



# Total hip arthroplasty: survival and modes of failure

Theofilos Karachalios<sup>1</sup>  
George Komnos<sup>2</sup>  
Antonios Koutalos<sup>2</sup>

- Total hip arthroplasty (THA) is a very satisfactory surgical procedure for end-stage hip disorders.
- Implant modifications, such as large femoral heads to improve stability, porous metals to enhance fixation and alternative bearings to improve wear, have been introduced over the last decade in order to decrease the rate of early and late failures.
- There is a changing pattern of THA failure modes.
- The relationship between failure modes and patient-related factors, and the time and type of revision are important for understanding and preventing short and late failure of implants.
- The early adoption of innovations in either technique or implant design may lead to an increased risk of early failure.

**Keywords:** total hip arthroplasty; failure modes; risk factors

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## Introduction

Since its introduction in the 1960s, total hip arthroplasty (THA) has proved to be an excellent and reliable treatment procedure for the end stages of hip pathology, with satisfactory clinical outcomes at 15- to 20-year follow-up.<sup>1-4</sup> Following the initial problems which pioneer surgeons noted in the 1960s and 1970s, such as surgical technique, structural implant failures and infection, orthopaedic surgeons in the 1980s faced problems regarding choice of appropriate acetabular and femoral implants and component fixation selection.<sup>5-8</sup> However, since then it has become obvious that the long-term survival of a THA is a multifactorial issue. Factors other than the implant, such as diagnosis, patient, surgeon and surgical technique, are also important in survival. Despite successful outcomes, THA revision rates have grown steadily in recent years.<sup>9</sup> Increased life expectancy in a globally aging population is associated with the increased use of THA, resulting in

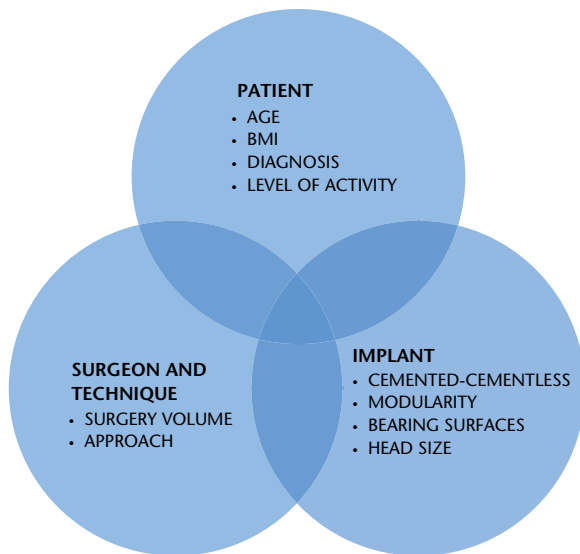
increased revision rates. Common causes of revision THA are wear, loosening, dislocation or instability and infection. It should be stressed that a changing pattern of modes of failure has been observed; failures are separated into either early or late, and factors related to failure modes have been identified (Fig. 1). With a more thorough understanding of reasons for failure, of revision timing and identifiable risk factors, surgeons are better placed to improve their THA outcomes.

During the past 60 years of THA, it seems that surgeons have had to learn from some devastating clinical failures, with patients often having been almost 'fashion victims'.<sup>10</sup> Despite recent advances in THA technique and improved outcomes, we must still pose the question: why do some THAs fail, leading to technically complicated and expensive revision surgery? This question is of particular importance nowadays at a time when economic health providers are asking challenging questions. With this review we also aim to show that the relationship between failure modes and patient-related factors, and the time and type of revision, are important for understanding and preventing short and late failure of implants, and that the early adoption of innovations in either technique or implant design may lead to an increased risk of early failure. For this purpose, revision rates presented in studies and reported registry data were thoroughly evaluated.

## Common modes of failure

### *Wear*

Wear debris production from bearing surfaces is thought to be the main factor limiting long-term THA survival. Cobalt-chrome or ceramic heads on old (used mainly by the Charnley THA group) or conventional polyethylene (PE) liners (developed in order to avoid oxidative degradation) have been used in the majority of patients, but are associated with wear and periprosthetic osteolysis. Alternative bearing surfaces have been developed in order to reduce the amount of wear particle production. PE has undergone improvements, from the development of ultrahigh-molecular-weight to crosslinked (XL) PE. These



**Fig. 1** Factors related to total hip arthroplasty failure modes.

improved PEs have shown better wear characteristics in combination with mainly metallic heads *in vitro* and *in vivo*.<sup>11</sup> Hard-on-hard bearings, such as ceramic-on-ceramic (CoC), with survival rates of approximately 97% at ten years, or metal-on-metal (MoM), with survival rates of approximately 90% at ten years (in the best reports), were initially considered attractive options due to reduced production of wear particles, but they are not suitable for all patients.<sup>12</sup> CoC bearings have been found to squeak and break, and they require optimal placement to avoid the risk of neck-to-socket impingement.<sup>13,14</sup>

#### Aseptic loosening

Various theories have been presented to explain the cause of aseptic loosening based on observational, experimental and clinical studies.<sup>15</sup> The main mechanism seems to be the excess production of wear particles, triggering a pro-inflammatory reaction which leads to increased osteoclast differentiation, macrophage production, linear or focal osteolysis and aseptic loosening (inflammatory-mediated osteolysis). Patient susceptibility to aseptic loosening may be affected by host-, genetic-, surgical- and implant-related factors (their relative importance is not known).

#### Dislocation

Dislocation is a difficult problem for both the patient and the surgeon and its management is expensive for the healthcare system. The true incidence of post-operative dislocation varies depending on surgical, patient and implant factors (0.3% to 3%).<sup>16</sup> Most dislocations occur in the immediate post-operative period (30% to 60%).<sup>16,17</sup> Patient risk factors include previous surgery, neuromuscular disorders, dementia, female gender, inability to

comply with activity restrictions and alcohol abuse. Avascular necrosis, congenital hip disease, THA performed on hip fractures and revision surgery are also predisposing factors.

Surgical factors related to dislocation include component positioning, failure to restore leg length or offset, abductor mechanism and capsule insufficiency and posterior approach.<sup>17</sup> Component positioning within the “safe” zone is important (combined anteversion being more important). However, other factors such as pelvic inclination and obliquity are equally important.<sup>18</sup> Implant-related factors that decrease the head-to-neck ratio increase the risk of dislocation. Larger heads with modern necks improve the head-to-neck ratio, increase jump distance, reduce component impingement and increase range of movement.<sup>19</sup> When the implant neck impinges against an osteophyte, scar tissue, liner, cement or heterotopic ossification there is a risk of dislocation.<sup>17-19</sup> The aetiology of late instability is often multifactorial and includes PE wear, longstanding malposition of the components, trauma and neurological and abductor muscle dysfunction.<sup>17,20</sup>

#### Infection

In the 1960s and 1970s THA pioneers noted a high incidence of septic complications which were occasionally lethal.<sup>21</sup> Advances in duration of surgery (reduction), surgical technique, the use of antibiotics and modern operating theatre settings have led to a dramatic reduction of infection.<sup>21</sup> However, there has recently been a global increase in infection rates.<sup>22</sup> New resistant biofilm-forming pathogens may be responsible for this, as may THA performed in patients with comorbidities (e.g. obesity, diabetes), and the use of immunosuppressive drugs. In addition, an increased incidence of low-virulence infections has been observed and a number of revision procedures, previously recorded as ‘revision due to aseptic loosening’, are now correctly being documented as infections.<sup>22</sup>

#### Reaction to metal debris

Recent advances in metallurgy and tribology have led to a renewed interest in the use of MoM bearings in THA. With improved fixation techniques, the concept of large head femoral components coupled with thin monoblock acetabular components (close to hip joint geometry) were rapidly adopted for MoM hip arthroplasties. Preliminary results with these second-generation MoM hip resurfacings were excellent, and their use became popular in the early 2000s.<sup>23</sup> Later, large diameter MoM bearings combined with cementless stems were used. A decade later, adverse reactions to metal debris (ARMD) came into focus. Metal debris, caused by increased wear of the bearing surface and/or corrosion of the neck-head taper (trunnion) in stemmed THA can lead to local soft-tissue reactions such

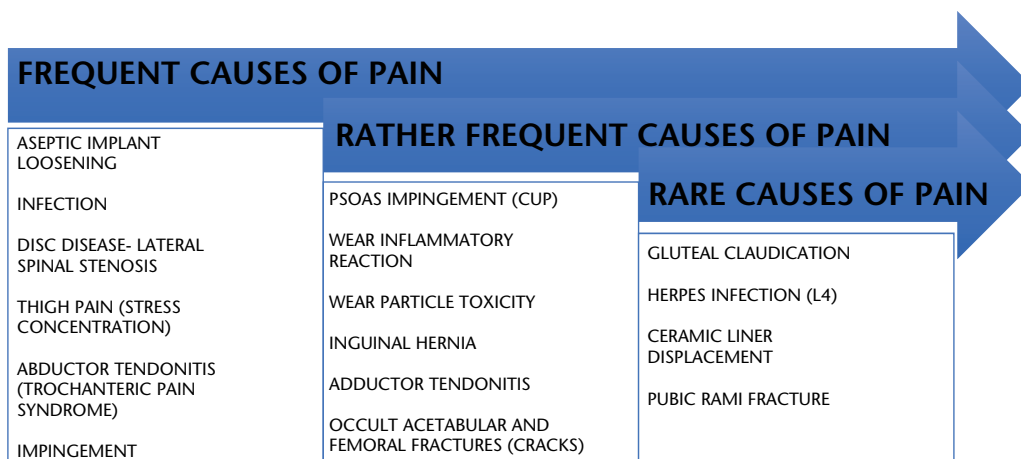


Fig. 2 Frequent and rare causes of painful total hip arthroplasty (which may lead to revision surgery).

as synovitis, necrosis and formation of extra-articular cysts or solid masses, i.e. pseudotumours.<sup>24,25</sup> Blood metal ion measurements and cross-sectional modern imaging (MRI) have proven useful in the diagnostics of ARMD in patients with unexplained hip pain. However, systematic screening for ARMD has been challenged due to methodological reasons.<sup>23-27</sup>

#### Periprosthetic fractures

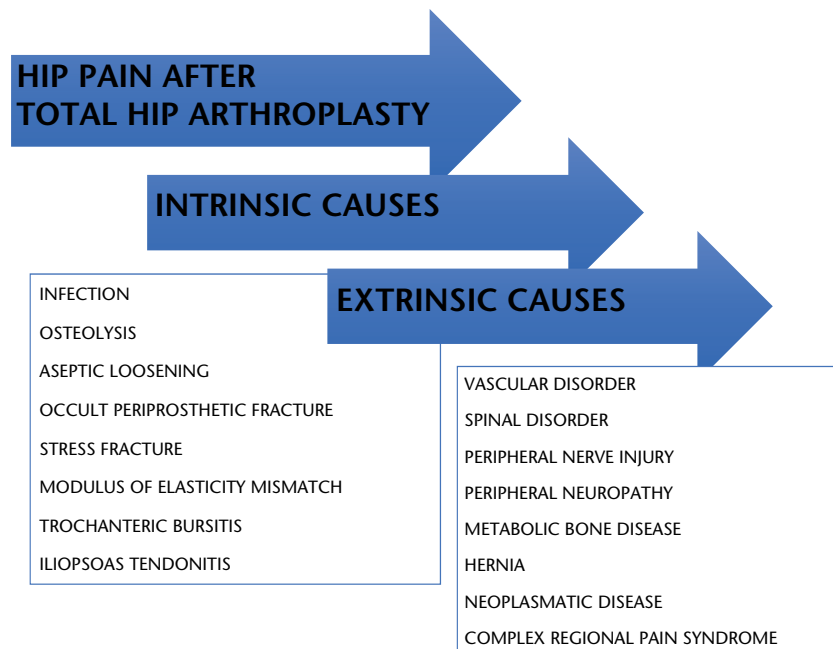
Periprosthetic femoral fracture (either intra-operative or post-operative) is a clinically important complication after primary and revision THA and hemi-arthroplasty. These fractures are associated with a poor clinical outcome and functional recovery and a high mortality rate.<sup>28,29</sup> Their incidence appears to be increasing as a result of increasing patient longevity, more demanding activity levels that persist into advanced age, and increasing rate of revision THA due to patients' increased life expectancy. Risk factors for intra-operative fractures are osteoporosis, rheumatoid arthritis, femoral preparation and surgical rasping technique, press-fit cementless stems and revision THA.<sup>28,29</sup> Risk factors for post-operative fractures are advanced age, female gender, post-traumatic osteoarthritis, osteoporosis, rheumatoid arthritis, proximal femoral deformities, previous hip surgery, type of implant and fixation, technical errors (cortical perforation and stress risers), low-energy trauma, osteolysis, loosening and revision THA.<sup>28,29</sup>

#### Unexplained hip pain

There are a number of patients who, following THA, experience hip pain for which the aetiology is difficult to define and which often leads to revision (Fig. 2). These hip pain causes are either intrinsic or extrinsic (Fig. 3).

### Risk factors

Identifying risk factors for THA failure is difficult because revision arthroplasty is relatively infrequent with late occurrence. The relationship between failure modes and patient-related factors, time and type of revision are important for understanding the short and late failure of implants.<sup>30</sup> In a systematic review of the demographic and clinical factors related to aseptic loosening and revision for any reason, young age at primary THA (risk of revision decreases per decade of age), gender (male patients), comorbidity (higher Charlson score) and diagnosis (rheumatoid arthritis and avascular necrosis) were all found to be important risk factors. Evaluating surgical and implant-related factors, cemented, cementless, hybrid fixation and head size proved not to be risk factors (due to confounding factors). For healthcare factors, low volume hospitals and low volume surgeons were risk factors for revision. When revision for infection was evaluated, longer operating time, male gender, cementless implants and cemented implants (without antibiotic-loaded cement) proved to be risk factors. When revision for dislocation was considered, older age, smaller head sizes and a posterior approach were found to have a higher risk.<sup>30</sup> In a systematic review evaluating host factors related to aseptic loosening, male gender and high activity levels were found to be risk factors.<sup>31</sup> Pre-operative diagnoses of depression and anxiety, liver disease, hypoalbuminaemia, vitamin D deficiency and diabetes mellitus are associated with increased risk of post-operative complications and unsatisfactory THA outcomes.<sup>32,33</sup> In a systematic review and meta-analysis of all randomized trials comparing cemented *versus* cementless fixation, it was found that fixation is not a risk factor as measured by revision rates. However, improved early clinical outcome can



**Fig. 3** Intrinsic and extrinsic causes of pain following total hip arthroplasty (which may lead to revision surgery).

be achieved by cemented fixation (due to less pain). However, in the long term, the relationships between clinical and functional outcomes, complication rates and mortality, are unclear.<sup>34</sup>

### Changing pattern of failures

Fevang et al<sup>35</sup> have reported on THA revision rates (1987 to 2007) from the Norwegian Hip register. A marked reduction in aseptic loosening of both components, over all time periods and in all subgroups of THA, was observed. This improvement was due to the increasing use of well documented implants with good outcomes. A change in the timing of revision was also noted, with more early revisions and fewer late revisions. Revision due to dislocation and infection increased over time. Similar findings were reported from the Swedish Hip register.<sup>36,37</sup> In two reports from the United States (revisions from 1990 to 2004) an increasing revision rate was found.<sup>38,39</sup> Concerning early failures, Melvin et al<sup>40</sup> reported (revisions from 2001 to 2011) a 24.1% revision rate at five-year follow-up. Aseptic loosening, infection, instability, reactions to metal debris and fracture were common causes of failure. In their previous report (revisions from 1986 to 2000), 33% were early revisions (70% due to instability and aseptic loosening). There are alarming reports of the incidence of metallosis and aseptic loosening of monoblock MoM acetabular components as the main causes of early failures.<sup>40-43</sup>

### Recent registry data

#### *Australian Registry<sup>41,42</sup>*

The proportional THA revision rate has decreased from a peak of 12.9% in 2003 to 8.9% in 2016. Osteoarthritis has a lower revision rate compared with hip fracture, osteonecrosis, rheumatoid arthritis and congenital hip disease (first month).

The most common modes of failure and revision of conventional THA are: loosening (25.6%), dislocation (21.6%), fracture (19.5%) and infection (17.7%). Since 2014, large head MoM bearings have been separately evaluated. In the first six years, dislocation is the most frequent mode of failure, and after seven years aseptic loosening becomes the most common. Early reported loosening is due to failure of initial fixation (surgical technique error). Late reported loosening is often due to loss of fixation (osteolysis and bone resorption). Revision rate changes with age and time. After two years, patients aged 75 years or older have a lower revision rate compared with all other age groups. Men have a higher revision rate after 1.5 years (9.2% for men and 8.4% for women at 16 years). Furthermore, male patients aged 75 years or older have a higher early revision rate compared with younger groups. Later, this difference disappears. For female patients, the revision rate decreases with increased age. After three months, female patients aged less than 55 years have an almost double revision rate compared with older female patients (75 years or older).

There is no difference in revision rate for cemented compared to hybrid fixation. Cementless fixation has a higher revision rate compared with hybrid fixation. Cementless fixation also has a higher early revision rate (1.5 years) compared with cemented (later there is no difference). For patients aged less than 55 years and 55 to 64 years, there is no difference in revision rate related to fixation. An exceptionally higher early revision rate (first month) was seen for cementless compared with hybrid fixation in patients aged 55 to 64 years. Cementless fixation also has a higher revision rate compared with hybrid fixation for all patients aged 65 years or older, and with cemented fixation for patients aged 75 years or older (perhaps due to intraoperative or early fractures).

(XL)PE has a lower revision rate compared with non-(XL)PE after six months; the difference increases with time and at 16 years the rates are 6.2% and 11.7%, respectively. This difference is more significant for head sizes of 32 mm and less than 32 mm when compared with non-XLPE. Loosening and dislocation rates are 1.1% and 1.3% for XLPE compared with 3.3% and 1.7% for non-XLPE at 16 years. Ceramic-on-XLPE shows a lower revision rate compared with metal-on-XLPE after three years. It should be stressed that ceramicized metal-on-XLPE shows the lowest revision rate. However, this bearing is a single company product, used in a small number of implant combinations. Revision rates vary with head sizes. This variation is more obvious with non-XLPE (revision rate increases with larger head size). For XLPE, 32 mm head size has the lowest revision rate and no differences were found when head sizes less than 32 mm were compared with those greater than 32 mm. XLPE and non-XLPE liners are combined with three different femoral head bearing surfaces: ceramic, metal and ceramicized metal. Within each bearing surface, XLPE has a lower revision rate compared with non-XLPE. Large ceramic heads (36 mm to 40 mm or larger) have a lower revision rate compared with 32 mm heads. After 1.5 years there are no differences in the revision rates between 28 mm or smaller and 32 mm head sizes. Moreover, the revision rate of 36 mm to 38 mm heads was similar to those of 40 mm or larger.

It has previously been reported by the registry<sup>41</sup> that the use of larger head sizes combined with XLPE led to lower dislocation related revision rates. At one year, the revision rate for dislocation is 2.0% for head sizes 28 mm or smaller compared with 0.4% for 32 mm, 0.3% for 36 mm to 38 mm and 0.1% for head sizes 40 mm or larger.

The main causes for revision of primary resurfacing hip arthroplasty are metal-related pathology (28.1%), loosening (23.4%) and fracture (18.7%). There is a rapid increase of fracture rates during the first year which slows down later. Metal-related pathology rates continue to increase and become the most common reason for late revision (after seven years). Revision rates decrease as the femoral

component head size increases. Smaller femoral head sizes show a double revision rate (due to metal-related pathology, loosening, fracture, infection and lysis) when compared with head sizes 55 mm or larger. These observations are age- and gender-dependent.

The revision rates for conventional THA, for hip fractures, is 7.9% at ten years. Dislocation (32.9%) is the most common cause for revision, followed by fracture (27.1%), loosening (16.6%) and infection (16.0%). Cemented fixation has a lower revision rate, for all time periods, compared with cementless and hybrid fixation after three months. Cementless fixation only has a higher revision rate compared with hybrid fixation for the first three months.

Aseptic loosening rates for short-stemmed THA are double compared with conventional stems at ten years (2.7% compared with 1.3%). However, revision rates vary according to the type of implant. Femoral stems with modular necks show a double revision rate when compared with fixed neck stems due to a higher loosening rate (2.5% compared with 1.9% at 15 years), dislocation (1.8% compared with 1.1%) and fracture (2.3% compared with 1.3%). Revisions rates for implant fracture were 2.9% for modular neck and 0.9% for fixed neck implants (for all bearing surfaces combinations). It has previously been shown that the stem/neck metal combination is important, with the revision rate of the titanium/cobalt chrome being higher than that of a titanium/titanium combination.

Revision rates vary among surgeons. Failure rates are improved when surgeons use satisfactory implants (low recorded revision rates). Higher revision rates were recorded for primary THAs (all diagnoses) performed in private practice compared with public hospitals. This difference was eliminated when implants with a known lower revision rate were evaluated.

#### *National Joint Registry (England, Wales, Northern Ireland, Isle of Man)<sup>43</sup>*

The revision rate after primary conventional THA for all groups of patients is 6.8% at 13 years. All cemented THAs showed the lowest revision rates (4.3% at 13 years, 3.8% for the ceramic-on-PE bearing combination). The revision rate for hybrid THAs is 5.1%, with the CoC bearing combination showing the best results (3.3% at 13 years). For cementless THAs, the pattern of failure varies over time. The revision rate is approximately double that of all cemented THAs (8.7% at 13 years) with the ceramic-on-PE bearing combination showing the best results (4.5%). Revision rate increases at a faster rate over time for younger patients (also seen in previous annual reports). Female patients under 55 years of age present a revision rate of 13.5% at 13 years which is 2.5 times greater than in female patients aged 65 to 74 years. Implant fixation affects



revision rate in the younger age groups and for women under 55 years a cemented ceramic-on-PE THA combination gives the best results (3.8% at ten years). For male patients aged under 55 years, the revision rate (all bearing surfaces) is 10%; 3.5% lower than that of female patients. The best recorded THA combination for younger patients is an all cemented implant with ceramic-on-PE bearing, which presents half the revision rate when compared with cementless implants with metal-on-PE bearings (at all time intervals). For older patients all THA combinations show satisfactory revision rates. When mortality and revision rates are evaluated together, it can safely be predicted that for most patients over the age of 75 at index operation, THAs will be retained for a lifetime.

For both metal-on-PE and ceramic-on-PE bearings, higher failure rates are seen with larger head sizes (36 mm for cemented and above 36 mm for hybrid and cementless THAs). When a CoC bearing is used, survival rates are improved with larger head size.

MoM implants, either resurfacing or stemmed, fail at higher rates than other bearings, with revision rates ranging from 14% to 27% for the worst implants at ten years. The best examples show lower revisions rates at the level of 8% to 9%. This has resulted in a dramatic and sustained reduction in their use.

The number of primary THAs performed for hip fractures is increasing. Revision rates are similar to those of THAs performed for other reasons, but mortality rates are higher.

The most common cause of revision is aseptic loosening, followed by pain. Within the first post-operative year, dislocation, fracture and infection are the most common reasons for revision, while the revision rate for aseptic loosening increases over the first ten years. Revision rates due to both aseptic loosening and pain increase with time from surgery, while rates due to dislocation, infection, periprosthetic fracture and malalignment are all higher during the first year and then fall. Both adverse reaction to particulate debris and osteolysis increase with time.

#### *Swedish Hip Arthroplasty Registry*<sup>44</sup>

Reoperation rates in relation to the total number of primary THAs performed (since 1992) have remained relatively stable (12% to 13%) (with a possible under-reporting of complications). Reoperation rates within two years decreased from 3.5% (1992 to 1995) to 1.9% (2000 to 2005). After this, the rate rises but stays at a constant level at just over 2%. Patients requiring reoperation became older and the proportion of women has increased. These patients are also sicker than those undergoing primary surgery and were most commonly operated on due to inflammatory joint disease, femoral necrosis and childhood hip disorders. The first-year reoperation rate is mainly due to infection and dislocation. During recent

years, infection continues to be the most common reason for early reoperation (two to three years). Comparing two sets of three-year periods (2006 to 2008 and 2012 to 2014), septic revisions have increased from 17.5% to 32.1%. The third-year reoperation rate decreased during the last observation period (2009 to 2011). From 1979 to 2009, revision rates increased with few periods of temporary falls. A small reduction in rates was then recorded and was followed by a constant rate over the last three years. Revision rates due to aseptic loosening and osteolysis have gradually decreased from 72.3% to 52.2% since the beginning of 2000 (2001 to 2005). For the same period, the second most common cause for revision is dislocation. After that infection rates increased, and in 2012 dislocation exchanged places with infection, with infection rates steadily increasing in 2013 from 13.9% to 14.6%. Early overall revision rate due to technical errors is around 1.7%, but in 2014 the rate increased to 2.3%. In this latest registry report, revision rates for reaction to metal debris, 'high and unclear pain' become apparent. Modes of failure and revision rates also vary with age. Revision rates due to loosening and osteolysis are relatively constant (66% of cases up to 84 years of age and 50.1% for those patients over 84 years of age). Revision rates due to dislocation and periprosthetic fracture increased with age (more apparent in patients older than 85 years). For the time-period (2005 to 2014), the most common (44.1%) cause for reoperation is aseptic loosening. The second most common cause is infection (19.5%), followed by fracture (13.6%) and then dislocation (12.6%). The revision rate due to periprosthetic fracture has doubled compared with the previous ten-year period (1993 to 2002, from 6.8% to 13.6%). The increased use of cementless stems, which have a greater risk of peri-operative or immediate post-operative periprosthetic fractures, is a possible explanation.

### Important considerations

It was found that for 24% of all THA implants available to surgeons in the United Kingdom there is no evidence of clinical effectiveness; these thus may be associated with potentially unknown modes of failure. Concern exists about the current system of device regulation, and the need for a revised process for introducing new orthopaedic devices is apparent.<sup>45</sup> A higher failure rate of newly introduced THA implants with no mid- and long-term clinical records was also observed in the Australian register.<sup>41,42</sup>

There is wide availability of various cemented designs with long-term proven records of clinical success.<sup>41-44</sup> However, a surprising number of series have recently reported early failures of cemented stems.<sup>46</sup> Some designs have consistently produced high early failure rates. Others

have failed infrequently, but the failures have occurred early and with extensive osteolysis. Failures are often multifactorial and defy a simple explanation based on a single parameter.<sup>46</sup>

The effect of femoral head size and surgical approach on the risk of revision for dislocation after THA was evaluated by the Dutch arthroplasty register.<sup>47</sup> Compared with the posterolateral approach, direct anterior and anterolateral approaches reduce the risk of revision for dislocation, but at the cost of more stem revisions, and revisions for other reasons. With the anterior approach, larger 36-mm heads increased the risk of revision for other reasons.

More recently, periprosthetic fractures have increased;<sup>41-44</sup> this is probably due to the increasing use of cementless implants worldwide. For late fractures, age and poor bone stock are predisposing factors. With an aging population, this failure mechanism will likely continue to increase.

## Conclusions

As we have come to better understand the failure mechanisms of THA, numerous modifications, such as large femoral heads to improve stability, porous metals to enhance fixation and alternative bearings to improve wear, have been introduced over the last decade in the hope of decreasing the rate of early as well as late failures. Early failures are most often attributed to either technical errors or early acceptance of alternative surgical techniques or innovations. Before evidence-based data are available to justify the risk of their use, care must be taken to make sure that early adoption of such innovations in either technique or implant design does not result in an increased risk of early failure.

### AUTHOR INFORMATION

<sup>1</sup>School of Health Sciences, Faculty of Medicine, University of Thessalia, University General Hospital of Larissa, Mezourlo Region, 41110 Larissa, Greece.

<sup>2</sup>Orthopaedic Department, University General Hospital of Larissa, Greece.

Correspondence should be sent to: T. Karachalios, School of Health Sciences, Faculty of Medicine, University of Thessalia, University General Hospital of Larissa, Mezourlo Region, 41110 Larissa, Greece.  
Email: kar@med.uth.gr

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