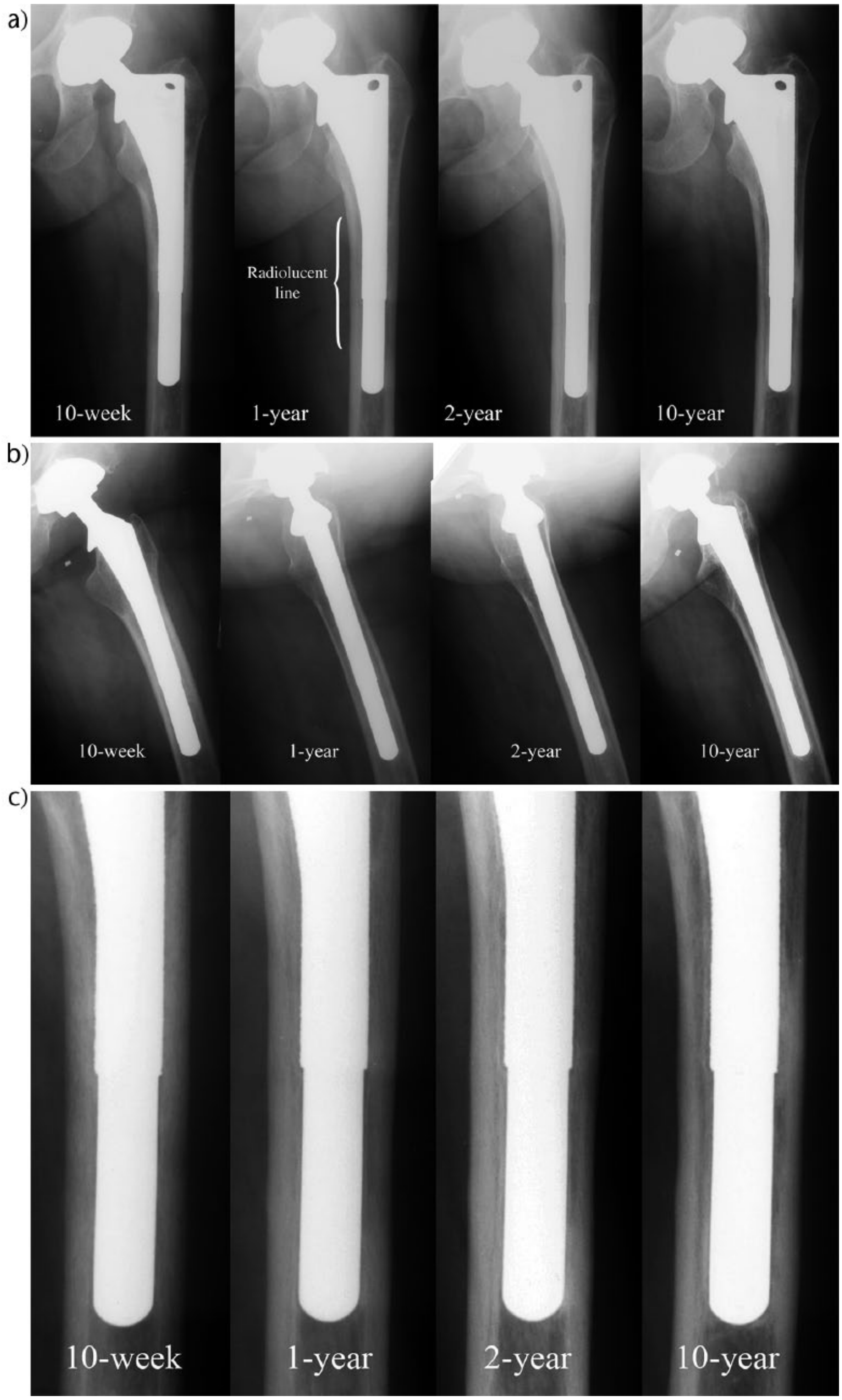

Fig. 5 A fibrous stable stem will be seen when bone ingrowth does not occur. Instead of a spot weld, a fibrous stable stem will develop parallel radiolucent lines. The stem is stable and does not migrate distally. No calcar hypertrophy and no distal pedestal can be seen. a) Successive AP radiographs of an AML® stem at one year, two years and ten years post-operatively showing the development of parallel radiolucent lines along the stem. b) Lateral views showing similar changes. c) A close-up view of the distal stem revealing more of these changes.

sagittal planes (dual taper). Increments from size to size are in all directions. The stem is fully grit-blasted to produce a 3- to 5-μm thickness micro-texture. The design rationale for this stem is to achieve stability due to a meta-diaphyseal junction cortical press fit. The Alloclassic stem uses a 'fit without fill' surgical technique and provides a

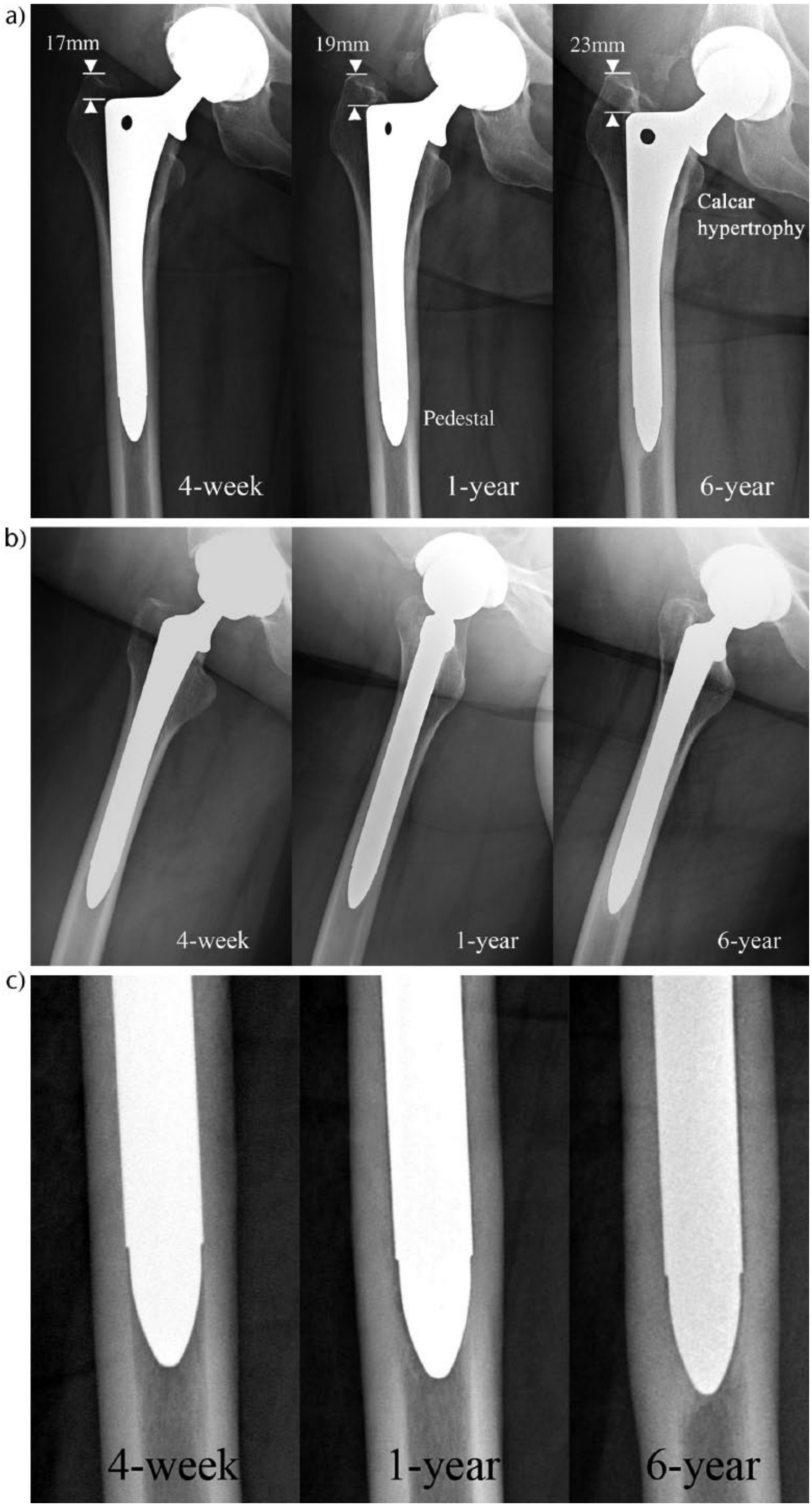

Fig. 6 A loose stem characteristic hallmark is distal stem migration. a) Successive AP radiographs of an AML® stem at four weeks, one year and six years post-operatively showing an increase in the distance between the tip of the femoral stem and the tip of the greater trochanter, indicating distal stem migration. Pedestal formation can be seen as early as one year post-operatively. b) Lateral views showing the pedestal formation. c) A close-up view of the distal stem showing more of these changes.

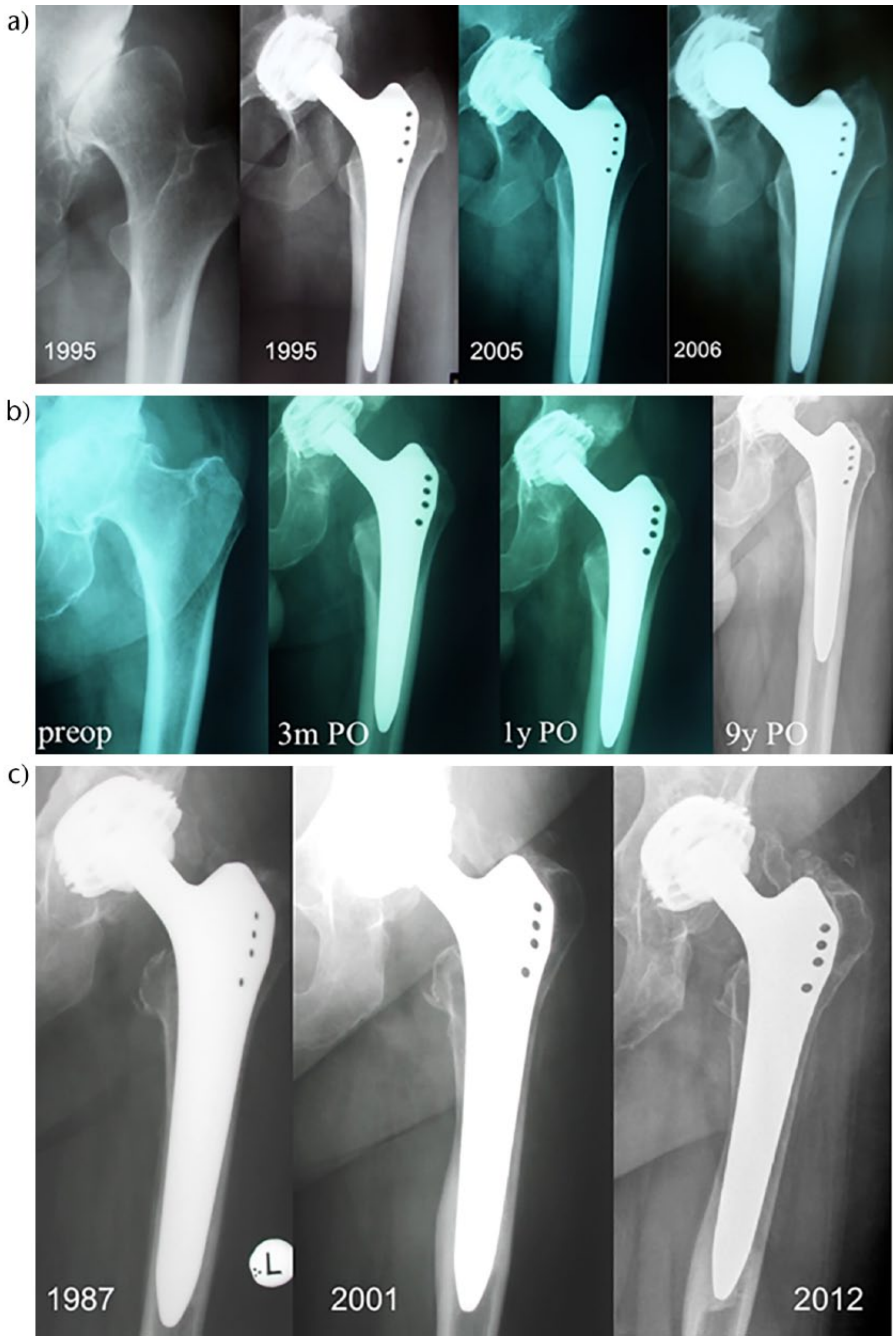

Fig. 7 a) Successive AP radiographs of an Alloclassic SL® stem immediately following surgery, and ten years and eleven years post-operatively, showing proximal cortical atrophy mainly in Gruen zones 1, 2, 6 and 7, indicating stress-shielding. b) Sequential AP radiographs of an Alloclassic SL® stem at three months, one year and nine years post-operatively showing cortical diaphyseal hypertrophy developing combined with proximal stress-shielding. c) Sequential AP radiographs of an Alloclassic SL® stem showing the adaptive behaviour of the stem in patients with osteoporosis.

posterior-anterior-posterior (PAP) cortical fixation when seen in the axial view. This technique preserves endosteal blood supply, improves initial stability and enables to fit a variety of bone shapes.

Long-term bone remodelling: Proximal cortical atrophy, a major sign of stress-shielding, is seen mainly in Gruen zones 1, 2, 6 and 7 (Fig. 7a). The average BMD loss usually ranges between 27% and 50%, and appears two years after implantation, but usually reaches a steady state at five years post-implantation. The amount of stress-shielding depends on the pre-operative anatomical situation, especially the cortical index with a proximal 'stove pipe' femoral shape tending to show more stress-shielding. Severe stress-shielding is uncommon and was only seen in two of 4000 patients (0.5%), suggesting that the low volume rectangular design is forgiving and reduces stress-shielding. Cortical diaphyseal hypertrophy developing in early years can be seen in about one-third of patients. It is a sign of distal stress transfer and is normally non-progressive and usually accompanied by proximal bone resorption secondary to stress-shielding (Fig. 7b). Non-progressive benign radiolucent lines have been described in 40% of patients and mainly occur in the proximal femur (Gruen zones 1 and 7). A reason for those radiolucent lines might be a proximal micro-motion with a distally well-fixed stem, but might also result from an intra-operative change of the primary rasping direction. Wear-related osteolysis is normally found proximally in Gruen zones 1 and 7, but in rare cases can occur more distally, thus allowing the distalization of the osteointegration area. In these rare cases, diaphyseal hypertrophy can develop secondarily. The positioning of the stem in the canal (varus or valgus) does not significantly influence the periprosthetic bone remodelling pattern or long-term survival of the stem. The Alloclassic stem has also proven to be suitable for patients with osteoporosis (Fig. 7c).[16,17,44,45]

CLS-Spotorno® stem

Design rationale: The CLS-Spotorno® stem is a collarless, tapered straight, grit-blasted stem. The design consists of a wider proximal and lateral portion with a thinner distal and medial portion, creating a triple wedge-shape (triple taper). The primary rotational stability is increased by ribs on the anterior and posterior surface providing interdigitation with the cancellous bone.[46] The stem is made of a titanium alloy that is roughened by 'grit-blasting' with 3- to 4-µm sized particles of aluminium oxide or corundum. The roughened surface allows bone ongrowth, leading to long-term stability. The design rationale for this stem is to obtain a press-fit in both the metaphysis and the meta-diaphyseal junction. The tapered shape prevents a complete fill in the distal diaphyseal portion, encouraging a more physiological load transfer in the proximal part of the femur. The triple taper creates compressive loading forces throughout the proximal femur to optimize further bone remodelling by reducing stress-shielding.

Long-term bone remodelling: The tapered geometry of the CLS provides long-term stability through osteointegration in the metaphyseal region (taper-lock effect). Indeed, rare severe stress-shielding and distal cortical hypertrophy have been detected after 30 years of follow-up (Fig. 8a). In patients with high congruence between the femur and the stem shape ('champagne-flute' proximal femur), stress-shielding is unlikely to occur. Conversely, in patients with low congruence ('stove-pipe' proximal femur), the stress-shielding onset is mild to moderate, suggesting osteointegration in the inter-sub-trochanteric region. At long-term follow-up, non-progressive radiolucent lines can be seen in one and up to three Gruen zones around the stem without affecting the stability of the stem.[47] These findings suggest that the CLS design prevents a more distal load transfer even in the long term. Wear-related osteolytic lesions are usually restricted to the proximal zones of the femur (Fig. 8b). The eutrophic bone in the metaphyseal region and circumferential stem osteointegration tend to prevent the distal progression of osteolysis. However, bone loss from wear-related osteolysis along with bone aging can result in the distalization of the load transfer, resulting in increased proximal bone loss secondary to stress-shielding.

Discussion

Bone remodelling around a stem is an unavoidable long-term physiological process highly related to implant design. For some predisposed patients, it can lead to periprosthetic bone loss secondary to severe stress-shielding, which is thought to be detrimental by contributing to late loosening, late periprosthetic fracture and rendering revision surgery more complicated. However, these concerns remain theoretical since late loosening has yet to be documented among bone ingrown cementless stems demonstrating periprosthetic bone loss associated with stress-shielding. In their daily practice, orthopaedic surgeons need to differentiate physiological long-term bone remodelling patterns from pathological conditions such as loosening, sepsis or osteolysis. To aid in this, we decided to clarify the behaviour of five of the most successful femoral stems still widely used. Our experts' review of the remodelling of these stems after long-term implantation showed that none of these replicate the physiological load pattern on the proximal femur, each stem design being associated with a specific load pattern leading to specific adaptive periprosthetic bone remodelling.

In a randomized study, Karachalios et al have shown the impact of stem designs on bone remodelling. When compared with the Alloclassic stem, the Corail stem has been shown to generate less bone resorption in the proximal femur with a return to baseline BMD values at ten years of follow-up.[25] Interestingly, no correlation was found between a set timeline and the severity of stress-shielding,[32] which may imply that only a subgroup of 'predisposed patients' might develop severe stress-shielding. Capello et al found in a cohort of patients with CLS stems followed for 15 years that one-third had no or little bone remodelling, and women with poorer bone quality

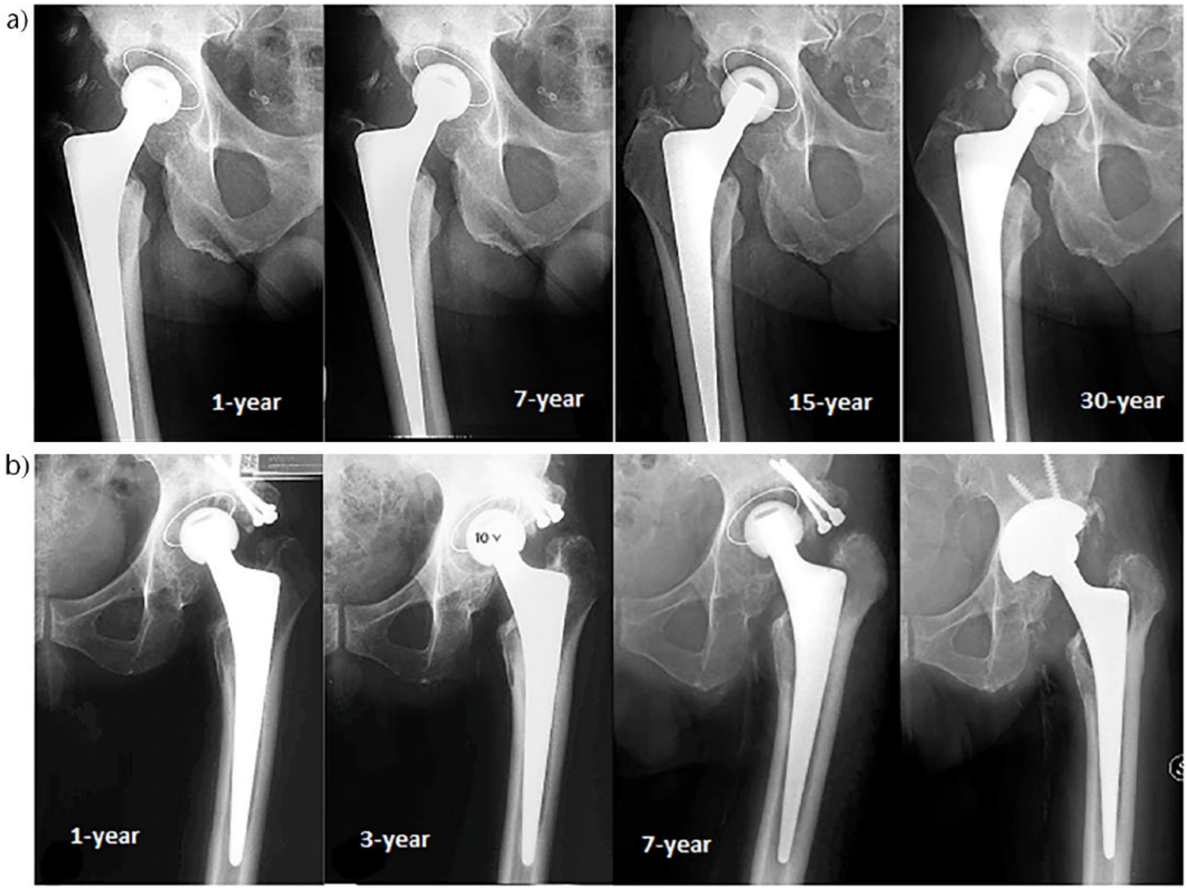

Fig. 8 a) Successive AP radiographs of a CLS-Spotorno® stem at one-year, seven-year, 15-year and 30-year follow-up revealing no stress-shielding and distal cortical hypertrophy. b) Successive AP radiographs of a CLS-Spotorno® stem at one year, three years, seven years and after a revision surgery performed to change the worn polyethylene of the acetabular cup shows that wear-related osteolytic lesions are restricted to the proximal zones of the femur.

Table 1. Femoral stems: long-term survival[7-12, 13-16, 44, 45]

Stem type	Survival (percentage)	Follow-up (years)
CLS stem	93	22
AML stem	98	20
Corail stem	99	23
Taperloc stem	99	26
Alloclassic stem	99	24

at the time of implantation were more likely to develop periprosthetic cortical porosity after ten years or more.[37] HA coating was found to improve osteointegration or 'internal bone remodelling' as defined by Braun.[48] Many studies supported this by finding significantly fewer radiolucent lines, superior proximal femoral osteointegration and less proximal stress-shielding, but without affecting the clinical outcomes.[17,25,49]

Despite all the differences between the stems reviewed, there is currently no evidence that one design is superior to another in terms of clinical outcome or extended long-term survival (Table 1). Thus, it is currently not possible to define what exact design features are more advantageous for long-term bone-stem compatibility. Nonetheless, by knowing the strengths and weaknesses of each design, it is possible to select the stem design that best serves each patient. For example, patients with low bone density who are at higher risk of developing stress-shielding-related bone loss will benefit more from a Corail-type proximally loaded, titanium alloy, HA-coated stem.

When looking at the long-term evidence for those stems more precisely, everyone should realize that excellent survival rates for aseptic loosening with more than 93% in the third decade does not reflect the true behaviour of these stems. In fact, those figures were gathered in retrospective studies describing the loosening rate by taking into account the whole initial cohort. It included patients lost to follow-up and those who died at a shorter follow-up. Using the Kaplan-Meier survival curve, including all implanted hips, the failure rate would become much higher. For instance, previously cited major studies relating excellent survival rates of the reviewed stems – 93% in Streit's study (20 CLS loose stems from 354 initial THAs), 98% in Belmont's study (six AML from 223 THAs), 99% in Vidalain's study (four Corail from 347 THAs), 99% in McLaughlin's study (two Taperloc from 145 THAs) and 99% in Kolb's study (two Alloclassic from 208 THAs) – have, respectively, only 40% (143 hips), 53% (119), 36.5% (127 hips), 25% and 34% of patients followed in the third decade.[10,14,15,42] In other words, the long-term survival rates given in the literature reflect the percentage of loose stems to be revised rather than the real survival rate of the stem. Because nowadays THAs are becoming much more common for younger patients with longer life expectancy, and are inserted in randomized studies, further reports based on the current trend of THAs could potentially show more realistic and perhaps inferior outcomes. On the other hand, tying to improve current results of these legendary stems is a very difficult task and the risk of failure probably outweighs the benefits. Arnand et al found analysing the Australian registry to be of no benefit in the introduction of new prostheses over the years 2003 to 2007, and moreover 27% had a significantly higher revision rate.[50] As shown in our review, replicating femoral bone remodelling using a femoral stem made of a material and a shape that differ from the natural bone structure was not possible. Each expert surgeon described the normal and abnormal bone remodelling patterns associated with their stem. Such knowledge is of primary importance for the follow-up of these well-performing stems over time.

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