Complications of Total Hip Arthroplasty

Abstract Despite the worldwide success achieved by total hip arthroplasty (THA), this procedure is nonetheless associated with a variety of complications that could have deleterious outcomes on the patient's life. The effects of the surgery are frequently evaluated using the patient-reported outcome measures (PROMs), which are short questionnaires used to assess the health gains perceived by the patients through an analysis of a variety of factors, including pain, range of motion, and ability to return to their daily activities following the major orthopedic procedure. The article reviews some of the main complications and adverse events associated with the THA procedure, providing a detailed description, the perceived health status of the patients evaluated using the PROMs, and data regarding the potential factors increasing the incidence associated with each individual complication.

1 Introduction

The total hip arthroplasty procedure is performed to ultimately relieve the pain experienced by the patients, as well as improve their range of motion and lead to a better quality of life [1].

However, the surgery could potentially lead to several adverse events that negatively influence the outcome of the procedure, decrease the overall satisfaction of the patient, and substantially increase the costs correlated to healthcare [2]. Such challenges include postoperative task deficit, as well as other severe complications, including loosening of the implant frequently leading to dislocations, fractures, nerve damages, postoperative delirium, and heterotopic ossification [3]. In some instances, these challenges could lead to revision surgery, which is a particularly complex procedure requiring thorough preoperative planning [4]. The aforementioned complication could be associated with the employed surgical technique, the perioperative medical treatment, and the postoperative management and rehabilitation; furthermore, they could also arise as a result of the symptomaticity of the patient—such as the excessive wear of the prosthetic component [2].

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Patient-reported outcome measures (PROMs) are among the most used evaluation methods to assess the perceived health status of the patient following the surgical procedure, also providing useful information for the evaluation of the overall effect of the intervention.

2 Patient-Reported Outcome Measures

PROMs not only assess the functional outcomes of the procedure—which include the physical, social, and cognitive capabilities of the patient—but also examine the adverse events correlated to the surgery (such as tiredness, uneasiness, and pain) and multidimensional constructs, which specifically encompass the health-related life quality [5]. A wide variety of PROMs is being used to assess the perceived health gains of the patients undergoing THA, some of which include the Harris Hip Score (HSS), the Oxford Hip Score (OHS), the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the modified d'Aubigne and Postel Method, and the EQ-5D-3L questionnaire.

The HSS is a questionnaire consisting of four subscales that add up to 100 total points, with higher scores indicating a greater degree of functionality perceived by the recently operated patient. The first scale measures the intensity of the pain experienced by the patient (up to 44 points), and the second one is composed of the activities performed on a daily basis and the gait (47 points). The third and the fourth scales measure the absence of deformities (4 points) and the range of motion (5 points), respectively [6].

The OHS is, instead, based on the responses given by the patients to a total of 12 questions regarding daily activities. Each of the 12 questions presents five options, and the ones corresponding to normal functionality are associated with a score of 1, which then increases proportionally up to 5 based on the degree of perceived disability. The scores of all the answers are then summed, thus yielding a minimum score of 12 points—indicating normal functionality—and a maximum score of 60, which indicates grave disabilities [7].

The WOMAC includes three portions. The pain subscale is composed of five questions, the stiffness part is characterized by two questions, and the physical function section—the most substantial of the three—is composed of 17 questions. Each question is scored on a scale from 0 (none) to 4 (extreme), and the scores obtained for each of the three subscales are then added together. The minimum score obtained for each subcategory is 0, whereas the maximum score corresponds to 20 for the pain section, 8 for the stiffness subscale, and 68 for the physical function portion [8].

The modified d'Aubigne and Postel Method is extremely useful in the examination of pain, mobility, and gait. The various items are evaluated on a scale from 1—indicating the worst condition of the patient—to 6, which indicates their best condition, and are then summed to yield a minimum of 3 points and a maximum of 18 [9].

Finally, the EQ-5D-3L questionnaire comprises a total of five dimensions, each presenting ranging from no problems (level 1) to extreme problems (level 3). The five dimensions are mobility, daily activities, personal care, discomfort/pain, and anxiety/depression [10].

3 Postoperative Task Deficit

Despite the substantial improvements of the affected patients following the THA surgery, results show that the recovery in the period ranging from 6 to 12 months is not analogous to the functionality observed in healthy individuals [11, 12]. In fact, the functionality of patients undergoing THA corresponds to approximately 70% compared to healthy individuals prior to the procedure and increases by 10% in the first 6 to 8 months following the surgery [11]. Among the most frequently used tools for evaluation of post-surgical outcomes, the patient-reported outcomes (PROMs) provide a detailed analysis of several areas of function through the administration of questionnaires [13], clinical evaluations estimate the functions of the body—including the range of motion of the hip joint—and medical imaging measures the various structures of the body, e.g., offset of the femur.

Moreover, the timed "up and go," or TUG, test is another frequently used test to denote the degree of motor functioning of the patients [14], and it consists of a practical test that analyzes multiple skills performed on a daily basis to ultimately evaluate the progress achieved during rehabilitation regarding mobility [15]. When used in the presurgical stage, this test functions as a reliable predictive indicator of the length of stay following the procedure, the ability to ambulate up to 6 months after surgery [16], and the risks of complications such as deep vein thrombosis [17].

3.1 Deficient Functional Task Analysis of Patients After THA

The goal of the study conducted in [18] was to use the TUG test to establish the point at which patients displayed substantial differences in terms of deficits compared to the healthy control group, both prior and following THA, and to analyze the variations of these stages after the surgical procedure. Moreover, the alterations and deficits recorded in the overall TUG time were also analyzed and compared to the corresponding data gathered for each distinct phase.

To achieve this goal, a total of 123 patients were included in the research, 71 of which were diagnosed with primary osteoarthritis of the hip and the remaining 52 were healthy individuals, assigned to the control group. Among the 71 patients diagnosed with OA, 38 were subjected to THA via the mini-invasive Rottinger approach—a lateral approach involving dissection of the deep fascia anteriorly to the greater trochanter and carried down until reaching the neck of the femur—[19]

the mini-posterior approach is applied to 29 patients [20], and 4 patients had the lateral approach surgery. A dual-mobility cup was implanted in all 71 cases.

In order to perform the measurements, a total of 35 reflective markers were attached over the entire integument of the patients, and their trajectories were calculated at 100 Hz using an eight-camera optoelectronic system, later filtered at 6 Hz using a fourth-order Butterworth design [21]. The participants were then asked to perform a specific set of actions at a self-selected speed, which included sitting on an armchair—with its seat positioned 47 cm off the ground—standing up, walking up to a line positioned 3 meters away, turning around, and walking back to the armchair before sitting on it. This evaluation was performed both prior and 6 months following the surgery in patients affected by hip osteoarthritis, whereas it was only performed once in the healthy control group.

Analysis of the results obtained with the TUG test before the surgery highlighted a significantly higher deficit, corresponding to −41% (the negative correlation indicating abnormal functioning), in the walking phase of the THA patients compared to the healthy group, which appeared to be the most significant deficit even 6 months after the procedure, but with an inferior mean, corresponding to −22%. The average times calculated during the TUG tests were 14.9 ±4.1 s prior to the surgery and 12.9 ±2.8 s 6 months following the surgery, thus displaying an overall improvement of 11%, nonetheless still presenting a higher average time—by 20%—compared to the control group, which performed the task in 10.7 ± 2.1 s. In general, patients undergoing THA displayed a substantial improvement in the performance of all the tasks of the TUG test. However, they still presented significant deficits when compared to the control group, thus indicating an enhancement in their functionality but a partial restoration of the latter by 6 months after the procedure [18].

4 Dislocations

One of the major complications following THR is dislocation, which substantially impedes the performance of daily tasks for recently operated patients and increases their dissatisfaction [22]. Approximately 60 to 70% of THA dislocations occur in the first 6 weeks after the surgical procedure, whereas only a small population percentage, around 1%, will incur in dislocation several years after the surgery, usually correlated to implant wear, destruction of the soft tissues, or infections [23].

The term dislocation refers to the loss of articular contact between the previously implanted artificial components of the joint, perhaps attributable to the failure in meeting biomechanical requirements to achieve complete stability of both the pelvis and femur [24]. Figure 1 shows the pelvic radiograph of a patient experiencing dislocation after the total hip arthroplasty procedure [25].

Dislocation could be caused by three mechanisms: malpositioning and loosening of the acetabular or stem components of the prosthesis, leading to unstable contact between the articular surfaces; muscular insufficiency of the patient, leading to an excessive range of motion; and contact between the bony femur and bony

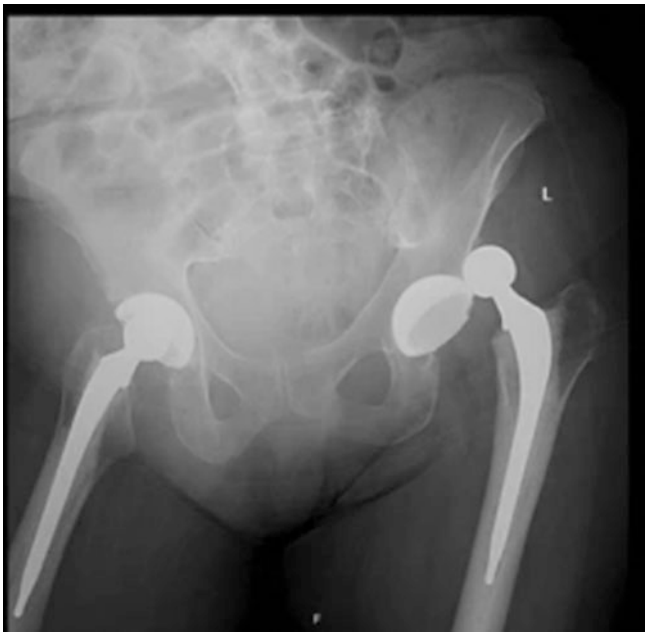

Fig. 1 Dislocated hip after THA

pelvis, or between the neck of the femoral stem and the acetabular component, leading to primary and secondary impingement, respectively [24]. In terms of patient-related factors leading to instability and subsequent dislocation, a higher incidence has been indicated for patients affected by neuromuscular conditions, including cerebral palsy, muscular dystrophy, dementia, and Parkinson's disease. Additionally, in patients of 80 years of age or older, a higher risk has been attributed to sarcopenia—a disorder affecting skeletal muscles and resulting in a progressive loss of muscular mass—to the loss of proprioception, which substantially increases the risk of incurring in falls and potentially leading to dislocation, and noncompliance to the postoperative rehabilitation protocol. One of the procedure-related risk factors leading to implant dislocation is the elected surgical approach, as the methodology chosen to perform the surgical procedure has a direct impact on the stability of the operated joint. In fact, the posterior approach has been associated with higher dislocation rates compared to other conventional approaches, mainly because of the detachment of both the external rotators and the external joint capsule, whereas the transgluteal approach has been correlated with the weakening of the abductor muscles, attributed to the partial detachment of the gluteus medius. The alignment of the implants constitutes another major factor in the stability of the operated joint. Based on the Lewinnek safe zone, the desired measurements regarding the position of the femoral and acetabular cups correspond to an inclination of 40°± 10° and an anteversion of 10° ± 20°, and failure in meeting the aforementioned requirements will result in instability of the hip. The experience of

the surgeon also affects the outcome of the procedure, as studies have shown that the level of experience acquired by the surgeon is inversely proportional to the risk of postoperative dislocation.

The incidence of dislocation is further influenced by the materials chosen for the prosthetic implant [24], as well as its design [23]. In fact, the service life of the components and the wear resulting from their constant friction are two of the main prosthesis-related factors ultimately leading to late dislocations [24]. In terms of implant design, several studies have indicated that the use of femoral heads with larger diameter substantially diminishes the risk of dislocation while simultaneously increasing the range of motion and jumping distance of the patient [26].

4.1 Transfer of Gluteus Maximus and Mass Graft (Capsulorrhaphy) for Hip Dislocation Prevention Following THA

The age of the patients, abductor weakness, female sex, and previous revision surgeries [22, 27] are among the main identified factors that could potentially increase the risk of dislocation, whose reported rate ranges from 1.7 to 4.8% following primary THA and significantly increases after revision THA (5.1–27%). In addition, the use of a femoral head with a size inferior to 32 mm was determined to be an ulterior risk element for re-dislocation, therefore suggesting the use of a larger head size to ultimately decrease the incidence of dislocation. Furthermore, the presence of medical comorbidities has been shown to have a significant impact on dislocation rates, particularly osteonecrosis of the femoral head (ONFH), mainly due to the intraoperative administration of corticosteroids, which result in a decreased rigidity of the tissues surrounding the surgical site, therefore allowing the patients to engage in activities foreseeing an augmented motion range compared to what they should supposedly undertake, thus increasing the likelihood of incurring in re-dislocation [27].

To prevent dislocation and in an attempt to increase stability, transfer of gluteus maximus to the femoral intertrochanteric region—to replace the abductor and thus cover the defects present within the pelvic structure—[28–31] alongside hip joint capsule enlargement, through the use of synthetic mesh, was performed. The procedure was then followed by patient education, who were instructed to avoid vulnerable positions such as flexion of the hip above a 90° angle, internal rotation beyond 0°, and adduction across the medial section of the body [32]. The previously analyzed procedure may ultimately aid in the prevention of re-dislocation of the hip; nevertheless, further assessments should be performed to corroborate the usage of mesh and gluteus maximus transfer for routine surgeries.

4.2 Dislocation and Revision Incidences in Patients Subjected to THA Receiving Lumbar Spinal Fusion Prior to or Following the Surgery

Lumbar spine fusion (LSF) could potentially increase the risk of impingement and dislocation [33–35] because of the substantial decrease in the mobility of the hip joint following its performance, thus causing an alteration in the biomechanics of the femur in an attempt to reestablish appropriate balance and stance. Such limitations in mobility could occur in two forms, namely, struck-standing and struck-sitting. Struck-standing alludes to the excessive rotation of the anterior aspect of the pelvis and excessive inward curvature of the spine in the lumbar region while sitting, potentially leading to increased incidence of impingement of the anterior aspect and subsequent posterior dislocation of the head of the femur when the hip is flexed [36]. Instead, struck-sitting refers to the excessive rotation of the posterior aspect of the pelvic and flattening of the normal curve of the lumbar region of the vertebral column while standing [37], a phenomenon that heightens the incidence of impingement occurring posteriorly and ensuing dislocation of the femoral head anteriorly when the hip is extended [35, 36].

The main goal of the study performed in [38] was to ascertain the presence of hypothetical differences in the occurrence of dislocation and revision surgery in THA performed either prior to or following LSF. A total of five studies were included in the analyzed review, comprising 43,880 LSFs performed prior to the surgery and 25,558 executed after. A higher incidence of dislocations occurring in the early postoperative period was detected in [39] for patients subjected to THA following LSF—2.8% occurring in the first 90-day period and 4.6% within 2 years—attributed to the already limited mobility of the hip joint, later subjected to the insertion of a new prosthetic implant which inflicted ulterior damage to the soft tissues and muscles of the patients. Instead, patients receiving LSF after undergoing THA displayed a higher incidence of late dislocations, with a percentage of 0.2% occurring within the first 90 days and 1.7% at 2 years, thus signaling an 8.5-fold increase [39]. A longer average time to dislocation was observed in [40] when THA was performed before LSF—15.33 ± 5.86 months—compared to when it was executed after, 11.71 ± 18.23 months.

In another study, a decreased incidence of revision surgeries determined to be required after dislocation as the time separating THA and ensuing LSF augmented, with a percentage of 24% after 1 year, 23.8% after 2 years, and 20% after 5 years, thus highlighting the importance of the healing process of both the muscles and soft tissues following THA [41]. Other studies assert the increased limitation in the mobility of the hip joint when LSF is executed after the THA procedure, because of the ulterior rigidity caused by the vertebral fusion [42] (which increases the incidence of dislocation), thus additionally stressing the substantial advantages in terms of biomechanics when the condition affecting the vertebral column is corrected prior to performing THA, a decision that allows for the optimal determination of the position of the acetabular cup, and increasing the stability of the joint [42].

In general, regardless of when it is performed, lumbar spinal fusion is observed to constitute a substantial risk factor for dislocation in THA [38].

4.3 Dislocation Incidences Following the Direct Anterior THA Approach

The DAA surgery is generally performed with the patients positioned supine, to simplify the utilization of intraoperative imaging, which substantially increases the accuracy of the installation of the acetabular component and the restoration of the length and offset of the leg. The supine position of the patients is correlated to decreased alteration in the position of the pelvis within the surrounding soft tissue, which allows for the comprehensive visualization of the acetabulum even without the use of technological instruments, ultimately enabling more precise placement of the acetabular component of the prosthesis compared to other approaches performed with the patient positioned laterally [43].

The DAA is associated with a decreased incidence of dislocation [44, 45], alongside inferior instability compared to other approaches, such as the direct posterior (DP), the anterior lateral (AL), and the direct lateral (DL) [44, 46–49]. Nonetheless, the DAA presents an abrupt decrease in the learning curve for the surgeons performing such procedure after operating via other approaches, a factor that could potentially increase the occurrence of periprosthetic fractures, as well as other complications [50–52]. Similarly, an increased rate of periprosthetic fractures has been indicated for surgeons who had already surpassed the initial learning curve.

One of the major risks of dislocation is the decreased mobility of the spinopelvic complex, which modifies the kinematics of the acetabulum and the femur [53–57], and ultimately raises questions regarding the appropriate surgical approach to perform for managing such issue.

The objective of the study performed in [58] was to assess the incidence of dislocation in a large, nonselective cohort of patients subjected to THA through the DAA, later subdividing the results based on the characteristics of the patients, risk factors, and surgeon factors. Moreover, the incidence of complications, reinterventions, and revisions was also analyzed.

All the surgeries were performed by seven surgeons, and no patients were excluded due to comorbidities or factors that could have potentially increased the risk of instability. The patients who experienced dislocations following the surgery were then examined to establish their body mass index (BMI), the time at which such dislocation occurred—categorized as early or late dislocation by reference to a 1-year threshold—as well as its direction, the position of the acetabular prosthetic component, measured using the Lewinnek safe zones [59] and based on the last anteroposterior (AP) pelvic plain film obtained before the dislocation had occurred, and the need for ensuing revision surgery.

A total of 2831 hips in 2205 patients were included in the study, with an average age of 64.9 years, and a mean BMI of 29.2 kg/m^2. The scores obtained via the American Society of Anesthesiologists (ASA) classification was I in 96 cases (3.4%), II in 1728 (61.0%), III in 968 (34.2%), IV in 38 (1.3%), and V in one instance (0.04%); moreover, the average follow-up period after the surgery was 61.4 months. All the procedures were performed using hemispherical acetabular prosthetic components with hard-on soft bearings with no face changing, lipped, or constrained liners, and no dual-mobility constructs were employed. Forty-three hips (1.5%) were subjected to the insertion of a 28 mm head, while other insertions included a 32 mm head in 590 hips (20.8%), a 36 mm head in 1909 hips (67.4%), a 40 mm head in 288 hips (10.12%), and a 44 mm in only one hip (0.04%) [58].

The dislocation rate obtained at the end of the study corresponded to 0.46%, as the overall number of dislocations amounted to 13, 11 of which (0.38%) were defined as early—since they occurred before the aforementioned 1-year threshold—whereas the remaining two were traumatic in nature, and documented 902 and 1556 days following the surgery. Out of the 13 recorded dislocations, only five (38.5%) were subjected to revision because of the instability of the joint: one was resolved via an elevated lipped liner, two were subjected to modifications and ensuing installation of a constrained liner, and two sustained the revision of the femoral component because of prior installment of undersized femoral stems. The subdivision by age yielded an incidence of dislocation of 1.65% for patients under the age of 50, 0.62% for patients within the age range of 50 to 59, 0.43% between the age of 60 and 69, and 0.17% for patients over 75 years old, whereas no dislocations were reported in the age range 70–74; moreover, the dislocation rate evaluated for females was slightly higher (0.63%) compared to the one measured for men (0.24%). The dislocated hips were located within the Lewinnek safe zone for anteversion in 11 cases, whereas the acetabular component of the remaining two was in an excessively vertical position, which was measured at 55° and 54° of abduction. During revision surgery, a 32 mm head was installed in five hips, a 36 mm one was employed in six hips, whereas the 40 mm one was used in two cases. Only two dislocations were recorded in 666 patients presenting decreased mobility of the spinopelvic complex (0.30%). In both instances, the patients had been previously diagnosed with degenerative lumbosacral pathology (2/627: 0.32%), whereas one of the patient's experiencing dislocation had been also subjected to spinal infusion prior to the procedure (1/104: 0.96%). The incidence of dislocation was 1.14% after THA performed by surgeons in their learning curve, 0.15% when the procedure was performed by surgeons who had surpassed the learning curve, and 1.11% for a single surgeon—who had transitioned to the DAA after 15 years of practice—and had performed 8 out of the 13 procedures that then resulted in dislocation.

The incidence of periprosthetic fractures of the femoral bone amounted to 0.67% (19 instances), 7 of which occurred within the first month following the surgery (0.28%), whereas 14 occurred within the first 90 days, yielding an overall incidence of periprosthetic fractures of 0.86% in non-cemented constructs, and 0.14% in the cemented ones. Among other complications, surgical debridement and antibiotics were required in 12 hips (0.42%) following the superficial breakdown of the wound,

and a total of 15 infections following the installation of the prosthesis were reported (0.53%), one of which took place within the first month, and five within 90 days (0.18%). Final recorded data indicated a reintervention rate of 1.94% and implant survivorship of 98.98% [58].

In summary, the results obtained in the analyzed study demonstrated a particularly low incidence of dislocation for the DAA, as well as fractures, periprosthetic joint infection, complications at the wound site, reintervention, and revision. Additionally, no differences in the dislocation rates of patients diagnosed with the pathology of the lumbosacral region were observed [58].

5 Metal Debris Complications of Dual-Mobility THA Implants Due to Acetabular Components' Corrosion

Patients at high risk of dislocation are presented with the option of undergoing THR with dual-mobility (DM) constructs, which consist of a small femoral head articulating within a mobile polyethylene liner that additionally articulates within a fixed acetabular shell. All the components of the previously described construct enhance the stability of the patient by increasing the head-neck ratio, jump distance, and range of motion [60]; however, the combination of products used contributes to the creation of a new interface that could potentially undergo corrosion and cause subsequent adverse reactions to metal debris (ARMD).

The systematic review conducted in [61] shows an estimated incidence of 0.3% of ARMD following modular dual-mobility (MDM) constructs, which is significantly higher compared to the one registered for non-metal-on-metal (non-MOM) primary hip replacements, corresponding to 0.032% [62]. The obtained results indicate a calculated median of dislocation of 0.8% and a percentage of 3.3% for revision rates. The mean calculated levels of serum cobalt postoperatively corresponded to 0.81 μg/L, while it was slightly lower compared to the one calculated for chromium, which was estimated to be around 0.77 μg/L, and about 1.8% of the patients included in the study displayed measurements of ≥7 μg/L—the cutoff value recommended by the Medicines and Healthcare products Regulatory Agency—for cobalt or chromium [61]. Despite the elevated levels of serum ions, there is currently no evidence that correlates the latter to an increased probability of adverse reactions to metal debris or worse clinical hip function scores. The only indication thus far is to address the postoperative care process with meticulous attentiveness [61].

5.1 Constrained Acetabular Liners' Outcomes and Survivorship upon Primary THA and Revisions

Some of the most frequently adopted techniques for the treatment of hip instability include revision of the implant for misalignment, the increase of the size of the femoral head—usually leading to the substitution of the polyethylene liner—to

achieve a greater range of motion (ROM) without incurring impingement, or conversion to dual-mobility or more constrained acetabular liners (CALs) [63–66].

CAL requires the input of greater force to lever out the head of the femur, which is mechanically captured by the implant and results in a decreased motion of the primary arc of the hip, which could result in early impingement. Highly constrained liners have been shown to transmit higher strain across the various interfaces of the implant, ultimately augmenting the risk of polyethylene wear, aseptic loosening, and recurrent dislocation [66–69].

The superior-ROM CAL is instead characterized by a constraining mechanism granted by a polyethylene liner extending past the middle part of the head of the femur. The reduction of the head necessitates a "snap" into the liner, and the mechanism is protected by a locking ring placed around the rim of the liner which decreases the opening of the cavity. The additional polyethylene structure present in the insert significantly expands the area of contact of the acetabular component with the femoral head, ultimately preventing the latter from displacing [70].

The tripolar CAL's constraining mechanism is instead granted by a bipolar component stabilized through a locking mechanism located on the peripheral ring [71].

The study conducted in [72] aimed to determine the most frequent complications deriving from the usage of CALs, as well as dislocation rates and survival of the implant compared to other methods.

A total of 37 studies were analyzed, including 4152 hips. The average age of the patients at the time of the surgery was 69.7 years, and the average follow-up period was 6.9 years.

The results indicated an overall complication rate of 22.2% [69, 71, 73–107], with an incidence of dislocation corresponding to 9.4%, 5.2% for aseptic loosening, 4.6% for infection, and 3.4% for fractures occurring after the implantation of the prosthesis.

The reintervention rate indicated at the time of the follow-up corresponded to 20.1%. Dislocation was the major factor leading to reintervention, with an incidence of 9.2%, followed by infection, which occurred in 4.6% of the cases. Moreover, the reintervention rates for aseptic loosening of the acetabular cup corresponded to 2.9%, whereas it was slightly lower for stem aseptic loosening, 1.5%. Finally, breakage of the implant and occurrence of fractures accounted for 2.2% of the overall reoperation rate, whereas infections accounted for 4.6% of the reinterventions. Overall, about 79.9% of the CAL implants didn't result in any reinterventions after the average 6.9 years to the follow-up procedure.

The preoperative Harris Hip Score (HHS) were recorded in 9 [73, 76, 77, 81, 90, 91, 98, 99, 103], out of the 37 included studies, whereas the postoperative HHS was indicated in 16 [71, 73, 76, 77, 81, 83, 88–93, 96, 98, 99, 102, 107], with an average score corresponding to 73.4 points. Moreover, the nine studies that included data for HHS both before and after the procedure indicated an improvement from an average score of 39.3 points preoperatively, to a mean of 72.5 postoperatively. Two studies [83, 91] indicated a mean Oxford score recorded preoperatively of 16.8, whereas four studies [82, 85, 90, 93] observed a mean score of 36.9 at the latest follow-up. Moreover, the Western Ontario and McMaster Universities Arthritis Index was reported both preoperatively and postoperatively in the study performed in [96],

indicating an average score of 54 before total hip replacement, and of 63.8 after the surgery. Finally, the study performed in [94] gathered the modified d'Aubigne and Postel Score both before and after the surgery, indicating a preoperative score of 5.3 and a postoperative score of 9.6.

In summary, the CAL implants are particularly effective in the treatment of patients presenting a high risk of instability and dislocation after the primary THA procedure or revision THA. This statement supported by the overall reintervention rate of 22.2% indicated in the study which was, however, higher compared to other implants such as dual-mobility acetabular cups or femoral heads presenting a larger diameter. Despite the higher percentages indicated for complications, the functional scores substantially increased after the installation of the CAL implants, which also showed a survivorship rate of 79.9% after 6.9 years [72].

6 Periprosthetic Fractures

Periprosthetic fractures (PFs) have been identified by the UK National Joint Registry as the third most common cause of revision, with an overall incidence rate of 3.5% after primary THA, which is predicted to further increase at a rate of 4.6% per decade over the next 30 years [108]. Moreover, they have been associated with a particularly high mortality rate, corresponding to 17.7%, and approximately 80% of the fatalities occur within the first 3 months after the surgical procedure [109].

PFs can be subdivided into early and late fractures, depending on when they occur after the initial THA surgery. Early PFs occur within the first year following the procedure, whereas late fractures occur after the first 12 months [110]. Such fractures are typically diagnosed via conventional radiographs, which allow for the visualization of radiolucent lines around the prosthetics or the cement component of the implant, or via computed tomography, which provides more detailed imaging of the fracture lines and hypothetical loosening of the implant [111]. The surgical procedure aiming at the correction and treatment of PFFs is associated with relatively high complication rates, mainly due to the age of the patients and to the presence of substantial comorbid diseases and requires, therefore, expertise in both revision THA and fixation of the fracture [108].

There are a variety of factors that predispose the patient to the development of PFs, among which the female gender, the presence of comorbidities—such as rheumatoid arthritis—the advanced age, and the presence of vast osteolytic lesions, which refer to areas of substantial loss of calcium from the bone, in younger patients with elevated levels of physical activity [110]. In addition, osteoporosis has been categorized as an independent factor for the development of PFs, as the presence of this disease substantially weakens the bones, increasing the likelihood of incurring in fractures [111].

The Vancouver classification is the most widely used method for the categorization of femoral periprosthetic fractures, taking into account the location and pattern of the fracture, as well as the stability of the implant, and its eventual loosening.

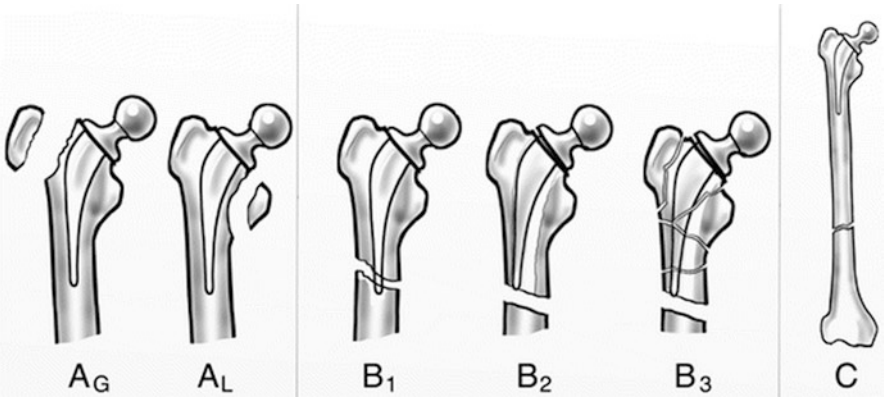

Fig. 2 Vancouver classification

Type A fractures occur in the trochanteric region and are further subdivided into AL, affecting the lesser trochanter, and AG, impacting the greater trochanter. Type B fractures occur around the femoral stem or slightly below it and are further subdivided into B1, in which the prosthetic implant remains well-fixed; B2, characterized by the loosening of the implant; and B3, in which the implant is loosened and the bone surrounding it presents relatively poor quality. Finally, the ones categorized as type C include fractures occurring well below the implant [112]. Figure 2 shows the categorization of periprosthetic fractures based on Vancouver classification [113].

6.1 Intraoperative Fractures During THA: Diagnosis and Management

The incidence of intraoperative periprosthetic fractures (IPPFx), as well as the potential risk factors, assessment, administration, results, and an overall estimation of the cost associated with these complications during primary THA, is studied in [114].

Primary THA has been associated with a rate of IPPFx ranging between 0.1% and 1% for cemented implants, while the same rate for the cementless procedure is significantly higher, corresponding to approximately 5% [115]. Other periprosthetic fractures could potentially occur at the acetabular component; however, these occur less frequently, as the reported incidence corresponds to 0.4% [115].

IPPFx have been associated with a variety of factors that could potentially increase the risk of incurring in such complications, including the increased age of the patients and female sex [116], both of which are primarily due to the decreased density of the outer surface of the bones.

The incidence of IPPFx has been reported to be particularly high for the THA procedure performed via the direct anterior approach (DAA), especially during the

learning curve period of the surgeons [117, 118], mainly attributed to the significant stress exerted on the tendons attaching to the trochanteric region of the femur and on the femur itself, which are already subjected to substantial strain during the preparation of the femoral canal and subsequent impaction of the prosthetic stem component [119].

The most commonly used acetabular implants are cementless and have been categorized as hemispherical, peripheral self-locking—characterized by a rim larger than the diameter of the true cup by 1.8 mm—and elliptical, which have a peripheral flare [120], and the greater incidence of IPPFx has been associated with the elliptical peripheral self-locking acetabular components. As for the cementless femoral stems, the highest risk of IPPFx has been associated with type-2 implants, characterized by "fit-and-fill" stems and comprising about 90% of periprosthetic fractures, whereas the type-6 implants (anatomic stems) have been associated with a 10% risk, correlated to the variation in the geometry of the proximal femur, which could potentially impact the overall distribution of the mechanical strain [121]. IPPFx of the femur could occur during the compression of the trabecular bone during stem broaching—due to the geometry of the instrument, cutting, or pattern of the compaction tooth, alongside the elected technique for performing the surgery—or during the impaction process of the implant, due to the geometry of the femoral component, as well as the previous preparation of the femoral canal and the technique used for the procedure [122].

IPPFx prevention constitutes a key factor for the reduction of fatality rates and worse clinical results, and it could be achieved via a meticulous preparation of the surgical procedure, as well as a thorough evaluation of the potential risk factors. According to current guidelines, women of age 65 and older should be screened with dual-energy x-ray absorptiometry to determine the bone mineral density of the patient [123], whereas an assessment of the osteoporosis state should be performed for men [124].

During the analysis of the acetabulum to assess the presence of hypothetical fractures, suspicions might arise when the reamer size of the prosthetic component and the implant itself are significantly larger compared to the template established during the radiographic evaluation performed preoperatively, or if the implant is not stable after its placement, thus requiring further radiographic evaluations to determine whether the fracture is present. In that case, the entire fracture should be exposed, because fractures previously deemed negligible could potentially spread in the proximity or into the sciatic notch, ultimately impacting the stability of the implant and requiring removal of the latter to evaluate the morphology of the fracture and acetabulum. Nondisplaced fractures identified during the surgical procedure could be left in situ when the components are stable and fixed via the addition of acetabular screws, followed by a rehabilitation procedure to achieve optimal healing of the bone, which involves protected weight-bearing with progressive increase after a period ranging from 6 to 8 weeks. However, if the components are unstable, an examination of the integrity of the vertebral column should be performed. In case of severe discontinuity of the pelvis or substantial instability of the fracture, a column reconstruction plate should be utilized to ultimately stabilize the

posterior aspect of the column, to then perform the conventional surgical procedure to reconstruct the acetabulum. However, if stabilization of the components is not achieved after the utilization of the column reconstruction plate, temporary fixation to allow for the healing of the fracture could be accomplished via the use of cup-cage or bone grafting techniques [125].

The process of femoral fractures' identification should be performed similar to the one used for the acetabulum, with particular attention given to the radiographs due to the difficulty in the diagnosis of nondisplaced fractures. Additionally, similar to the administration of IPPFx for the acetabulum, the procedure followed for femoral intraoperative fractures includes stabilization, prevention of its spread, preservation of the alignment of the prosthetic components, and stability [116]. The management of PPFx is further subdivided based on the type of femoral fractures. Fractures of the proximal metaphyseal region and perforation of the trabecular bone (type-A1) are commonly addressed via grafting of the bone, whereas nondisplaced, calcar fractures (type-A2) require further examination to ascertain the distal magnitude of the fracture. However, if identification of the fracture is achieved following the insertion of the prosthetic component, the latter should be extracted to allow for the examination of the metaphysis and diaphysis of the femur, and stabilization and prevention of spread could be achieved by utilization of metal or polymer cables along and distal to the fracture site [116]. Intraoperative diaphyseal fractures (type-B) are addressed through fixation with cerclage cables in case of stability; however, if the implant is not stable, a longer component is required to engage the diaphysis and ultimately prevent the spreading of the fracture. If the diagnosis is made after the surgical procedure, the management of the PPFx should be performed through the same weight-bearing process indicated for fractures to the acetabular component, thus via a protected weight-bearing with a progressive increase of 6 to 8 weeks. The incidence of fractures distal to the stem (type-C) is not as frequent for primary THA procedures; however, they could potentially result during the dislocation of the native hip due to excessive torsion or following trialing.

Calcar fractures occurring during the surgical procedures are usually addressed via the fixation of the lesser trochanter with cable or wire, a technique that has reported optimal clinical outcomes and decreased risk of spread of the fracture, alongside increased stability of the prosthetic implant [126]. Instead, fractures of the greater trochanter may occur in patients presenting osteoporosis or osteopenia, particularly during extension or removal of the broach after preparation of the intramedullary canal. However, such fractures do not necessitate fixation unless the stability of the implant is compromised, or displacement of the fracture occurs [127].

The overall cost of healthcare for patients experiencing IPPFx and PPFx, $30,114 and $53,669 respectively, was significantly higher compared to the one indicated for patients not experiencing any fractures during or after the THA procedure [114], thus emphasizing the importance of timely recognition and analysis of potential risk factors to reduce the incidence of complications [125].

7 Postoperative Delirium

Postoperative delirium (POD) is a complication that consists of a sharp decrease in the cognitive capabilities of the affected patients, resulting in a fluctuating state of confusion or disrupted psychological state [128], affecting up to 50% of the elderly undergoing orthopedic surgery [129]. Its overall incidence ranges from 9% to 87%, depending on the age of the patient and the degree of stress to which they are subjected during the surgery [130]; moreover, it is correlated to higher fatality and morbidity rates, alongside increased length of hospitalization and worsened surgical results [129, 131].

Postoperative delirium is often misdiagnosed; in fact, over 50% of the overall cases is often unrecognized by the clinical stuff; therefore, it is important to determine whether the patient is experiencing POD via the analysis of the three outlined motor types of delirium: irascible, uneasy, or agitated patients are probably experiencing hyperactive delirium, whereas hypoactive delirium could be diagnosed to patients displaying reduced motor activity, lethargy, or unawareness. Finally, the third motor type of POD consists of behaviors that present characteristics of both hypoactive and hyperactive delirium [130]. Moreover, an accurate diagnosis of POD could be achieved through the Confusion Assessment Method-Intensive Care Unit (CAM-ICU), or via the Mini-Mental State Examination (MMSE). The CAM-ICU is a reliable tool that combines the level of consciousness experienced by the patient with an examination of their mental status, whereas the MMSE allows for the evaluation of cognitive dysfunctions, as well as the monitoring of the fluctuations of the patient [130].

Besides the age of the patient, there are a variety of risk factors associated with the development of delirium following orthopedic procedures, which include the presence of comorbid diseases, psychopathological symptoms, functional impairment, and dementia [130].

This condition could be potentially prevented via specific interventions, which include an orientation protocol, carried out by the clinical staff and aimed at helping the patient familiarize with the surrounding environment; a sleep protocol, to enable the patient to rest uninterruptedly during the night; an early mobilization protocol, to increase the range of motion of the patient via daily physical therapy; and a vision and a hearing protocol, allowing the patient to easily gain access to visual and hearing aids, respectively [130].

7.1 Delirium-Related Factors Impacting Patients Following THA and TKA

Surgeries such as hip and knee replacement are the most frequently performed procedures in the orthopedic field, primarily treating patients over 60 years of age and yielding positive outcomes in terms of pain reduction and improvement of

functionality [132, 133]. Nonetheless, the incidence of complications—such as postoperative delirium (POD)—might affect the rehabilitation process, as well as the outcomes of the surgeries. Such complication is examined in [134]. The main goal was to identify potential factors leading to the development of POD in patients subjected to either hip or knee replacement surgery, to ultimately gather data that could aid in the elaboration of an optimum preoperative approach to decrease the occurrence of postoperative delirium. Twenty-two studies with an overall number of patients amounting to 11,934 were analyzed, and 1841 cases of POD were identified. The comprehensive rate of POD was 17.6%, with a slightly lower incidence following the knee replacement procedure (16.4%), and a higher one for the hip replacement surgery (18.8%), with a greater incidence following longer operational times, more elevated intraoperative blood loss, and administration of general anesthesia. The mean age of patients experiencing postoperative delirium was slightly higher—0.43 years—compared to the one indicated for the patients not incurring in such complication, and age was indicated to be one of the predictive elements for incidence of POD, with a combined odds ratio of 1.12 following adjustment for bias of the articles, mainly attributed to the stress experienced intraoperatively by the patients. Throughout the research, the cognitive abilities of the patients were determined using the Mini-Mental State Examination (MMSE)—a questionnaire consisting of 30 points—which indicated cognitive impairment when the obtained score resulted lower than 24. Eleven of the analyzed studies indicated a significantly lower MMSE score in patients affected by POD, ultimately establishing a correlation between decreased cognitive abilities and incidence of postoperative delirium. Other factors that could potentially lead to POD include cerebrovascular events, stroke, and other neuropsychiatric diseases such as dementia—mainly due to inflammation, stress, and damage to nerve cells [129, 135]. Moreover, disorders affecting the nervous system, such as Parkinson's disease, were also identified as potential risk factors for POD, alongside other psychiatric illnesses, and sleep perturbation. Eight studies signaled a higher incidence of POD in patients scoring 3 or higher in the American Society of Anesthesiologists' (ASA) classification. Similarly, five studies indicated higher scores in the Charlson Comorbidity Index (CCI) for patients experiencing POD compared to patients not affected by such disorder. Preoperative laboratory tests performed in some studies demonstrated an inferior level in overall proteins, albumin, and hemoglobin in patients affected by POD [134].

In conclusion, the advanced age of the patients undergoing hip or knee replacement is a potential factor leading to a higher incidence of POD, potentially correlated to changes affecting the neurotransmitters involved in stress regulation as well as the systems implicated in the transduction of nerve signals [136]. A greater risk of POD was indicated in patients obtaining a score greater than 3 in the ASA or overall higher scores in the CCI, suggesting that patients presenting reduced physical abilities were more prone to developing postoperative delirium. Individuals with preexisting cognitive abnormalities—including memory deterioration and disorders related to the identification of visual and spatial correlations between objects—[137] are at higher risk of experiencing POD, as well as the ones affected by neuropsychiatric disorders and cerebrovascular conditions. Moreover, patients subjected

to knee replacement developed POD more often than the ones undergoing hip replacement, perhaps due to the longer duration of the surgical procedure, increased intraoperative blood loss, and greater pain postoperatively, which could potentially facilitate the generation of the delirious state [138]. Finally, patients receiving general anesthesia were more prone to developing POD, perhaps due to the decreased output of the cardiac muscle, alongside decreased blood flow to the central nervous system and subsequent vasoconstriction at the cerebral level [139].

8 Nerve Damages

The reported incidence of nerve damages ranges from 0.6 to 3.7% after primary THA, further increasing up to 7.6% after revision THA. Such injuries could be caused by a variety of factors, including compression, stretch, ischemia, as well as transection [140]. Figure 3 shows the nerves originating from the lumbar plexus [141].

Compression damages affect the structure of the nerve itself, as well as its vascular supply, and occur mainly during the perioperative stage of the procedure. Stretch injuries emerge primarily during the intraoperative manipulation of the patient, therefore during the dislocation—before the installation of the acetabular implant—or the leg-lengthening procedures. Neural ischemia, described as the insufficient blood flow to the nerve which causes the inability to meet its metabolic demands, typically results after prolonged compression, presumably as a result of the positioning of the patient. Finally, transection or laceration of the nerve is correlated to the direct trauma caused by the instruments used intraoperatively, therefore including scalpel, screws, retractors, and electrocautery [140].

Nerve injuries are diagnosed via a meticulous clinical assessment performed both prior and following the THA surgery. In fact, complaints of numbness or weakness by the patients could be indicators of previous minor damages to nerves that could potentially increase the risks of undergoing additional surgical procedures, whereas the diagnosis of nerve lesions or damages after the procedure is essential in the determination of most suitable treatment to be used for ultimately addressing the issue [142].

The main risk factors associated with nerve lesions following THA are the female sex, history of surgery, spinal problems, anatomic anomalies—such as hip dysplasia or congenital dislocation of the hip—and excessive leg lengthening [143].

Because of its location, the sciatic nerve has been determined to be the most commonly affected nerve after THA, constituting about 90% of the cases [142]. The sciatic nerve is, in fact, located deep to the piriformis muscle, and then extends distally deep to the muscles of the gluteus and superficial to the external rotators, therefore making it extremely vulnerable during the placement of the retractors in the posterior aspect of the acetabulum, and during the traction, both anterior and lateral, of the femur [144]. The femoral nerve is the second most commonly damaged nerve during the total hip arthroplasty procedure [142]. It originates at the L2, L3, and L4

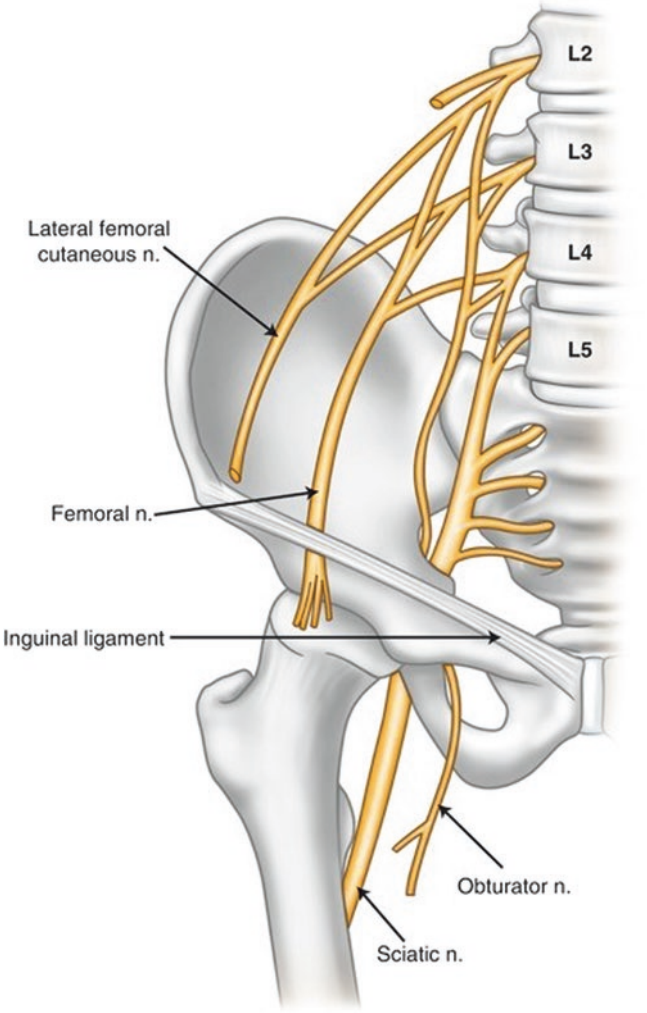

Fig. 3 Anatomy of the lumbar plexus

nerve roots and travels through the psoas and the iliacus muscles to access the thigh, a location that makes it particularly vulnerable to stretch damages [144].

As mentioned in the previous paragraph, the treatment of neural injuries is strictly correlated to the nature of the injury. If the cause of the injury is not immediately detected, no treatment to decrease the hypothetical compression or stretch of the nerve is advised, as it could recover without any interventions. If the lesion is discovered during the procedure, a prompt repair is usually performed in an attempt to minimize the damage; instead, if signs of severe lesions are detected during the postoperative assessment, further surgical intervention is required. The motor deficits correlated to neural damages are often treated with physical therapy, mainly

aimed at strengthening the muscles involved in the dorsiflexion movement of the ankle, and the stretch antagonist muscles [142].

8.1 Lateral Femoral Cutaneous Nerve Damage Rate via the Direct Anterior THA Approach

One of the downsides of the DAA is the potential risk of incurring in damages to the lateral femoral cutaneous nerve (LFCN) [145]. The LFCN is a sensory nerve arising from the dorsal branches of the second and third lumbar vertebrae. It emanates from the lateral margin of the psoas major muscle and crosses the iliacus muscle obliquely to reach the anterior superior iliac spine while piercing the tensor fascia lata underneath the ligament of the groin and running both distally and laterally through the subcutaneous layer of the integument of the anterolateral surface of the thigh [146]. Damages to such nerve would result in numbness or burning sensation in the region of the anterolateral thigh, and, in some instances, it could result in dysesthesia—which is defined as stinging, burning sensation, or even pain experienced at the cutaneous level [147]. Multiple studies have indicated that the branches of the LFCN are inevitably impacted in about 32% of the procedures due to the variations in the anatomy of the patients [146], whereas others have reported no damages to the branches of the aforementioned nerve. Therefore, the primary aim of the research was to determine the risks correlated to LFCN damage following the execution of primary THA.

In order to do so, a total of 45 studies including 17,076 THA procedures were evaluated, reporting an overall incidence of LFCN lesions corresponding to 680 (3.95%). The included studies were subdivided into two groups. Group A consisted of 6 studies, analyzing 1113 cases and primarily focusing on the lesions of the LFCN occurring after the DAA, whereas group B comprised 39 studies, which evaluated a total of 16,741 cases and only mentioned such lesions, not providing a standardized definition of the latter [145].

Among the studies included in group A, only one provided an exhaustive description of the follow-up intervals performed on the patients and the evolution of their symptoms [148]. Two articles analyzed the patients at two [149] and three intervals [150], and the remaining publications evaluated the potential factors resulting in lesions of the LFCN, alongside the impact of the latter on the quality of life of the patients. Additionally, other studies analyzed the occurrence of LFCN lesions in independent groups at various intervals after the surgical procedure [151–153]. Out of the 1113 patients included in cohort A, a total of 345 lesions were reported, thus indicating a median occurrence rate of 28%. However, no calculations were made regarding the correlation of sample size and lesion rates because of the small number of articles included in this cohort. The incidence of lesions reported for group B was 2.00%, with a total of 335 cases observed in 16,741 patients, and a negative correlation of $r_s = -0.39$ was indicated between the population size and the number

of affected patients. Moreover, a positive correlation of $r_s = 0.521$ was recorded regarding the incidence of lesions and year of the publication of the 45 analyzed articles, with recently published studies reporting a higher incidence of LFCN damages. In summary, the reported incidence of lesions to the LFCN ranged from 0 to 83%, indicating higher rates in the articles primarily focusing on such lesions and in the more recently published ones [145].

9 Heterotopic Ossification

Heterotopic ossification (HO), or heterotopic bone formation, is a disorder that foresees the transformation of mesenchymal cells into osteoblasts, which deposit calcium and minerals, therefore provoking the development of extraskeletal bone connective tissue in soft tissues or muscles and ultimately resulting in the progressive loss of mobility of the joint and functionality of the patient [154]. Figure 4 shows the evidence of HO after the THA surgical procedure.

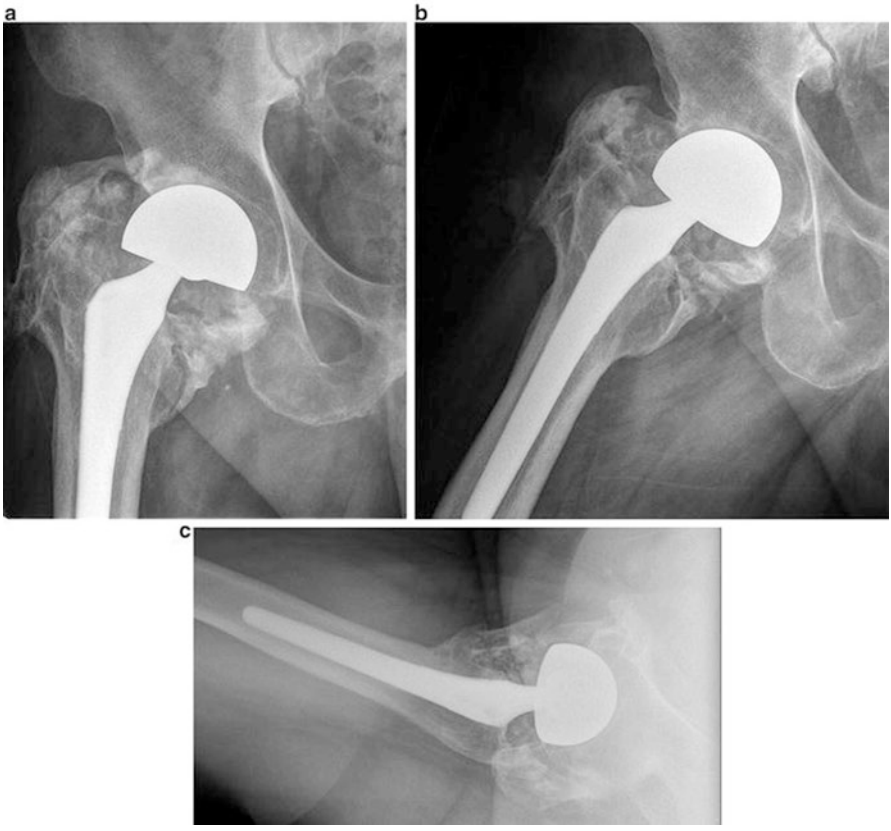

Fig. 4 Sign of HO after THA [211]

Such condition could arise following injuries to the central and peripheral nervous systems, with an incidence rate ranging from 10% to 20% and from 20% to 30%, respectively [154], or traumas to the musculoskeletal system occurring mainly during orthopedic procedures such as THA, for which the reported incidence rate ranges from 2% to 90% [155]. The higher reported rate is commonly associated with comorbidities, which include hypertrophic osteoarthropathy, and idiopathic skeletal hyperostosis, as well as other factors such as the male gender, history of surgery of the hip joint, and age over 65 years [156–161].

The main indicators of early onset of the disorder, which include fever, localized swelling, or joint soreness, are particularly hard to distinguish from bone infections or thrombophlebitis—formally described as the formation of blood clots that subsequently block one or multiple veins [154].

The main methods exploited for HO prophylaxis are radiation, which slows down the mitotic process of the cells and hinders the differentiation of the cells within the mesenchyme region into osteoblasts [162], and nonsteroidal anti-inflammatory drugs (NSAIDs) [162–170], which inhibit the enzymatic activity of cyclooxygenase (COX) to ultimately regulate the generation of prostaglandins.

The decision regarding the appropriate prophylaxis administration is based on a variety of factors, including the action of the elected instrument and the possible deleterious outcomes. In fact, the immune system of patients at high risk for HO is subjected to a strong inflammatory response [171–173], thus favoring the use of NSAIDs to mediate such inflammation instead of other prophylaxis techniques such as radiation. Additionally, the likelihood of facing deleterious outcomes for a designated prophylaxis protocol might eliminate its use. For example, the use of COX-II selective or other nonselective NSAID is inadvisable for patients presenting cardiovascular, renal, or gastrointestinal problems [174, 175].

9.1 Efficacy Comparison of NSAID and Radiotherapy for Prophylaxis of Heterotopic Ossification on High-Risk Patients After THA

The main aim of the study performed in [176] was to examine the effects of radiotherapy and NSAIDs in high-risk patients previously subjected to THA, alongside of comparing the effectiveness of nonselective NSAIDs and COX-II selective NSAIDs [176].

The severity of HO observed in the patients was categorized into none, mild, and severe, corresponding to 0, 1–2, and 3–4 respectively, using the Brooker classification scale. Moreover, a similar categorization was used in studies not employing the aforementioned classification scale, in which 0 corresponded to none, 1–2 corresponded to faint, and 3–4 corresponded to widespread.

For the 37 articles analyzed, with a total of 8653 patients, 5043 of which were treated with NSAIDs (58.28%), 1260 received the radiotherapy (RT) prophylaxis (12.56%), and the remaining 2350 didn't receive any treatment (27.16%).

The low-risk population was analyzed in 24 out of the 37 publications, including a total of 4302 patients treated with NSAIDs, and 2124 not receiving treatment. The results obtained in these studies reported the lack of formation of HO within a range of 47.3% and 90.4% of the overall study sample, mild formation was observed in 2.8–52.7%, and severe formation in none to 10.4% of the patients. The studies including a control group not receiving any treatment reported a range of 21.4% to 68.8% of the study sample not experiencing HO formation, whereas mild formation ranged between 8.3% and 55.6%, and severe formation was between 3.2 and 32.1%.

The remaining 13 studies analyzed a population at high-risk for HO, 4 of which included NSAID prophylaxis, 12 RT treatment, and 4 integrated a control group not receiving treatment. NSAID treatment was administered to 741 patients, RT prophylaxis was performed on 1260, and the control group comprised 226 patients. The results reported in the studies evaluating RT prophylaxis indicated a range of 28.6% to 97.4% of patients not developing HO, mild HO formation was indicated in 1.9% to 66.7% of the population, and severe formation was observed in 0% to 11.9% of the sample size. The studies including NSAID treatment reported a range of 76.6% and 88.9% of the overall population not developing HO formation, mild formation was between 11.1% and 23.4%, and severe formation was between 0% and 1.8%. Additionally, the publications integrating control groups reported a range between 15.8% and 73.6% for lack of formation of HO, mild formation ranging from 26.4% to 68.5%, and severe formation occurring in the range of 0.0% and 42.1% of the population.

With regard to the effectiveness of the NSAID treatments used for the studies, the incidence of risks leading to the development of HO after the THA procedure following administration of COX-II and other nonselective NSAID drugs was not statistically significant.

The patient-recorded outcomes were reported in 5 of the 37 included studies, 3 of which used the Harris Hip Score (HHS)—2 analyzed the outcomes following NSAID prophylaxis and 1 reported the outcomes after RT treatment [177–179]—and 2 used the Marie d'Aubigne, one of which included the outcomes following NSAID treatment, whereas the other one analyzed the outcomes following both RT and NSAID prophylaxis.

Out of the five aforementioned studies, four reported no significant differences in terms of patient-reported outcomes between the cohort subjected to treatment and the control groups when the occurrence of HO was not statistically different [177, 179–181]. However, the only study reporting a significant difference in the occurrence of HO between the two groups also indicated a statistically significant difference in the HHS scores recorded after the THA surgery [178].

In summary, the treatment with NSAIDs reported a lower occurrence of formation of HO after the surgical procedure in patients presenting both high- and low-risk compared to the RT prophylaxis modality and the lack of treatment for the control groups, mainly attributed to the anti-inflammatory action of the

administered drug. Moreover, the administration of COX-II and nonselective NSAIDs' treatments didn't display a statistically significant difference. Finally, the augmented severity of HO was correlated with decreased scores for patient-reported outcomes, primarily due to the decreased range of motion and functionality of the patients experiencing such condition [176].

10 Revision THA

Revision total hip arthroplasty is performed in instances if the prosthesis implanted during the primary THA procedure fails. The expected lifespan of the artificial joint is 10–20 years, after which the prosthesis won't result as efficacious and consequently lead to the requirement of revision surgery; however, there are a variety of factors that substantially decrease the implant's lifespan. Such factors include dislocation, mechanical failure, and infection [182]. Recurrent dislocation could be potentially caused by the misalignment of the femoral and acetabular components, weakness of the muscles that surround the hip, or traumatic events, which ultimately cause the head of the femur to displace out of the acetabular cup. Mechanical failure is, instead, commonly correlated to wear, which is caused by the continuous friction between the prosthetic components and results in the detachment of small portions of the implant. It is, therefore, particularly common in younger patients with increased levels of physical activity. The consequence of the detachment of such particles is a strong response generated by the patient's immune system, which could lead to osteolysis (the gradual destruction of the bone tissue surrounding the prosthesis) and the subsequent loosening of the implant, which will cause further loss of bone due to its excessive movement within the surrounding specialized connective tissue. Another form of mechanical failure is breakage, which is often the result of traumatic events such as falls or motor vehicle accidents. Finally, infections of the prosthetic implant could be caused by bacteria entering the bloodstream from any location within the body and will result in localized hip pain and fever [182].

The revision surgery consists of the removal of the previously implanted prosthesis while simultaneously preserving the surrounding bone. Moreover, if cement was employed during the primary THA procedure, the removal of the latter is performed alongside the implant removal. This passage is followed by the preparation of the bony surfaces of the pelvis and the femur, in order to properly accommodate the revised implant. In cases of excessive bone loss recorded, bone grafts or metal augments are used to compensate for the lack of bone connective tissue. The insertion of the new implant is often accompanied by the addition of several screws to maintain the newly positioned acetabular cup in place until the bone tissue is formed. Revision THA is a particularly complicated procedure, and it could possibly give rise to a variety of complications, including ensuing dislocation, infection, formation of blood clots, loosening of the implant, and lack of attachment between the reamed bony surfaces and the newly implanted prosthesis [4].

10.1 A Practical Performance of Revision THA in Low-Resource Settings

One of the main concerns regarding the THA procedure is the survivorship of the prosthesis, which is expected to endure for 15 years in about 89.4% of the patients, to then decrease to 70.2% of the patients after 20, and to 57.9% after 25 years [183]. Therefore, considering the decrease in the average of the patients undergoing such procedures, the overall percentage of revision surgeries is predicted to increase over the years [184].

Jehovah's witnesses are part of a Christian denomination that, because of their literal interpretation of the Bible, refuse to accept blood, thus creating a variety of issues when requiring surgery.

The case study performed in [185] describes the revision THA procedure performed on a Jehovah's witness in a low-resource hospital in the Caribbean. The patient, 61 years old at the time of the surgery, was subjected to revision THA 4 years after the primary procedure required for post-traumatic osteoarthritis resulting from a motor vehicle accident, which caused a combined injury of the acetabulum and the pelvic ring.

Prior to the surgery, his blood examinations were within the normal parameters, displaying hemoglobulin levels of 14.1 g/dL, serum creatinine of 0.96 mg/dL, C-reactive protein of 7.8 mg/dL, and rate of erythrocyte sedimentation of 12 mm/h. The procedure was performed under general anesthesia via a modified Hardinge approach, practiced with utmost care to prevent the removal of excess tissue during the development of the surgical planes.

Following dislocation of the hip, the femoral stem was easily removed, and synovial fluids, alongside samples of the tissues obtained from the femoral canal, were collected for further analysis. An isolated femoral revision was then performed after confirming the stability of the acetabular cup, notwithstanding its eccentric wear and excessive anteversion.

Following the removal of the excess heterotopic ossification (HO) on the soft tissues surrounding the posterior aspect of the acetabulum, rotation of the hip was performed to enable access to the femoral canal, which was subsequently rinsed and subjected to the cemented insertion of the same femoral stem. However, the joint resulted unstable, presumably because of the excessive anteversion and wear of the acetabular cup, alongside the laxity of the tissues following the removal of the HO, thus leading to the revision of the acetabulum with a cemented all-polyethylene cup.

Before the installation of the cup, the stability of the acetabular cage was confirmed, and 2mm holes were drilled to facilitate the interdigitation of the cement used in the procedure. The cup was then inserted and cemented, with an abduction angle of 40° and an anteversion of 10°, and a femoral component with a 36 mm head and 8 mm neck was used. After the installation was completed, the wound was then soaked for a total of 3 min with dilute povidone-iodine solution. Moreover, prior to the suturation, a meticulous examination with a layered watertight approximation of the soft tissues was performed to locate any potential bleedings.

After the surgery, the patient was administered with an intravenous antibiotic for a total of 5 days (cefuroxime 1.5 g, three times a day), and anticoagulants (rivaroxaban, 10 mg daily) were administered 24 h following the procedure, corresponding to the beginning of the mobilization procedure. Despite the low hemoglobin levels recorded postoperatively (9.8 g/dL), the patient disclosed minimal pain and was able to continue his physiotherapy cycle [185].

Hemoglobin optimization performed preoperatively is among the various suggestions presented to successfully perform revision THA in a low-resource setting. In fact, this technique is particularly useful for the elimination of the origins of blood loss and the maximization of the production faculty of hemoglobin before the procedure. Moreover, natural erythropoiesis is strongly advised via the daily intake of supplements of 325 mg of ferrous sulfate (three times a day), 500 mg of vitamin C (two times a day), 1000 mcg of vitamin B12, and 1000 mg of folic acid (once a day) [186].

Hypotensive anesthesia constitutes another key technique because it allows for the minimization of bleedings occurring intraoperatively via the reduction of blood pressure. The technique suggested in the [185] aimed at decreasing the mean arterial pressure by 30%—ultimately maintaining systolic blood pressure within 60 to 80 mmHg—and involved the use of heavy 0.5% bupivacaine, without morphine in the primary cases, alongside an epidural catheter, later removed for revision procedures once the surgery was completed. However, in some instances, patients could refuse the administration of neuraxial anesthesia, therefore requiring the injection or inhalation of propofol with either sevoflurane or isoflurane.

The third suggestion involves meticulous planning of the procedure, to avoid unpredictable complications during surgeries in which the transfusion of blood does not represent a viable alternative, followed by the administration of a 100 ml local analgesic cocktail—composed of 17.5 ml of 0.5% bupivacaine, 30 mg of ketorolac, 500 mcg of adrenaline, 750 mg of cefuroxime, and normal saline—into the soft tissues to ultimately decrease the blood loss. Moreover, thromboprophylaxis should be started 24 h following the surgery—unless unsuitable—via thromboembolic deterrent stockings, alongside early manipulation and aspirin (81 mg, administered twice a day).

Finally, the administration of 1 g of tranexamic acid intravenously, both during the incision and after the suture, has been shown to be particularly effective to achieve the reduction of blood loss after surgery without increasing the incidence of thromboembolic events [187].

10.2 Dual-Mobility Implant Utilization for Revision THAs

Revision THA (R-THA) is considered a particularly complicated procedure, characterized by technical complexities, as well as increased incidence of complications, especially when compared to primary THA [188]. Aseptic loosening and

instability of the prosthetic components are among the main factors leading to failure of R-THA, caused by a variety of aspects including impingement of the prosthesis on the bone, decreased quality of the bone and surrounding soft tissues, and misalignment of the implants, specifically regarding acetabular and femoral offset, which have been respectively defined as the distance separating the center of the head of the femur and the true acetabulum, and the distance separating the center of the head of the femur and its axis [189, 190].

To decrease the incidence of dislocation and simultaneously increase the stability of the joint, dual-mobility (DM) implants are being used more frequently, as they are characterized by a large polyethylene liner in correspondence to the internal bearing—the point of articulation between the polyethylene and the proximal head of the femur—and do not result in increased limitations at the interface between the bone and the implant, further ameliorating the load dispersion interface [191, 192]. Figure 5 illustrates a conventional dual-mobility cup used combined with a cementless stem revision [193].

Numerous studies have indicated the disadvantages related to the use of DM including intraprosthetic dislocation (IPD) of the bearing surfaces, wear increment of the polyethylene (PE) leading to aseptic loosening, and higher incidence of infection; however, such complications are less common in new-generation DMC and PE [194, 195]. Therefore, the study performed in [196] aimed at gathering information concerning the DMC employed for R-THA.

A total of eight articles including 1777 revision THA procedures were examined with 49.9% including the use of a DM acetabular cup and the remaining

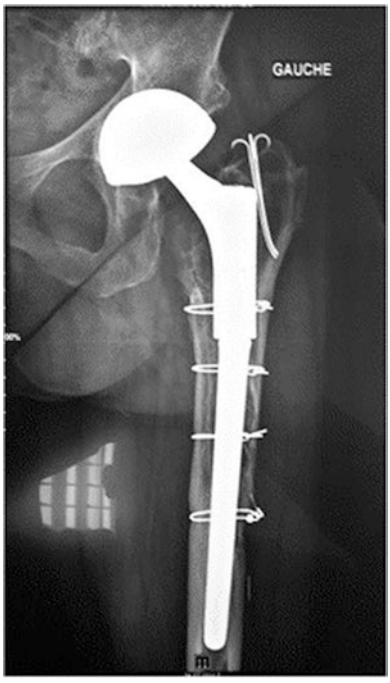

Fig. 5 An example of a DM implant

procedures completed using standard fixed-bearing (FB) implants. The average age of the patients ranged from 57 to 73 years, and the percentage of women was slightly higher (53%) compared to the one indicated for men (47%). The average follow-up period after the procedure ranged from 12 to 60 months for all the examined articles.

The data gathered regarding the survival of the implant reported a risk ratio of 1.08, specifically 1.12 for the FB cup and 1.05 for the DM implant, thus indicating a statistically significant survival rate favoring the DM cohort. Similarly, the recorded data relative to the incidence of dislocation indicated a risk of 0.13 for the DM group and 0.37 for the FB group, with an overall risk ratio of 0.22, and data for aseptic loosening revealed a decreased risk for the DM implants, corresponding to 0.29, compared to the one recorded for the FB group, with a comprehensive risk of 0.51. No statistically significant differences were identified between the two analyzed cohorts when comparing the incidence of infection, which was measured to be 0.94 overall.

In summary, the utilization of DM implants for revision surgery is more effective compared to standard FB cups, specifically regarding the survival of the implant and incidence of dislocation, whereas no significant differences were observed in terms of increased risk of infection between the two examined implants [196].

10.3 Intrapelvic Pseudotumor Occurrence with Deep Vein Thrombosis by Using a Metal-on-Metal Bearing Surface Implant Following THA

The use of metal-on-metal (MoM) implants—characterized by a metal femoral head directly articulated with a metal acetabular cup [197]—was particularly widespread in the late 1990s, but was then gradually abandoned because of the greater incidence of revision compared to other implants [198], which is currently thought to be correlated to the adverse reactions stemming from the metal debris [197], potentially triggering an inflammatory reaction, alongside necrosis of the surrounding tissues, ultimately resulting in the formation of a pseudotumor and subsequent compression of the adjacent nerves [199]. Figure 6a shows the signs of corrosion at the taper junction of the femur of a MoM implant. Figure 6b shows similar signs of wear at the taper of the stem [200].

The case report conducted in [201] presented a patient—a 61-year-old woman—that had undergone bilateral THR for osteoarthritis and Crowe I acetabular dysplasia. During the procedure, the left hip was subjected to the implantation of the Biomet MoM bearing prosthetic component, which yielded good results up to 15 years postoperatively. After 15 years, the patient started experiencing swelling on her left lower extremity, which was then diagnosed as an occlusive thrombus located within the posterior tibial veins and the left superficial femoral vein. Moreover, the patient presented a mixed cystic and a solid left adnexal mass, which

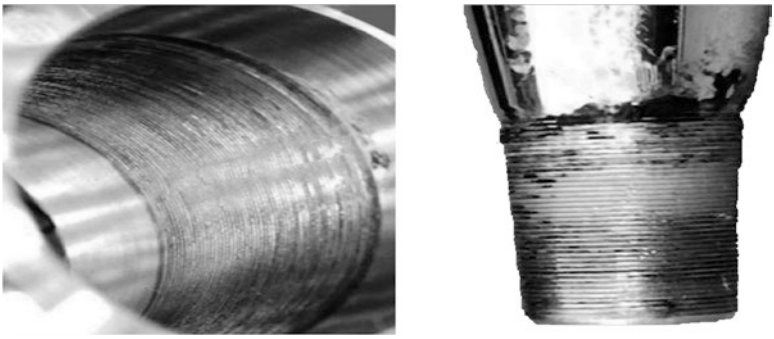

Fig. 6 (**a**) Left, wear at the taper junction of the femur, (**b**) wear at the taper of the stem

constricted the external iliac vein. Heparin drip was therefore started to treat her condition, and the patient was later discharged on apixaban. Despite the intake of medications, the patient's swelling was still extending throughout the left lower limb, nonetheless not resulting in pain or any other perturbations of her functions. After a close analysis of the computed tomography scan, a mass located within the left distal psoas muscle was identified. Further magnetic resonance imaging confirmed the presence of a heterogeneous mass arising on the anterior surface of the left prosthetic implant and extending through the inguinal canal to reach the retroperitoneum.

All the performed blood tests yielded results within the normal range; however, elevated levels of cobalt (5.9 compared to the 3.0 ng/mL used as reference), and slightly inferior but still significant chromium levels, corresponding to 2.7, were recorded compared to the reference value of 3.0 ng/mL.

The patient was therefore subjected to a surgical procedure divided into two stages: the first stage aimed at excising the pseudotumor through the pelvic retroperitoneal and the inguinal approaches, whereas the second part, sustained 3 months after the first surgery, consisted in the revision of the left implant through the posterior approach, and foresaw the installation of an active articulation dual-mobility femoral head.

During the first follow-up, performed 2 months after the second procedure, the patient only displayed a slight swelling in her upper thigh, perhaps due to the irreparable damage of the venous valves previously compressed by the mass. Additionally, a venous duplex ultrasound of the affected area was performed 1 month later, showing no trace of deep vein thrombosis, thus leading to the discontinuation of apixaban, which was then substituted by the intake of aspirin daily.

In summary, the use of MoM implants is associated with an increased risk of complications correlated to the excessive wear of the prosthetic component, which could lead to the dispersion of metal debris and ultimately result in an inflammatory reaction and subsequent necrosis of the adjacent tissues [201].

10.4 Femoral Revision of THA Through the Direct Anterior Approach Interval

Revision THA has been associated with high readmission (10%) and reintervention rates (22%), as well as complications occurring after the procedure (18%) [202–205], alongside higher morbidity and length of hospitalization and increased loss of blood [206]. Therefore, surgeons might decide to re-examine the approaches used during primary THA to determine whether or not changes to the previously used approaches should be introduced to perform femoral revision surgery, in an attempt to reduce the complications and the overall costs, as well as achieve better outcomes. Therefore, the main goal of the study performed in [207] was to evaluate the outcomes of revision THA on the femoral stem via the DAA interval, to ultimately determine the incidence of complications, such as dislocations, nerve damages, fractures, and infections, alongside examining the outcomes related to the clinical procedure and the functionality of the patients.

The surgical procedure was performed by four surgeons using the direct anterior approach, with an average operative time of 135 min. To perform such procedure, the incision was performed slightly posterior and lateral to the anterior margin of the tensor fasciae latae (TFL) muscle, starting distally to the anterior superior iliac spine (ASIS) and extending distally to allow access to the diaphysis of the femur while simultaneously curving the incision laterally for cosmetic causes. Once the margin was identified, the IT band was split longitudinally and subsequently mobilized from the vastus lateralis muscle, allowing the area surrounding the femoral diaphysis to be accessed and the connected muscle fibers to be dissected. Medial mobilization of the vastus lateralis was performed laterally and distally to the greater trochanter, sparing a muscular bridge between the vastus and the medial gluteus to guarantee adequate blood supply to the bones [208].

The DAA interval was performed on 149 patients, 16 of which were subjected to bilateral revision surgery. The average age of the patients was 68.9, the mean body mass index (BMI) was 28.6, and the average follow-up period after the surgical procedure was 4.2 years. In the period following the procedure, a total of six fatalities were recorded, but the causes were not related to the revision surgery or the hip, which resulted asymptomatic during the last performed follow-up.

The factors leading to revision surgery were aseptic stem loosening in 131 patients, fractures that occurred after the implantation of the prosthesis in 29 cases, stem misalignment in 1 case, and failure of the implant in 4 patients. Moreover, the primary THA procedure was performed through the direct lateral approach in 105 instances, the DAA in 59 cases, and the posterior approach only in 1 case.

During the procedure, the endofemoral approach was performed in 156 hips, whereas the transfemoral approach was only used in 9 instances; moreover, ulterior revision of the cup was carried out in 52 cases. With regard to the femoral prosthetic component, a modular stem was employed for 52 hips, a standard stem was used in 113, and femoral allograft was utilized in 10.

Revision THA performed via the DAA in the analyzed study presented 14.5% of complications, alongside an overall number of ten hips (6.1%) requiring re-revision for dislocations, in six instances, and infections, in the remaining four (2.4%). Ulterior revision surgery performed on four of the six dislocated hips ultimately modified the acetabular cup into a dual-mobility one, whereas the remaining two were corrected with constrained liners, to ultimately decrease the risk of dislocation. Moreover, the four hips suffering from infections were subjected to a revision plan divided into two stages, consisting of the explanations of the implants and subsequent implantation of spacers permeated with antibiotics, which were then removed during the second stage of the revision procedure—after 3 to 6 weeks—to allow for the implantation of a new stem component and cup. Four patients experienced intraoperative fractures/fissures, three concerning the lesser trochanter and treated with cerclage cable, and one of the greater trochanter, which was instead treated with a claw plate. Femoral nerve palsy was observed in four patients. Moreover, the placement of 16 stems was mildly varus, whereas only one was valgus; nonetheless, the patients experiencing these slight misalignments were not affected by any sort of pain, and were otherwise asymptomatic; therefore, no revision surgery was necessary in the 17 aforementioned cases [207].

Gruen zones [209] were used to classify the radiolucent lines employed for further analysis, to evaluate the various regions of the interface between the prosthetic component and the surrounding bone. Seventeen percent of the radiographs displayed nonprogressive radiolucent lines; however, the stems resulted asymptomatic in all cases. Heterotopic ossification was documented in 13 patients, but none of them displayed any symptoms. Figure 7 shows the Gruen zones for the categorization of femoral stem loosening [210].

Finally, the Western Ontario McMaster Universities Osteoarthritis Score (WOMAC) used to establish the level of pain and functionality experienced by the patients improved from a mean value of 52.5 calculated preoperatively to a value of 27.2 measured 1 year following the surgery.

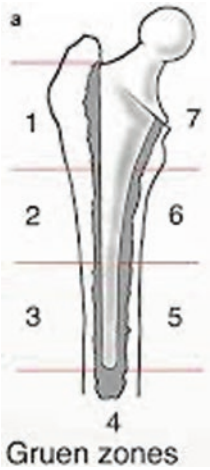

Fig. 7 Gruen zones 1–7

In summary, the results observed in the analyzed study fail to demonstrate that the incidence of dislocation following DAA for femoral revision surgeries is lower compared to other approaches, and other parameters calculated throughout the study, including complication rates and patient-reported outcomes, are analogous to the ones indicated in other studies in which other surgical approaches were analyzed [207].

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