Principles of Primary Total Hip Arthroplasty

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Preface

Total hip arthroplasty (THA) is undoubtedly one of the most successful surgeries in the past decades. In terms of relieving pain and improving function, there is no other operation compared with it. After decades of development, especially in the past 20 years, orthopedic surgeons have a deeper understanding of hip disease and failure mechanisms of THA. At the same time, they have made great progress in prosthesis design, materials, and implantation methods.

Today, expectations of surgeons and patients for THA are no longer limited to pain relief and function improvement. How to improve the patient's satisfaction and make the patient completely painless, or even completely return to normal life and sports after surgery, is a higher goal pursued by clinical practice.

Although most hip arthroplasties can be perfect, some patients will still have postoperative complications. Therefore, how to avoid periprosthetic infection, periprosthetic fractures, and other postoperative complications is still a hot topic in THA.

At the same time, with the advent of intelligent orthopedics, new navigation and robot technology has also changed the way of hip implantation. What these technologies bring to us and how to use them are also the concern.

As surgeons in the Department of Joint Surgery of Beijing Jishuitan Hospital, we hereby write this book to feed readers and provide some help for them to understand modern hip arthroplasty technology.

Beijing, China
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Part I

Basic Knowledge of Total Hip Arthroplasty

Total Hip Arthroplasty: Indications and Contraindications

1

Hao Tang

Key Points

1. The success of hip arthroplasty depends on the right indication.
2. Surgeons need to carefully evaluate the patient's main complaint, underlying disease, and general condition before the operation and weigh the potential individual benefits and risks.
3. Indications for hip arthroplasty include pain, low functional level, failed conservative treatment.
4. The contraindications for hip arthroplasty surgery include active joint infection, osteomyelitis, and systemic infection.

Hip joint disease is a common health problem that has plagued humans throughout history. With the advancement of medicine over the last hundred years, various treatments have been attempted, such as spacer placement, joint fusion, osteotomy, and even hip resection arthroplasty. However, it remained difficult to effectively treat the severe pain and functional loss caused by hip joint disease. The loss of working capacity caused by hip joint disease places a heavy economic burden on patients.

In the twentieth century, hip arthroplasty was one of the most revolutionary medical advances.

Innovations in material science, surgical technology, and aseptic techniques, among others, have made the dream of joint reconstruction, even in advanced disease, a reality. Modern artificial joints not only effectively control pain, but the functional reconstruction allows patients to live independently from crutches and wheelchairs thereby greatly reducing the disease and economic burden on families and society.

Long-term follow-up shows that the survival rate of total hip arthroplasty after 20 years is as high as 85–90% [1–4]. Furthermore, given the continuous progress in surgical techniques, prosthesis design, and manufacturing processes, the outcomes are still improving. However, similar to any other medical treatment, the success of hip arthroplasty depends on selecting the right patients. Any surgical intervention bears risk, and the decision-making process requires weighing the potential benefits against these risks.

Surgeons have to consider whether the patient actually needs surgery and if so, identify the optimal type and timing of surgery that are most beneficial to the individual patient. Apart from joint replacement, various other hip surgeries exist that have different clinical effects and risks, and there is no broad clinical consensus on the indications and contraindications of many of these interventions to date. An individual's severity of symptoms, expectations of surgery, comorbidities, and

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other factors vary from patient to patient, and no single treatment can be applied to all patients. Therefore, clinical decision-making requires open communication and discussion between patients and doctors with careful evaluation of the individual situation so that patients fully understand both the potential risks and benefits of surgical treatment, enabling them to actively participate in shared decision-making. A multidisciplinary discussion is frequently required for complex cases, such as systemic inflammatory disease, joint infection, revisions, and patients with severe systemic comorbidities.

Indications and contraindications are the keys to weighing the pros and cons in surgical decision-making, and they are also the basis for shared decision-making by physicians and patients. In short, surgical indications refer to a clinical situation in which the benefits of surgery outweigh the disadvantages for the patient. Conversely, contraindications refer to a clinical situation where the risk of complications and failure is too high to perform surgery.

In hip arthroplasty surgery, it is necessary to carefully evaluate the patient's main complaint, underlying disease, and general condition and to weigh the possible benefits and risks before considering the operation. Total hip arthroplasty surgery is associated with serious complications such as postoperative thromboembolism, infection, dislocation, fracture, and even death. The probability of these complications continues to decrease with the advancement of technology but as surgeons, we have to balance the benefits of long-term pain relief and functional recovery with the risk of complications before we can make an appropriate decision. This chapter will focus on the indications and contraindications for hip arthroplasty.

## 1.1	Indications for Hip Arthroplasty

The purpose of hip arthroplasty is to relieve pain and improve function. Surgical indications are constantly changing and expanding, and there is no uniform gold standard. Surgical decision-making includes evaluating the patient's history and severity of symptoms, possible surgical outcomes, and the risk of complications and failure of the intervention. Patient expectations and compliance are important aspects that need to be considered. The interaction of these complex factors requires the indication for surgery to be established individually in each patient.

The main indication of hip arthroplasty is pain. Hip pain often manifests as pain in the groin or proximal thigh. Mechanical pain often increases with activity and is relieved after rest. Inflammatory pain may present as persistent pain at rest. Hip pain usually does not extend below the knee joint. Buttock pain must be carefully assessed to establish whether it originates from the hip or lumbar degeneration. Pain radiating to the foot, accompanied by numbness, is more likely to be caused by lumbar radiculopathy. Importantly, different patients have different pain tolerances. A certain degree of pain may be considerably affecting some patients' daily lives, whereas it may not impact other patients. In summary, clinicians need to identify whether the patient's pain, in fact, comes from the hip joint, whether conservative treatment might be effective, and whether the impact of pain on the patient's quality of life requires surgical intervention.

Imaging examinations can assist in diagnosing the disease and its severity and help with surgical decision-making, but they cannot replace the due consideration of the patient's clinical symptoms. The degree of hip pain does not necessarily correspond to the degree of hip joint disease on radiographs. As orthopedic surgeons, we should always bear in mind that it is the patient whom we are treating and not the radiographs. While the manifestations of hip joint disease in imaging studies mostly correspond to the clinical symptoms, there may also be considerable discrepancies between the two. Some patients demonstrate severe joint disease on images, but their clinical symptoms are mild, whereas other patients with obvious symptoms may have only mild radiographic changes. Therefore, the decision on treatment should be based on clinical symptoms rather than imaging examinations. In

patients with mild to moderate joint lesions on imaging studies but with atypical hip pain symptoms and a normal range of motion, the source of symptoms should be carefully identified before appropriate treatment options are considered.

The functional ability of a patient plays an important role in clinical decision-making. Joint replacement can help patients rebuild the motor function required for their daily activities, which may allow them to return to nonphysical work, complete housework, and maintain personal care. If the function of the patient in daily life is severely restricted because of their hip pain and cannot be improved under conservative treatment, then joint replacement should be considered to restore such function. Some patients may substantially reduce their mobility and stay in bed for prolonged periods of time because of their joint disease. While this may alleviate the pain, it simultaneously increases the risk of systemic complications, such as pneumonia and bedsores.

In other cases, where a patient's pain is not obvious, the improvement in mobility after joint replacement can greatly improve their quality of life. If a patient who exercises regularly has activity-related joint pain, reducing physical activity can usually relieve symptoms. In general, strenuous activities should be avoided after joint replacement to extend joint life. Therefore, patients with high expectations of their exercise ability, such as athletes, need extensive physician-patient communication to reduce unreasonable expectations of the surgery outcomes. Most athletes will not recover to their previous level of performance after joint replacement.

Conservative treatment failure is another valid indication for joint replacement (Fig. 1.1). Common conservative treatments include the use of walking aids (crutches/canes), local or systemic medications, and lifestyle adjustments. Behavior adjustment can prolong the lifetime of human joints. In patients with mild joint disease, avoiding strenuous exercise can effectively relieve the symptoms. The use of walking aids can reduce load in the joints while ambulating thereby reducing symptoms. Nonsteroidal anti-inflammatory drugs are commonly used oral

Fig. 1.1 36-year-old patient suffering from avascular necrosis of the left femoral head after failed conservative treatment

analgesics and can effectively control pain in patients with mild to moderate symptoms but have side effects such as liver and kidney damage and gastrointestinal bleeding. Young patients should initially always try conservative treatment. Even patients with severe joint diseases should attempt conservative treatment because this cannot only improve some of their symptoms but also helps physicians understand the lifestyle requirements, expectations of treatment, and pain tolerance of patients to further assess the need for surgical treatment [5–7].

Age and weight are also important factors that affect decision-making. Patients younger than 40 years usually have a longer life expectancy and may have to undergo multiple revisions if they receive joint replacement early [8–10]. Therefore, young patients should initially take measures to preserve their joints, and surgeons should be more cautious about joint replacement in this situation [11, 12]. Some surgeons may choose interventions to buy time, such as osteotomy and joint fusion. However, we should try to minimize the adverse effects of these operations on subsequent joint replacement. Obese patients present a higher degree of difficulties during surgery, place greater postoperative stress on the joint, and have an increased risk of complica-

tions, such as thrombosis, dislocation, and loosening of the prosthesis compared to patients of normal weight [13–15].

The decision for the replacement of a fused hip should be carefully considered. These patients have severe mobility limitations without significant hip pain but may experience low back pain, contralateral hip pain, or knee symptoms instead. A fused hip is one of the common causes of hip-spine syndrome, which describes lumbar back pain or degeneration secondary to hip arthritis. In these circumstances, the orientation of the artificial joint components needs to be carefully individualized to compensate for any stiffness or/ and imbalance between the lumbar spine and the pelvis (Fig. 1.2). Furthermore, long-term immobilization in hip ankylosis causes atrophy of the gluteus medius and soft tissues, which may result in even worse pain and instability symptoms of the hip joint itself after hip arthroplasty. A fused hip that allows walking is better than a painful artificial hip with repeated dislocations. Therefore, the advantages and disadvantages of hip replacement in ankylosis should be carefully considered.

1.2 Contraindications of Artificial Hip Arthroplasty

Absolute contraindications for hip arthroplasty mainly include active joint infection, osteomyelitis, and systemic infection [16–18]. These conditions lead to a significantly increased risk of periprosthetic infections and failure. Patients with a history of hip joint infection also have an increased risk of infection recurrence after surgery. When infection is suspected, the respective blood tests (white blood count, C-reactive protein, erythrocyte sedimentation rate, blood culture, etc.) and joint fluid aspiration tests (white blood count, culture, antibiotic sensitivity test, etc.) should be performed. For patients with persistent septic arthritis, thorough debridement, drainage, and resection arthroplasty are better treatment options. Other diseases that may cause infection are often considered as contraindications to hip arthroplasties, such as chronic renal failure, intravenous drug use, and immunodeficiency.

The relative contraindications to hip arthroplasty usually refer to clinical situations that substantially affect the safety and outcomes of
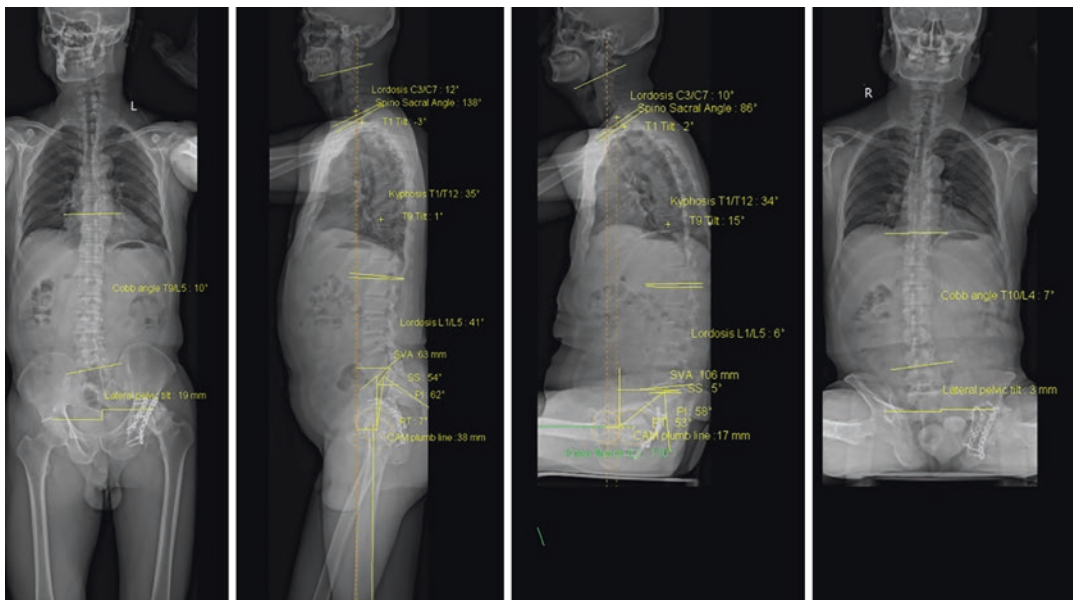

Fig. 1.2 The assessment of spinal-pelvic balance and motion using standing and sitting images. *PI* Pelvic incidence, *PT* Pelvic tilt, *SS* Sacral slope, *SVA* Sagittal vertical axis

surgery. Any comorbidity that increases perioperative complication and mortality rates may cause the risks to outweigh the benefits. Examples are acute myocardial infarction, cerebrovascular disease, and malignant tumors. High-dose radiation therapy of the pelvis, Charcot arthropathy, and other conditions may increase the risk of prosthetic loosening. Abductor muscle weakness, dementia, and other neuromuscular diseases may compromise postoperative joint stability and may cause complications such as dislocation. Surgeons can never be too careful in considering the indication for arthroplasty in these patients. They must also ensure that patients have realistic expectations of the surgical outcomes and are aware of the potential complications. Finally, patients need to commit to postoperative rehabilitation training and any necessary lifestyle adjustments. Any problem that interferes with the rehabilitation process is a relative contraindication to hip arthroplasty.

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Cemented Hip Arthroplasty and Cementing Technique

2

Jian Liu

Key Points

1. Optimal cementing technique is very important.
2. It is very important to know the concept of shape-closed fixation and force-closed fixation for cemented femoral stems.
3. Cement cups still have a role in THA.
4. Treatment of an infected total joint arthroplasty with antibiotic-loaded cement.

2.1 Introduction

The use of bone cement for hip implant fixation varies widely between geographic regions. In Europe and New Zealand, most stems and cups are fixed with cement. In North America, Australia, and China, cement fixation is much less popular, and the majority of hip replacements use cementless prosthetic designs.

Cementing of hip implants is more time-consuming and constitutes a more complex procedure than cementless arthroplasty and poses difficulties if a revision is required at a later stage. In our department, cemented implants are used in an older, less active population with poor bone quality, whereas cementless implants are used more often in young and active patients.

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Bone cement is an effective drug carrier. Antibiotic-loaded cement can be used for the prevention and treatment of hip arthroplasty infections.

Polymethylmethacrylate continues to be used in hip surgery in specific situations and cemented hip arthroplasty is unlikely to be replaced by cementless hip in the near future.

2.2 Importance of Optimal Cementing Technique

This chapter provides an overview of the evolution of cementing techniques and defines the current status of modern cementing in total hip arthroplasty (THA). Current techniques have the aim of improving the mechanical interlocking between the cement and bone to establish a durable interface. Using cement guns, distal plugs, pulsatile lavage, and cement pressurizing devices has been proven to markedly improve long-term survivorship of cemented hip.

2.2.1 Cement Restrictors

A distal plug allows pressurization during the cement application. Cement pressurization, thorough pulsatile lavage, and plugging of the canal

play an integrated part in cementing techniques. Consequently, the integral cementing techniques improve cement penetration, shear strength, and demonstrate better clinical outcomes.

2.2.2 Choice of Mixing System

Studies [1–3] reviewed that pores in bone cement decrease cement mechanical strength and the anti-fatigue properties can be significantly enhanced by the removal of these air inclusions. Currently, vacuum mixing is the most popular cement mixing technique, and there are many evidence [4–6] that cement porosity can be reduced by using vacuum mixing system.

The mechanical strength and the porosity of the bone cement may be affected by various factors.

1. Mixing system: The cement produced by the syringe-shaped vacuum mixing system has lower porosity and higher density, flexural modulus and flexural strength, compared to the bowl vacuum mixing system.
2. Mixing paddle: The material that does not adhere to bone cement could be the best choice.
3. Vacuum level: It can greatly decrease the porosity by about 50% and remarkably get the density in high-viscosity cement bigger at the vacuum level lower than 0.2 bar contrasted to atmospheric pressure. But if the vacuum level grows to 0.05 bar, the porosity will no longer decline compared to 0.2 bar. Generally speaking, the vacuum level between 0.25 and 0.05 bar is considered to be the best choice for various cements.

2.2.3 Bone Preparation

The bone-cement interface must be as strong as possible. The strongest interface is formed when we force cement into the spaces in the trabecular bone and keep it in this position until the cement polymerizes. Many factors can affect the interface, including fat in canel and cleaning the blood, cement mixing, hemostasis, pressurization, and component heating. The surgeon must know the effect that all these factors have on obtaining a reliable cement-bone interface during the primary procedure. Every surgeon has the duty to make sure that the mechanical interlock between the bone and cement is optimal at the time of the initial operation.

When we are preparing the proximal femur, a layer of strong trabecular bone should be preserved at least 2–3 mm, so that an adequate cement interdigitation can be achieved. Clinical evidence and experimental studies [7–9] have shown that pulsatile lavage is as important as pressurization for cement interdigitation. Pulsatile lavage can improve cement penetration, and markedly reduce the risk of embolic complications associated with cement pressurization. Since manual bone lavage is less effective, the use of pulsatile lavage is considered mandatory for cleansing the femoral bone bed in cemented THA.

2.2.4 Cement Mantle Thickness

The ideal thickness of the cement mantle does not exist, but we have no doubt that a deficient cement mantle may decrease the long-term implant survival. Thin layers of cement may crack and fail because of a low potential for energy absorption. Based on experimental, clinical, and radiographic findings, it is widely accepted that a minimum of 2 mm thickness cement mantle should be achieved [10, 11]. As a consequence of the mismatch between the intramedullary cavity and femoral stem in different locations, asymmetric cement mantle will be very common. However, to avoid metal-to-bone contact, it should not be thinner than 1–3 mm in the mid and lower Gruen zones (anteroposterior: 2–6; lateral: 9–13). In the proximal femur, corresponding to Gruen zone 7, the thickness of the cement layer should be at least 4–7 mm [12–14].

Several factors can influence the quality and thickness of the cement mantle:

1. Quality of cementing technique;
2. Femoral anatomy (shape and bone architecture);
3. Surgical technique (canal preparation and broaching);
4. Stem design and instrumentation;
5. Centralizer usage;
6. Stem size.

Femur preparation entails several key points. Optimal posterior and lateral canal entry and preparation are essential to prevent stem malalignment and minimize the risk of thin cement mantles. Straight stems without distal centralizers carry the highest risk of thin cement mantles, whereas anatomical stem designs respect the proximal femoral geometry and reduce the risk of thin cement mantles in Gruen zones 8 and 9. Centralizers are effective in preventing stem tip-bone contact and do not influence the proximal cement mantle. Thin cement mantles are easy to crack in long term which lead to loosening and osteolysis, even resulting in periprosthetic fractures. Hence, both implant choice and surgical technique determine the long-term outcomes of cemented femoral stems.

Acetabular bone preparation should include the removal of all soft tissue and cysts and opening of the honeycomb structures in the bone bed. Mechanical stability of the bone bed can be increased by partial preservation of the subchondral plate. Multiple anchorage holes can facilitate cement penetration into the subchondral trabecular bone. Pulsatile lavage is another key point in the acetabular bone bed.

2.3 Cemented Femoral Stems

In the last few years, two prosthetic design philosophies have been introduced by Huiskes et al. [15] who introduced the concept of force-closed fixation versus shape-closed fixation for cemented femoral stems.

Migration studies have suggested that more or less all stems migrate with their cement mantle [16]. A shape-closed design includes features to minimize this migration. These features can provide additional mechanical stability. Collars, ridges, profiles, or anatomic shape are the typical features in a shape-closed design. Different from that, the force-closed design accepts micromotion at the stem-cement interface. It relies on a taper that transfers the load at the stem-cement interface onto the cement. At the stem-cement interface, the frictional forces are equal to the external load. As the cement creeps or micro-cracks accumulate in the cement, the circumferential stresses are reduced. Therefore, the stem migrates distally to increase the frictional forces to balance the external forces.

For example, Two entirely different design philosophies of prosthetic stems that both perform clinically very well can demonstrate the importance of design.

One of the prosthetic stems is The Exeter® stem (see Fig. 2.1). It has many features, such as double tapered, no collar, symmetric, highly polished, and made of stainless steel. All those features benefit the philosophy behind this design that it distributes the stresses evenly across the cement mantle (no collar or ridges), anticipates stem-cement debonding, and accommodates cement creep and stress reduction. Therefore, it might migrate safely without any cement damage.

Another stem opposes that the stem of the Lubinus SPII® (see Fig. 2.2) has other features to make the mechanical interlock between the cement and bone more stable. Features Such as an anatomical shape and a longitudinal profile, matt surface finish, and collar of the Lubinus SPII® stem center around its maximal mechanical stability in the cement mantle [17].

One stem must obey one design philosophy. The Exeter® stem has the philosophy that it could migrate safely without any cement damage to
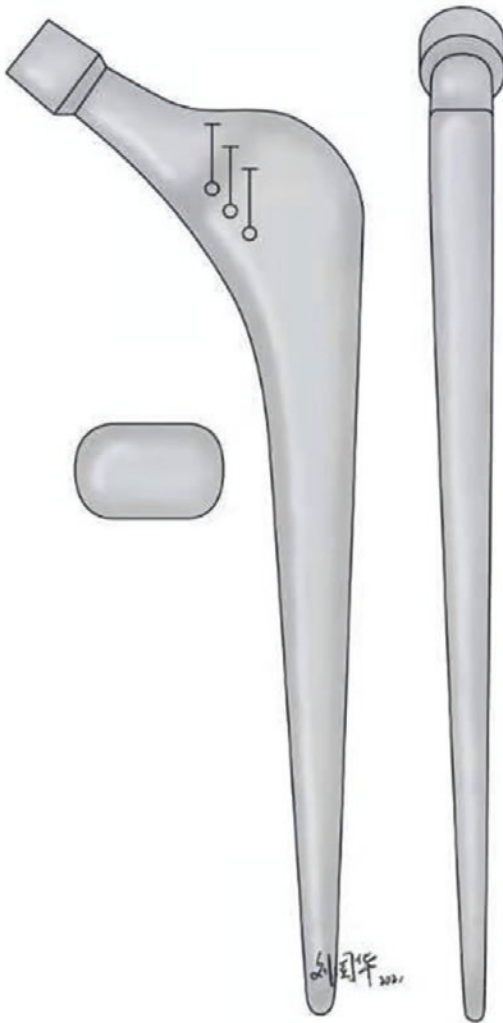
Fig. 2.1 Force-closed design stem has many features, such as double tapered, no collar, symmetric, highly polished, and made of stainless steel

balance the external load and the frictional forces. Any features opposite the design philosophy will compromise the survival rate of the stem. If the Exeter® stem were widened the size at the proximal level, provided with a collar, if the surface roughness of the Exeter® stem would be increased, and if the Exeter® stem were changed from a straight tapered design to an anatomic design, migration would be markedly reduced.

The cementing technique used is dependent on the implant design. There are two main techniques of femoral broaching that depend mostly on the implant design. The most common technique is that the implant is smaller than the last broach used. This technique is called the standard or "over-broaching" technique. Depending on the implant design, this allows for a 2 mm cement mantle. Several studies have suggested that a thin cement mantle is subject to increased strain and may fragment [18, 19]. Although, clinically, a thick cement mantle has very good outcomes [20, 21], a recent study found that increased cement thickness results in increased stem subsidence than standard cement thickness [22]. Another preparation technique uses an implant of the same size as the last broach, resulting in a very thin cement mantle [23, 24]. This technique is commonly associated with complete removal of the medullary cancellous bone and occasionally with reaming of the canal. This line-to-line broaching and the standard technique have very good outcomes in the literature [25–27]. We should not use one cementing technique in another type of implant design; it tends to perform worse if a wrong cementing technique is used [24, 28, 29].

Another type of cemented stem used with the line-to-line cementing technique is similar to the shape-closed design type (see Fig. 2.3). However, it achieves a press-fit fixation in the anteroposterior plane and has a self-centering effect [30]. These stems are rectangular in cross-section and were originally designed with a rough surface coating. The composite beam effect in implants is achieved with a self-centering, press-fit design, a thin cement mantle, and close stem-bone contact in the coronal plane [23]. The femoral canal is usually prepared using the line-to-line technique with either impaction or complete removal of the cancellous bone. Because the implant has the same size as the last broach, these implants need to be hammered down the canal as one would with an uncemented implant. The cement mantle thickness varies along the length of the stem, and in some regions, the stem is in direct contact with the cortical bone.

Fig. 2.2 Shape-closed stem has many features such as an anatomical shape and a longitudinal profile, matt surface finish, and collar
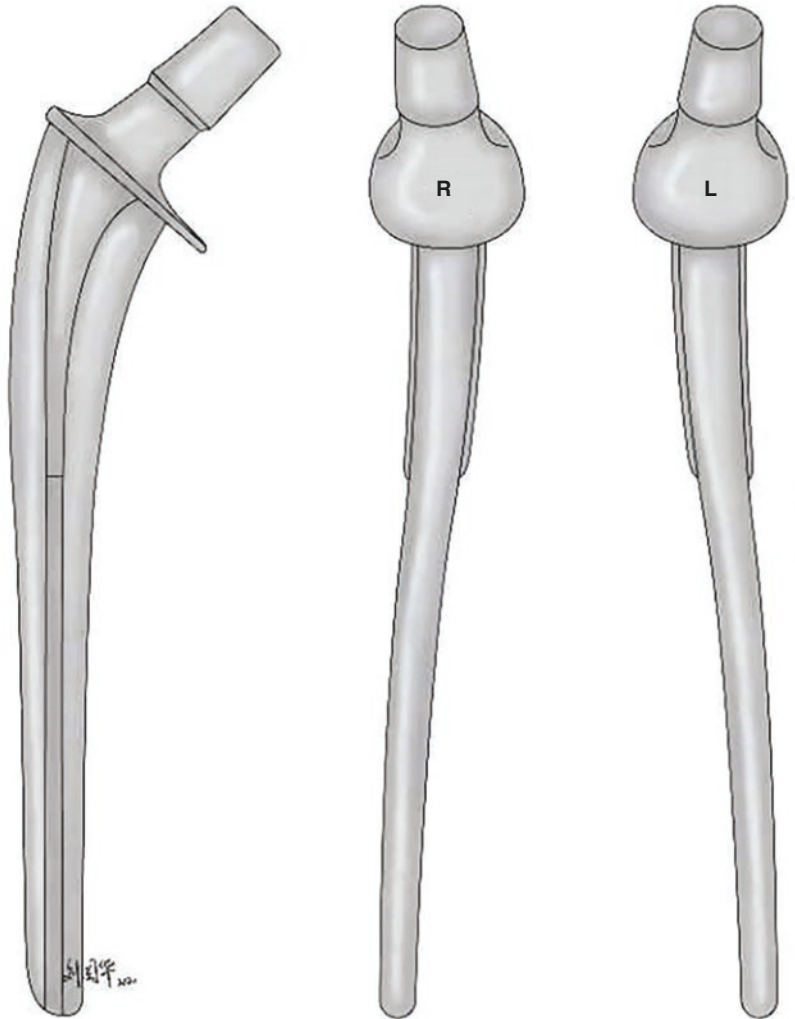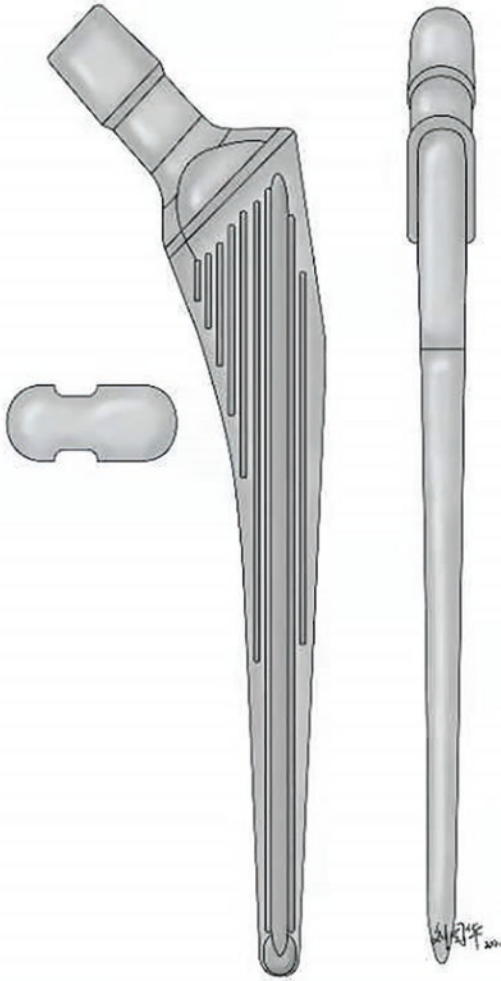
Fig. 2.3 Line-to-line design stems are rectangular in cross-section and were originally designed with a rough surface coating

2.4 The Role of Cemented Cups

Over the past decade, cementless acetabular components in THA have been popular. Most THAs performed in North America and China currently use cementless acetabular components. However, the optimal method for acetabular socket fixation remains controversial. A systematic review concluded that there is no evidence for better survivorship of cementless acetabular components than of cemented ones [31].

Cemented sockets show good long-term outcomes with lower overall reoperation rates than cementless designs. It is acknowledged that the revision rates for aseptic loosening within 10 years are lower in cementless sockets with polyethylene liners than in cemented sockets. However, the reoperation rate for other indications, such as pelvic lysis, polyethylene wear, and failure of the cup-locking mechanisms, means that the overall reoperation rate is significantly higher in cementless than in cemented cups.

Two main factors are important to prevent the loosening of cemented sockets. The most important factor is the surgical technique. In addition to routine reaming and preparing of the acetabulum, anchoring holes are required to improve cement penetration. In the acetabular roof, multiple anchoring holes are made using a flexible drill. Care must be taken not to perforate thin anterior or posterior walls, where only grooves and dimples should be made using a drill or small sharp gauge. The single most important step is copious and thorough pulsatile lavage. Irrigation not only renders soft tissue remnants visible as white strands but also effectively removes blood and bone marrow from the bone interstices thus aiding cement penetration. The lavage is repeated several times between the different steps of bone preparation to ensure a clean bone bed and facilitate visualization. Prior to the last wash, an H_2O_2-soaked sponge is firmly packed into the acetabulum to reduce bleeding and blood loss. Sustained cement pressurization ensures adequate cement interdigitation. The diameter of the acetabular component should be at least 4 mm less than that of the largest reamer used to guarantee a minimal cement mantle thickness of 2–3 mm.

The second factor is the design of the cemented cup. Hodgkinson et al. [32] reported the early and long-term radiographic findings in 302 Charnley THAs to determine the effect of a flanged socket on the bone-cement interface. The most significant finding on the postoperative radiographs was statistically significantly less radiolucency around flanged cups: No demarcation was observed in 82% of the flanged cups compared with that in 60% of the unflanged cups, and grade I demarcation was visible in 14.7% and 36.8%, respectively. After 10 years, the statistically sig-

nificant difference in radiolucent lines was maintained, but approximately 50% of patients in both groups showed progression of the radiolucent demarcation lines. The authors concluded that the better long-term radiological results in flanged sockets were due to the superior cement-bone interface compared to that of unflanged cups at the time of implantation.

2.5 Cementing Hip Could Have Good Results Using Modern Cementing Techniques

Modern cementing techniques have led to better results than those found in uncemented designs [33]. Since the 1990s, uncemented devices have shown improved stability that is nowadays considered equivalent to that of cemented fixation [34]. Consequently, it is quite possible that their use will result in a situation where certain problems of longevity will be replaced with different complications that have yet to emerge. What has been demonstrated are the improved results of modern cementing techniques.

2.6 Treatment of Infected Total Hip Arthroplasty with Antibiotic-Loaded Cement

Antibiotic-loaded cement has become a standard in the treatment of infections after THA because of the high local concentrations of antibiotics that can be achieved directly at the surgical site. Two different strategies can be used, and the choice of either the single- or two-stage procedure depends on the infectious agent, the local situation after implant removal, and the experience of the surgical team.

In the single-stage procedure, removal of the infected implants, extensive debridement of the implantation site, and reimplantation of new implants are performed in a single sitting. If reconstruction with cemented implants is feasible, the use of antibiotic-loaded cement is a good choice. Up to 10% of the cement volume may be replaced with a carefully selected antibiotic, or a combination of antibiotics, mixed into the cement in powder form, and both the cup and stem are cemented.

In the two-stage procedure, implant removal, extensive debridement, and implantation of an antibiotic-loaded "cement spacer" are performed during the initial procedure. Once the infection is controlled, which mostly requires several weeks of antibiotic treatment, another debridement and reimplantation of a cemented or uncemented device are performed during the second procedure. There are different cementing techniques when implanting the cement spacer, and it is preferred to cement the proximal part of the spacer and not to use a cement restrictor or cement gun. The spacer is implanted after the phase of optimal working viscosity of the cement, which makes it easy to revise the spacer when performing the second procedure.

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Cementless Component Design

3

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Key Points
1. Different component designs for total hip arthroplasty (THA) differ from one another mainly in terms of the fixation pattern (associated with the coating type and extent, stem shape, and stem length) and modularity.
2. Cementless stems can be divided into different types according to their shape, coating type and extent, length, and modularity.
3. Cementless cups are available with different profiles, coatings, liners, screw-hole clusters, and other anti-rotational stabilizers.
4. Most modern designs achieve excellent fixation and bone integration with 10 year survivorship of over 90%.

If we want to know how and why our world is the way it is today, we must look to history for answers. The history of implant design provides us with a comprehensive understanding of the important aspects the designers considered in the process and the outcomes that were achieved sometimes with and sometimes without coincidence. The design of a cementless THA prosthesis describes the underlying reasons for the artful application of insights from material science, mechanics, biology, and anatomy.

Cementless stems can be divided into different types according to their shape, coating type and extent, length, and modularity. Cementless cups can have different profiles, coatings, liners, screw-hole clusters, and other anti-rotational stabilizers. In this chapter, we discuss different modern designs of cementless components for THA.

3.1 Cementless Stem Design

Although the first THAs had a cemented implant design [1], the majority of THA prostheses implanted across China and the United States today are cementless. Several modern cementless femoral stems have been reported to have excellent long-term survival. They differ from one another in terms of the fixation pattern (associated with the coating type and extent, shape, and length) and modularity.

Most modern stem designs have achieved excellent fixation and bone integration. The 10-year survivorship rate is usually over 95% [2]. Less stem loosening and thigh pain than for earlier designs were observed, although some authors reported different findings in relation to some stem design.

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3.1.1 Coating

The cementless femoral stems for primary THA are mostly made of cobalt-chromium-molybdenum alloys or titanium-aluminum-vanadium alloys. Different coatings are integrated on the surface of stems to enhance bone integration. Bone on-growth and bone in-growth coatings have been commonly used for decades and remain similar until today.

The on-growth coating is a rough surface manufactured by grit blasting or plasma spraying [3]. Through the grit blasting technology, the surface could be textured by forcibly propelling fine particles, such as corundum. The surface roughness of the on-growth coating ranges from 3 to 5 mm. In plasma spraying, the metal powder (in most cases titanium) is mixed with an inert gas (usually N_2) in a high-energy flame by pressurization and ionization. The molten metal particles are then sprayed onto the implant surface to create a textured surface. A plasma spraying coating possesses less interconnecting porosity than an in-growth surface but retains better fatigue strength in the implant than sintering.

An in-growth coating is a rough surface that allows bone units to grow into the material. The optimal pore size is 50–400 μm [4]. A pore size smaller than that of a bone unit would not allow any bone units to grow into it. Pores larger than 500 μm are too wide and only allow macro-locking. To retain the mechanical strength, the percentage of voids is usually required to be 30–40%. Several technologies are used to produce these in-growth surfaces, such as sintering, fiber meshes, and porous metals. Trabecular metal is a highly porous coating with higher porosity than other in-growth coating and has been reported to have the best potential for bone in-growth. It is controversial whether a highly porous coating is needed in a cementless stem design. The biological and biomechanical conditions in the intertrochanteric zone create favorable conditions for bone growth that have low demands on in-growth potential.

Hydroxyapatite, whose osteoconductive ability has been widely proven, can be sprayed either directly on the implant or over a coated surface [5]. Long-term survival could be achieved after the growth of mineralized bone on the implant. There are concerns about potential interface degradation when these coatings are sprayed onto a porous surface [6]. Some authors are concerned about the destiny of the interface once hydroxyapatite is totally absorbed.

3.1.2 Stem Shapes

The stem shape determines the intramedullary cortical contact and initial stability. Since the late 1970s, various femoral stem shapes have been used, and a vast spectrum of stem shapes is available today. There is no consensus on the classification method according to the stem shape. We suggest a classification system based on the distinct geometry of the stem in the areas where fixation is obtained [7]. It was reported by Michael A. Mont from Baltimore and defines six general types based on the stem shape, which are a modification of the four categories previously described by Daniel J. Berry [8].

In Mont's classification system, straight stems are categorized in Type 1–4, and as the number increases, so does the fixation area [7]. In details, stems of type 1 and type 2 are wedge-shaped and fixed in the metaphyseal of the femur. Type 3 is tapered in shape and achieved fixation in the metaphyseal-diaphyseal junction or even the proximal diaphysis. Type 4 is cylindrical in shape and commonly fully coated to achieve fixation in the proximal diaphysis. The modular prosthesis, comprised of the separate component for metaphysis and diaphysis, are classified as type 5. Type 6 stems are not commonly used due to the less forgiveness of the curved and anatomic design during the preparing process.

3.2 Cementless Cup Design

Unlike the cementless stem, the cementless cup has conquered almost the entire current market for primary THA in China, and the situation is similar across the world. The primary stability is achieved by the press-fit while the long-term stability relies on the bone on-growth or in-growth.

Ries reviewed the evolution of cementless acetabular cups and distinguished three generations of cups based on their development periods and characteristics [9]. The first-generation cups were developed in the 1980s. Their polyethylene (PE) liner was easily damaged by impingement, which resulted in frequent damage to the locking mechanism between the cup and the liner. Furthermore, the congruity between the liner and the inner surface of the cups was not sufficient, which resulted in substantial backside wear of the liner. In the second-generation cups that were introduced in the 1990s, the extruded part of the PE liner was much thicker and endured impingement better. Furthermore, congruity was improved to reduce backside wear. In the third-generation cups, the liners were not extruded from the cup rims to avoid impingement and damage to the locking mechanism. Further, congruity was significantly improved, and different types of liners could be loaded. The majority of cementless cups used worldwide today are third-generation cups.

Acetabular cup design is currently less discussed than stem design because of the promising clinical survivorship, concision, and simplicity of the implants across different systems. However, the coating still differs between cups, which results in different extents of clearance between the reamer and the final implant, as well as varying friction properties [10]. In some extreme cases, such as limited host bone contact, a highly porous coating (i. e., trabecular metal)

would help to secure initial instability and future bone integration.

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Bearing Surfaces for Total Hip Arthroplasty

4

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Key Points

1. The main bearing surfaces used for total hip arthroplasty include highly cross-linked polyethylene (XLP), ceramic, and metal. Metal-on-XLP has the longest clinical follow-up and most favorable results of all combinations, even in patients aged <50 years.

2. Polyethylene has the longest history and lower concern for liner fractures than ceramic liner. Cross-linking by gamma radiation increases the wear properties but decreases the fracture resistance. Free radicals can be oxidized and destabilize the liner, which may lead to liner delamination or fracture. Annealing, remelting, and vitamin E are used to eliminate free radicals. Data from in vitro studies, randomized and nonrandomized clinical trials, and registries all support the routine use of XLP.

3. Hard-on-hard bearings (metal-on-metal(MoM), ceramic-on-ceramic(CoC)) have a lower friction coefficient than hard-on-soft bearings (metal-on-polyethylene(MoP), ceramic-on-polyethylene(CoP)). Metal-on-metal combinations are strictly limited to well-informed concerned patients with strict indication because of adverse local tissue reactions to the metal ions. Minor differences were observed in the wear rates between metal-on-XLP, ceramic-on-XLP, and ceramic-on-ceramic bearings. The latter have a higher dislocation rate owing to their flat geometry.

4. No consensus exists on the optimal femoral head material. Cobalt-chromium heads are associated with trunnion corrosion when implanted for a certain amount of time, especially in situation of using large metal heads coupled with a thin stem neck. Therefore, alumina ceramic or oxidized zirconia femoral heads may be a better option in young, active patients.

Total hip arthroplasty (THA) is considered the most successful surgical innovation of the twentieth century. It continues to achieve excellent short-term outcomes with regard to pain relief and regaining mobility. However, implant loosening still limits the long-term outcomes. The survivorship of conventional THA is limited by the wear of the articulating surfaces, which may cause fracture, instability, or loosening resulting from osteolysis and tissue reactions to wear particles. Wear refers to the loss of particles from the bearing surface. It is influenced by *implant, surgeon, and patient factors*. Tribology is the science and engineering of interacting surfaces in relative motion. It focuses on how to influence the implant factors to reduce wear rates and improve implant survivorship [1].

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4.1   Polyethylene

Bearing surfaces have been the focus of substantial research efforts over the decades. Metal-on-polyethylene (MoP) is the most popular bearing couple. Alternative ceramic and metal biomaterials have been developed to meet the demands of younger and more active patients on bearings. *In general, compared to soft bearings, hard bearings show lower wear rates because their surface is less rough and less vulnerable to deformational forces* [2, 3].

Ultra-high molecular weight polyethylene (UHMWPE) was first introduced in 1962 by Charnley. He used small femoral heads coupled with polyethylene to create a low-friction arthroplasty. UHMWPE has a higher surface roughness factor (0.1–0.2) than ceramic and metal [2, 3]. It has a low Young's modulus and higher frictional resistance that creates more pronounced deformation under force. This results in more wear particles than what is seen with other bearing surfaces [4]. Polyethylene bearings use either boundary or mixed lubrication. In mixed lubrication, the load is carried by the surface asperities and lubrication fluid. Microscopically thin film reduces the sliding friction between the surfaces. In boundary lubrication, there is substantial contact between the bearing surfaces. Wear debris leads to osteolysis, then aseptic loosening of the prosthetic components may happen. Hip joint simulator studies have demonstrated that the majority of polyethylene wear particles are in a size range from 0.1 to 1 μm, resulting in osteolysis and bone resorption [5]. Studies have shown that particles <1 μm are biologically active, they can be phagocytosed by macrophages [6]. The threshold for osteolysis resulting from polyethylene debris has been estimated to be about 0.1 mm/y for linear wear and 80 mm^3/y for volumetric wear [7]. The exact quantity of osteolysis that causes implant loosening has not been defined to date.

Several treatments attempt to make the polyethylene in UHMWPE harder and reduce deformation when weight-bearing. These include sterilization in the absence of oxygen, irradiation, thermal stabilization of free radicals, and irradiation with antioxidant stabilization of free radicals. The most efficient wear protection is cross-linking of the polymer [8].

Initially, UHMWPE was sterilized using gamma radiation. Polyethylene consists of crystalline and amorphous regions. Gamma radiation causes the scission of carbon-carbon and carbon-hydrogen bonds, producing free radicals [9–11]. The bonding sites then create cross-links with nearby chains thereby developing a more interconnected network, especially in the amorphous regions. This increases the molecular weight of polyethylene and enhances its wear resistance. Highly cross-linked polyethylene (XLP) is irradiated with 50–100 kGy to increase cross-linking. Cross-linking is maximal at 100 kGy, above which higher doses trigger malfunction of the mechanical framework [2]. McKellop et al. [12] showed that radiation doses over 100 kGy reduced the wear performance. Therefore, commercially available remelted UHMWPE seldom exceeds a 100 kGy cross-linking dose.

If the energy available is not sufficient for all of the bonding sites to create cross-links, the free radicals participate in complicated reactions, leading to oxidation of the polymer [10, 13]. In the most extreme, oxidation causes a reduction in wear resistance or fracture of the material. It has been attempted to eliminate or reduce free radicals and promote cross-linking. The polyethylene is heat-treated, either above the crystalline melting point of the polymer at 137 °C (called remelting) or below that point (called annealing) to enhance the mobility of the free radicals and improve cross-linking [8]. Remelting allows more free radicals to be involved in the cross-linking but breaks down the crystalline regions, resulting in compromised mechanical strength [14]. In annealing, the crystalline structure is maintained, but residual free radicals may lead to increased oxidation and wear in vivo [2]. Compared to remelted XLP, annealed XLP has higher ductility and a lower risk of crack propagation [2].

Generally, increasing radiation dose in PE increases the wear resistance, but decreases the toughness and ductility of the polyethylene, whereas thermal treatment decreases the wear resistance and oxidation. Remelting prevents oxidation, while annealing permits some oxidation [8].

The total biological activity of the wear particles and osteolysis have both seen a remarkable decrease with the increased use of XLP over the past decade. Fisher et al. [15] found 100 kGy irradiated XLP liner has eightfold decrease in volumetric wear rates than a standard polyethylene (SP) using cobalt-chromium heads. Wear rates of 0.05 mm/year for highly cross-linked UHMWPE was found in a 5-year study, compared with 0.26 mm/year for standard UHMWPE [16]. Kuzyk et al. [17] performed a systematic review to compare the weighted average of femoral head penetration of XLP and SP. They found the wear rate of XLP was about 1/3 of SP (0.042 mm/y and 0.137 mm/y, respectively). And patients with XLP had an 87% lower rate of osteolysis. However, this did not translate into statistically significantly different revision rates at the 5.1-year follow-up [17]. In another research of The *Kaiser Permanente* hip arthroplasty registry, more than 26,000 patients showed a significantly lower revision rate for XLP (2.8%) compared with SP after a mean follow-up of 7 years (5.4%) [18].

The 2015 annual report of the Australian THA registry reported 152,076 uses of XLP liners in 312,828 primary THA cases [19]. During approximately 14 years of follow-up, the revision rate for aseptic loosening or osteolysis was higher for all femoral heads with SP than for bearings with XLP (3.6% and 1.1%, respectively). The lowest revision rate was *found for ceramicized metal-on-XLP THAs with 3.3%,* compared with rates of 9.9% for metal-on-SP, 11.2% for ceramicized metal-on-SP, 11.4% for ceramic-on-SP, 4.6% for ceramic-on-XLP, and 5.4% for metal-on-XLP [19].

When treating young patients with high activity levels, surgeons might consider metal-on-XLP as the bearing surface of choice. Babovic and Trousdale [20] reported 100% survivorship of 54 hips in 50 patients <50 years with metal-on-XLP THA (28 mm femoral head) with no visible osteolysis on anteroposterior radiographs after 10 years and a low femoral head penetration rate of 0.020 mm/y.

Vitamin E XLP has comparable wear rates but greater resistance to oxidation and better mechanical properties than what is seen with XLP in vitro. Without artificial aging, the in vitro wear rates of both XLP and vitamin E XLP were similar for 36 mm cobalt-chromium and ceramic femoral heads. However, a tenfold increase in the wear of XLP was observed after 6 weeks of artificial aging [21].

The clinical research on the wear rates of vitamin E XLP with cobalt-chromium heads is limited because of the low number of THAs and relatively short follow-up.

Adverse local tissue reactions have been observed in an increasing number over the recent decade of symptomatic patients with metal-on-polyethylene implants, which were previously seen only with metal-on-metal (MoM) implants. Fretting and corrosion at the junction of the femoral component trunnion and the cobalt-chromium head are believed to be the reasons for this observation. Trunnion corrosion may be found in patients with larger femoral head sizes, longer trunnion lengths, smaller trunnion diameters, longer neck lengths, wider taper angles, lower flexural rigidity, and dissimilar alloy pairings [22, 23]. This may affect the choice of bearing surfaces for surgeons, for example, large metal heads are coupled with thin and long stem necks in heavy patients. A ceramic femoral head is recommended to reduce the risk of trunnion corrosion [22].

4.2   Ceramics

Ceramics are defined as inorganic nonmetallic materials that are composed of metal and non-metal elements. They are made of zirconia, alumina, or alumina-matrix composite powders. The powder is compressed into the desired shape, and polished to get a low surface roughness [24]. The smooth surface gives the ceramic femoral head an advantage of low wear rates when coupled with PE [25]. Their hydrophilic properties allow for fluid film lubrication thereby minimizing the frictional forces. However, ceramics are brittle, meaning they show little deformation prior to failure. There is a concern that catastrophic failure may occur in the body, where multiple small fragments are extremely difficult to remove [26]. They can damage the femoral taper, leading to similar

adverse local tissue reactions as those seen in MoM couplings [2]. Minimizing the grain size and porosity and maximizing the purity of the ceramics lead to better material properties. Zirconia has better crack resistance than alumina. But there is a phase transformation of the zirconia, leading to volume expansion and fracture. Since the United States' *Federal Drug Administration* issued a warning in 2001, the use of pure zirconia has been discontinued worldwide [24]. Currently, most ceramic implants on market are made from alumina. It is the hardest ceramic but has lower crack resistance than zirconia [2, 24]. Scientists developed zirconia-toughened alumina to combine the superior crack resistance of zirconia with the stability and hardness of alumina, giving its color pink [2, 24]. These modern ceramic femoral heads and liners have extremely low fracture rates. The estimated overall fracture rate for Delta ceramic heads and liners is 0.003% and 0.03%, respectively [24]. Some companies use thermally treated zirconium and niobium to get a smooth and hard surface. This oxidized zirconia was commonly used as femoral ball and femoral components of knee arthroplasty. Except for their cracking and chipping resistance, the oxidized zirconia are choices for patients with a history of allergy to metal. They have a lower allergic reaction when comparing with CoCrMo materials.

Ceramic-on-polyethylene shows less friction and wear than standard MoP-bearing couples. COPE has significantly less wear rates compared with MoP. Galvin et al. [25] found 36 mm ceramic heads have 40% lower steady-state wear rates than CoCrMo heads when coupled with cross-linked PE at up to 10 Mc in vitro.

Ceramic-on-ceramic bearings have the lowest rate of wear among all the bearings available. Clarke and Gustafson [27] reported in vitro wear rates of ceramic-on-ceramic bearings, MoP, and MoM bearings using 28 mm femoral heads. The alumina-on-alumina bearings had the lowest wear rate (0.004 mm³/million cycle(Mc)). The wear rates of zirconia-on-zirconia were higher (0.013 mm³/Mc). MoP and MoM bearings had even higher rates of 0.028 mm³/Mc and 0.119 mm³/Mc.

Both ceramic-on-polyethylene and ceramic-on-ceramic bearings were reported with excellent wear rates and clinical outcomes. Milošev et al. [28] compared the 10-year survivorship of ceramic-on-ceramic couples with MoP and MoM couples. When defining aseptic loosening as the endpoint, patients using ceramic-on-ceramic bearings had a 98.4% overall survival rate. It was significantly lower for MoP (95.6%) and MoM (87.9%, $P = 0.005$).

Kim et al. [29] implanted alumina-on-XLP bearing in one hip and an alumina-on-alumina bearing in the contralateral hip in 100 patients. The survival rate was 100% for all femoral components and 99% for all acetabular components in both groups.

Ceramic bearings are usually recommended for young and active patients. The Australian THA registry includes 65,114 ceramic-on-ceramic hips, 30,835 ceramic-on-XLP hips, and 14,016 ceramicized metal-on-XLP hips [19]. Mixed ceramics (e.g., zirconia-toughened alumina) comprise 93.7% of all ceramic implants, as they have a lower risk of fracture than other ceramic materials. After 10 years, mixed ceramics show the lowest revision rate at 4.8% compared with alumina at 5.4% and zirconia at 8.2%. Ceramic heads coupled with XLP has a low revision rate (4.6%). When ceramic heads are paired with standard polyethylene, they had the highest revision rate of 11.4%. They found ceramic-on-ceramic implants has lower revision rates when using 32 mm heads than using 28 mm heads. No difference is seen in revision rates between 32 mm and 36–38 mm heads [19].

The New Zealand registry reported similar results, with low revision rates for ceramic-on-XLP (1.8%) and ceramic-on-ceramic (2.9%) bearings compared to MoP (5.0%) and ceramic-on-standard polyethylene (6.0%) bearings up to 14 years after THA [30].

## 4.3	Metal-on-Metal

MoM implants were very common in the 1970s as an alternative bearing surface to MOP in THA before the success of the Charnley low-friction arthroplasty led to a decline in the use of MoM bearings. Over time, surgeons became increas-

ingly concerned that MoP wear debris might cause severe osteolysis, and MoM experienced a revival as a bearing surface [31, 32].

MoM bearing surfaces show a lower wear rate in the laboratory and better stability than what has been established for MoP owing to the higher head-to-neck ratio. It was estimated that in 2010, MoM couplings were used in 32–40% of all primary THAs and in 26–32% of all revision THAs in the United States [33].

Although the volumetric wear rate of MoM bearing surfaces is low, metal debris are small and in large numbers. The estimated amount of metal wear particles is 10^{12}–10^{13} per year in low-carbon pairings. It is more than 5×10^{11} wear particles per year in UHMWPE acetabular cups [31, 34, 35]. Tipper et al. [32] showed that varying the carbon content of the alloys affects the wear property of the bearings. Low-carbon pairings (0.07%) have a higher wear rate than mixed and high-carbon pairings [31].

The metal ions released by cobalt-chromium wear particles are toxic according to their concentration. They could lead to DNA damage, or cause hypersensitivity. These minuscule particles may be distributed throughout the body, resulting in local and systemic reactions [34]. High concentrations of metal ions in the body have been shown to result in metallosis, which can cause pain, hypersensitivity, aseptic lymphocytic vasculitis-associated lesions, pseudotumors, and aseptic loosening. Glyn-Jones et al. [36] found that female sex, small components, dysplasia, and an age under 40 years correlated with an increase in both pseudotumors and revision rates in MoM-bearing surface implants.

Some patients with MoM THAs suffer severe systemic reactions as a result of prosthetic cobaltism [37, 38]. Case studies of arthroprosthetic cobaltism described cardiomyopathy, blindness, deafness, headaches, cognitive decline, peripheral neuropathy, convulsions, weakness, hypothyroidism, and fatigue [39, 40]. The serum cobalt levels in these patients were >60 µg/L [39, 40]. Following revision of THA and change to a non-MoM implant, serum cobalt concentrations dropped rapidly, and neurologic and cardiovascular functions improved [39, 41].

After studies in the United Kingdom and Australia had shown high revision rates for MoM couples due to soft tissue damage [42–44], the UK government issued a *Medical Device Alert* in April 2010 [45]. In August 2010, the voluntary recall of a widely used MoM product started [46]. Consecutively, the *Federal Drug Administration* required all manufacturers to perform postmarket surveillance studies of their MoM implants in the United States [47]. More manufacturers removed their MoM devices voluntarily from the market, and the clinical use of MoM implants declined sharply. The current use of MoM couples in the United States is estimated to be 0.5% of all THAs, limited almost exclusively to resurfacing arthroplasty in young, active male patients with high demands [48].

4.4   Summary

The main bearing surface materials used for THA are XLP, ceramics, and metals. Data from in vitro studies, clinical trials, and registries all support the routine use of XLP. Metal-on-XLP has the longest clinical follow-up and favorable results of all bearings. Currently, minor differences are reported in the wear rates between metal-on-XLP, ceramic-on-XLP, and ceramic-on-ceramic bearings. As the CoCrMo femoral head is associated with trunnionosis and metal allergy reactions, the alumina ceramic or oxidized zirconia heads may be considered in young, active patients. More data are required for the more recently introduced bearing couples.

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Preoperative Preparation and Surgical Techniques of Total Hip Arthroplasty

Preoperative Medical Evaluation for Total Joint Arthroplasty

5

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Key Points

1. A comprehensive preoperative medical evaluation of patients is critical and necessary to minimize perioperative complications.
2. Medical evaluation includes medical history, physical examination, and selected preoperative tests.
3. Cardiovascular disease, hypertension, cerebrovascular disease, pulmonary disease, and diabetes mellitus are the most common comorbidities observed in patients undergoing total joint arthroplasty.

Although surgical and anesthesia techniques and perioperative care have continually improved, patients continue to suffer from perioperative complications to date. Belmont et al. [1] searched the National Surgical Quality Improvement Program (NSQIP) database and identified 17,640 patients who had undergone primary total hip arthroplasty from 2006 to 2011. The 30-day postoperative mortality rate was 0.35%, and 867 (4.9%) patients had complications. The major systemic complications were postoperative sepsis (0.47%), pulmonary embolism (0.31%), myocardial infarction (0.24%), cerebrovascular accidents (0.17%), cardiac arrest requiring cardiopulmonary resuscitation (0.12%), septic shock (0.12%), and acute renal failure (0.07%). Tang et al. [2] analyzed the data of 1050 patients who underwent primary total hip and knee arthroplasties at a Chinese joint reconstruction center between May 2013 and December 2013. Postoperative major complications included myocardial infarction (0.1%), angina pectoris (1.9%), arrhythmia (1.2%), heart failure (0.4%), stroke (0.6%), pulmonary embolism (0.2%), and acute exacerbation of chronic obstructive pulmonary disease (COPD) (0.4%). Ninety percent of these major complications occurred within 4 days after surgery.

Therefore, a comprehensive preoperative medical evaluation is essential and necessary to minimize complications. Preoperative evaluation helps to note known or identify occult medical conditions, assess the medical risks, facilitate clinical decision-making, optimize patients preoperatively, and develop an individual intraoperative and postoperative management plan. Owing to the complexity of most underlying conditions, surgeons should perform the preoperative evaluation in close collaboration with anesthesiologists and internists. Further specialists may need to be consulted if the patient has a medical condition that requires further specific investigations and optimization.

The evaluation begins with history taking and physical examination. The medical history includes current and past medical problems. Patients are

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asked about common medical conditions, such as heart or vascular disease, liver disease, kidney disease, lung disease, nervous system disorders, muscle disorders, diabetes mellitus, bleeding or blood disorders, organ transplants, and use of alcohol or street drugs [3]. The past surgical history and complications, allergies, and medications should be identified. A basic physical examination includes blood pressure, resting heart rate, respiratory rate, temperature, height, and weight. It is particularly important to evaluate critical organ systems like the cardiovascular and respiratory systems. Based on a patient's medical history, further examinations on other systems may be performed, including the nervous system, musculoskeletal system, gastrointestinal system, hematologic system, and skin.

Preoperative tests establish patients' baseline characteristics, help to assess the risk, and may guide preoperative optimization if required. In 2012, the Task Force of the American Society of Anesthesiologists (ASA) Practice Advisory for Preanesthesia Evaluation stated that preoperative tests may be ordered selectively [4]. In 2016, the National Institute for Health and Care Excellence in the UK published an updated guideline for preoperative tests [5]. This guideline covers common preoperative tests, including full blood count, kidney function, lung function, arterial blood gas analysis, resting electrocardiography and echocardiography, cardiopulmonary exercise testing, polysomnography, glycated hemoglobin, hemostasis tests, chest X-ray, urine analysis, pregnancy testing, and sickle cell disease/trait tests. This guideline makes specific recommendations depending on both patients' ASA grades and the complexity of the planned surgical procedures.

Cardiovascular disease, hypertension, cerebrovascular disease, pulmonary disease, and diabetes mellitus are the most common medical conditions observed in patients undergoing total hip and knee arthroplasties.

5.1 Cardiovascular Disease

Common postoperative cardiac complications include postoperative myocardial infarction, arrhythmia, heart failure, and cardiac arrest.

These complications are frequent causes of morbidity and mortality among patients undergoing total joint arthroplasty. A systematic review found that older age and a history of cardiac disease were positively associated with the risk of cardiac complications in most studies [6]. Menendez et al. [7] utilized the Nationwide Inpatient Sample (NIS) database in the US and identified an estimated 3,096,791 total hip and knee arthroplasties between 2008 and 2011. They found that the incidence of in-hospital acute myocardial infarction (AMI) was 0.2%. The most significant risk factors of AMI were AIDS/HIV infection, coronary artery disease, and congestive heart failure. A study utilizing the NSQIP database identified 46,322 patients with total hip and knee arthroplasties between 2006 and 2011 [8]. The cardiac complication rate within 30 days after surgery was 0.33% in these patients, and 79% of events occurred within 7 days after surgery. An age of ≥80 years, hypertension requiring medication, and a history of cardiac disease were the most significant risk predictors of postoperative cardiac complications.

In 2014, the European Society of Cardiology (ESC) and the European Society of Anesthesiology (ESA) published guidelines on the cardiovascular assessment and management of patients undergoing noncardiac surgery [9]. These guidelines provide an evidence-based, stepwise approach for preoperative cardiac risk evaluation and perioperative management.

The preoperative assessment of patients undergoing total joint arthroplasty follows most of the steps suggested in these guidelines. The first step is to assess the urgency of the surgical procedure and allow urgent cases to proceed to surgery. Most total hip and knee arthroplasties are elective surgeries and, consequently, require further evaluation. The second step is to assess the patient's cardiac condition. Unstable cardiac conditions include unstable angina pectoris, recent myocardial infarction, significant cardiac arrhythmias, acute heart failure, symptomatic valvular heart disease, and residual myocardial ischemia [9]. Unstable cardiac conditions usually require delaying surgery, referral for consultation, and further management. The third step is to

determine the risk of the planned surgical procedure. Surgical procedures can be divided into low-risk, intermediate-risk, and high-risk [9, 10]. Total joint arthroplasty is an intermediate-risk procedure. The fourth step is to assess the functional capacity of the patient. Functional capacity is measured using metabolic equivalents (METs). Climbing two flights of stairs correspond to four METs. Patients with moderate or good functional capacity (>4 METs) can undergo total joint arthroplasty. The fifth step is to identify the cardiac risk factors. Clinical risk factors include diabetes mellitus requiring insulin therapy, stroke or transient ischemic attack, ischemic heart disease, heart failure, and renal dysfunction [9, 11]. For total joint arthroplasty patients with poor functional capacity and one or more cardiac risk factors, noninvasive stress testing may be performed.

5.2   Hypertension

Hypertension (high blood pressure) is common, and its worldwide prevalence may be as high as one billion individuals [12]. High blood pressure increases the risk of chronic kidney disease, ischemic stroke, myocardial infarction, and heart failure [13]. The duration and severity of hypertension are highly correlated with end-organ damage.

For patients with hypertension, preoperative evaluation includes the identification of other cardiovascular risk factors, understanding the causes of hypertension, and assessing target organ damage. Important identifiable causes of hypertension include coarctation of the aorta, pheochromocytoma, Cushing syndrome, chronic kidney disease, obstructive uropathy, renovascular hypertension, hyperthyroidism, and sleep apnea [12]. The search for target organ damage should focus on the heart, brain, kidney, vessels, and retina [12].

While preoperative hypertension is associated with an increased risk of postoperative cardiovascular complications, it does not warrant delay of surgery if the systolic blood pressure is <180 mmHg and diastolic blood pressure is <110 mmHg [9, 14]. In patients with severe hypertension, the management of antihypertensive therapy should be guided by a cardiologist. In general, most chronic antihypertensive medications can be continued perioperatively.

5.3   Cerebrovascular Disease

Stroke is a major cause of postoperative mortality. A study evaluated 333,117 patients who underwent elective primary total hip and knee arthroplasties between 2005 and 2016 using the NSQIP database [15]. The study found that 286 (0.09%) patients had a stroke. Independent risk factors of stroke included advanced age, increased ASA score, and smoking status. Another study examined patients undergoing primary or revision hip or knee arthroplasty from 2002 to 2011 in the NIS database [16]. The records of 1,762,496 total joint arthroplasties showed that 2414 patients (0.14%) developed stroke. Among these, 1918 (79.45%) patients had an ischemic stroke, and 496 (20.55%) had a hemorrhagic stroke. The in-hospital mortality rate of patients after a stroke was much higher than that of patients without a stroke (9% vs 0.15%). The data showed that pulmonary circulation disorders, advanced diabetes mellitus, cardiac arrhythmia, peripheral vascular disease, valvular heart disease, renal disease, and hip revision surgery were independent predictors of stroke.

Cerebrovascular disease is an important risk factor for postoperative complications. Unfortunately, there is no consensus on how soon elective surgery can be performed after a stroke. A Danish nationwide cohort study in 481,183 elective noncardiac surgeries between 2005 and 2011 studied the association between prior stroke and major adverse cardiovascular events (MACE) perioperatively [17]. Compared with patients without stroke, the odds ratios for MACE were 14.23, 4.85, 3.04, and 2.47 in patients who had had a stroke within less than 3 months, 3 to less than 6 months, 6 to less than 12 months, and more than 12 months prior to surgery, respectively. This demonstrates a particularly high-risk in patients who had a stroke less than 3 months prior to surgery.

The preoperative evaluation in these high-risk patients should focus on the causes, timing, and treatment of previous strokes. It is important to understand the cause of stroke in an individual patient to distinguish primary cerebrovascular disease from cardioembolic disease. While there are no specific prevention strategies, it is recommended to optimize risk factors preoperatively. If a patient is anticoagulated to prevent stroke, specialist consultation may be needed to establish optimal perioperative treatment protocols.

5.4 Pulmonary Disease

Perioperative pulmonary complications are associated with substantial morbidity and mortality. These include acute respiratory distress syndrome, pulmonary embolism, pneumonia, atelectasis, and respiratory failure. A study of the NIS database in an estimated 2,679,351 elective primary total hip procedures from 2004 to 2014 found pulmonary complications in 1.42% of patients [18]. Perioperative pulmonary complications were associated with an increased length of stay, hospital costs, and mortality.

Risk factors for postoperative pulmonary complications can be divided into patient-related and procedure-related risk factors. A systematic review identified advanced age, an ASA score of ≥2, functional dependence, COPD, congestive heart failure as patient-related risk factors [19]. COPD is the most common risk factor for postoperative pulmonary complications. In an NSQIP database study of 64,796 patients who underwent total hip arthroplasty between 2008 and 2014, postoperative complications were more likely to occur in COPD patients than non-COPD patients [20].

The goal of the perioperative management of COPD patients is to optimize their pulmonary function. This may include smoking cessation, inspiratory muscle training, and physiotherapy. More intensive treatment may be required in patients with a recent exacerbation, and elective surgery may have to be delayed. In general, chronic pulmonary treatment should be continued perioperatively, including oral and inhaled medications. Grau et al. [21] demonstrated the effectiveness of a pulmonary screening questionnaire and intervention protocol in identifying and preventing pulmonary complications. The preoperative interventions included smoking cessation, use of continuous positive airway pressure in patients with obstructive sleep apnea, optimizing inhaler use before admission, and the administration of albuterol through a nebulizer in the preoperative holding area and oxygen via a nasal cannula.

5.5 Diabetes Mellitus

Diabetes mellitus is the most common chronic disease worldwide and is predicted to affect up to 592 million people by the year 2035 [22]. Bolognesi et al. [23] analyzed 751,340 total hip and knee arthroplasties in the NIS database between 1988 and 2003 and identified 64,262 (8.55%) patients diagnosed with diabetes mellitus.

Diabetes mellitus is associated with renal dysfunction, gastropathy, retinopathy, and cerebrovascular disease. Diabetes mellitus has also been shown to be an important risk factor for postoperative complications, including myocardial infarction, stroke, pneumonia, surgical site infection, deep venous thrombosis, and death. An NIS database study in over one million patients who underwent total joint arthroplasty from 1988 to 2005 demonstrated that patients with uncontrolled diabetes mellitus had increased complications, higher mortality, and a longer hospital stay [24].

The preoperative evaluation of a patient with diabetes should establish the type of diabetes, therapy, glycemic control, hypoglycemia episodes, and diabetic complications. History and physical examination should especially focus on the cardiovascular, renal, and neurological systems. Preoperative investigations include baseline renal function, electrocardiography, and blood glucose concentration.

Theoretically, the outcomes in patients with well-controlled blood glucose levels should be better than in poorly controlled patients. The goals for glycemic control in adults recom-

mended by the American Diabetes Association are: hemoglobin A1c < 7%, preprandial capillary plasma glucose 90–130 mg/dL (5.0–7.2 mmol/L), and peak postprandial capillary plasma glucose <180 mg/dL (<10.0 mmol/L) [25]. However, there is no consensus on the hemoglobin A1c or blood glucose thresholds above which elective surgery should be postponed. Patients with a hemoglobin A1c > 8.5% or hypoglycemia unawareness should be referred to an endocrinologist prior to surgery [26]. In patients showing a hyperglycemic hyperosmolar state, ketoacidosis, or severe electrolyte imbalance, a delay of elective procedures may be considered.

Patients with poorly controlled diabetes require perioperative glycemic management in consultation with an endocrinologist. Ideally, patients with diabetes should not be subjected to prolonged fasting or be scheduled for operations in the evening.

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How to Avoid Periprosthetic Joint Infection

6

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Key Points
1. Thorough preoperative evaluation and optimization of a patient's condition are key steps to reduce the risk of postoperative periprosthetic joint infection. This includes diabetes control and stopping the use of alcohol and tobacco, among others.
2. Each surgical team member should be diligent in following the different aspects of infection prophylaxis during the intraoperative and postoperative process, e.g., skin preparation, antibiotic use, and wound management.

Periprosthetic joint infection (PJI) is one of the most severe postoperative complications of total joint arthroplasty (TJA). It results in high morbidity, substantial financial burden, and significant stress to patients [1]. The number of TJA cases has increased over the past 20 years [2]. Thus, the prevention of PJI in primary total hip arthroplasty (THA) is a major concern of arthroplasty surgeons.

There are dozens of risk factors that may increase the incidence of PJI. They include a high body mass index, diabetes mellitus, malnutrition, corticosteroid use, operation room traffic, and wound oozing [3–6]. It is helpful to distinguish

preoperative, intraoperative, and postoperative risk factors. It is the obligation of every surgeon to optimize these factors whenever possible to reduce the incidence of PJI.

6.1 Preoperative Measures

The preoperative evaluation of patients scheduled for THA is the most important step in PJI prevention. A few risk factors are non-modifiable, such as age, previous hip surgery, or organ transplantation, but most other risk factors are modifiable and should be managed before THA. Among them, diabetes is strongly correlated with postoperative PJI or surgical site infection [7]. Capozzi et al. [8] recommended that every patient should be screened for diabetes before THA, and surgery should be postponed if patients have hyperglycemia. Although a previous study [9] did not find an association between the preoperative hemoglobin A1c value and PJI, we use a hemoglobin A1c of 7% as the control target for TJA patients at our institution.

Smoking and alcohol abuse are potential etiologies of femoral head necrosis and are very common among our patients, especially males. After TJA, wound complications occurred more frequently in tobacco users than in nonusers (odds ratio 1.47, 95% confidence interval 1.21–1.78) [10]. Matthew et al. [11] demonstrated that alcohol misuse was an independent risk factor for

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postoperative complications following THA. Nicotine causes microvascular constriction and reduces oxygen levels in local tissue, while both tobacco and alcohol compromise patients' immune systems, resulting in a higher PJI rate. There is consensus that tobacco and alcohol should be stopped before THA, but the length of the recommended cessation period varies [12]. In our clinical practice, we ask patients to stop smoking and drinking for 4 weeks before they undergo THA.

Patients who underwent TJA for rheumatoid arthritis had higher postoperative PJI rates than those with osteoarthritis [13]. Rheumatoid arthritis patients receiving biologics or non-biologic disease-modifying antirheumatic drugs are immunosuppressed. The optimal perioperative management of these medications plays a critical role in reducing adverse events, including PJI. In 2017, the American College of Rheumatology and the American Association of Hip and Knee Surgeons published guidelines for the perioperative management of antirheumatic medication in patients with rheumatic disease [14]. These guidelines address the risks, including infections and other adverse events, for the use of each of the commonly used medicines and independent of their use. We follow these guidelines in our routine practice, and they will be discussed later in Sect. 5.3.

We see continuously increasing numbers of obese patients in our clinical work. Patients with a body mass index higher than 30 kg/m^2 have a higher infection rate [15]. However, it is unrealistic to expect patients to decrease their body mass index preoperatively, especially if they have hip problems. Nevertheless, we still recommend that they see a nutritionist to determine whether it might be possible to lose weight before surgery. We also evaluate these patients for diabetes and hypothyroidism.

Preoperative skin preparation can reduce postoperative infections [16]. We strongly recommended not to shave the skin above the surgical site on the day before surgery to avoid damage to the skin. We also ask patients to have a shower to prepare the skin the night before THA.

The other modifiable and not modifiable risk factors for postoperative infections are listed in

Table 6.1 Preoperative risk factors for periprosthetic joint infection

Modifiable risks for PJI	Non-modifiable risks for PJI
Active infection	Age
Diabetes mellitus	ASA score
Alcoholism	Previous surgery
Smoking	Previous joint infection
Obesity	Transplantation
Cardiovascular disease	
Chronic obstructive pulmonary disease	
Renal disease	
Immunosuppression	
Malnutrition	
Hepatitis	
Rheumatoid arthritis	
Skin colonization	

Table 6.1. As an arthroplasty surgeon, all efforts should be made to reduce all modifiable risks as much as possible before surgery.

6.2 Perioperative Measures

Before surgery, measures should be implemented to minimize the occurrence of PJI. We abandoned preoperative shaving entirely because it might damage the skin at the surgical site and increase the risk of infection. If patients have strong hair growth, we use a shaver only once they are in the operation room. We routinely use cefuroxime as a prophylactic antibiotic and administer it half an hour before the skin incision. First- or second-generation cephalosporins are the most frequently recommended prophylactic antibiotics, and the infusion time should be determined by their pharmacokinetics. Marrison et al. [17] compared single with repeated surgical site skin preparation and found that the latter may reduce infection. We strongly recommend the use of iodine and alcohol twice to prepare the skin at the surgical site.

During surgery, a surgical team with a strong aseptic concept is the most important factor in reducing infection. Instrument placement, sterile field maintenance, and surgery cooperation are

all essentials for the prevention of infection. The following are some tips from our surgical practice to mitigate the risk of infection:

- Use double gloves to compensate for potential glove perforation.
- Avoid putting a suction tip into the femoral canal unnecessarily, and change it when surgery lasts longer than 1 h.
- Avoid using handles for the operating lights.
- Use irrigation with pulsatile lavage before wound closure.
- Add another dose of antibiotics when surgery lasts longer than 3 h or bleeding is > 1500 mL.

6.3   Postoperative Measures

Careful observation of the wound is essential in all postoperative patients. A hematoma, seroma, and skin necrosis are all risk factors for infection [18]. These could result in persistent drainage and should be debrided in the operating room. If we encounter persistent drainage 1 week after THA, we stop the anticoagulants administered for the prevention of deep vein thrombosis and correct any unfavorable factors, such as malnutrition. However, if drainage persists for longer than 3 days after surgery, surgical intervention should be considered [19]. During debridement for persistent drainage, it should be differentiated whether or not the deep cavity is involved. If it is, we should perform thorough debridement and change the liner and femoral head.

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Preoperative Assessment and Templating in Total Hip Arthroplasty

7

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Key Points

1. Meticulous preoperative assessment including clinical history evaluation and physical Examination.
2. Standard X-ray is the premise of preoperative templating. Some cases need preoperative CT scan to assess the morphology of hip.

Meticulous preoperative assessment is a critical step before total hip arthroplasty (THA) performed in any patient. We have discussed the preoperative management of patients with comorbidities in Chap. 1, and how to optimize a patient's condition to prevent infections in Chap. 2. In this chapter, we will discuss how to evaluate a patient's individual hip status and how to perform templating before surgery.

7.1 Clinical History

Before THA, the exact diagnosis of the underlying hip disease is important. Femoral head necrosis is often related to steroid use or alcohol abuse, and developmental dysplasia of the hip may be difficult to reconstruct, while hip arthritis secondary to childhood hip infection may result in severe leg length discrepancy (LLD) [1–3]. Thus, careful history taking and discussion with patients and their family members are important to obtain this information.

We should also establish patients' chief complaints to assess whether their problem is indeed caused by their hip or if there are any other joint or spine problems involved. A thorough discussion with patients allows the surgeon to understand their expectations and them to comprehend whether THA is indeed the treatment they are seeking.

We routinely check the Harris Hip Score, Western Ontario and McMaster Universities Osteoarthritis Index, and 12-item Short-Form Health Survey to determine the patients' status and compare the results before and after surgery. Information on current and previous treatment is also important, such as what kind of surgery patients have undergone and steroid use in rheumatoid arthritis patients. All these elements are helpful for the surgeon in making a diagnosis and deciding on subsequent treatment.

7.2 Physical Examination

The physical examination begins when a patient enters the clinic room. Surgeons should take note of the posture, whether patients have LLD, are limping or not. After that, full exposure of the lower limb is necessary to see whether patients

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have a surgical scar or if there is any muscle atrophy, observations that indicate that patients had previous surgery. We should assess the spine, pelvis, and the other parts of the lower extremity apart from the hips, not only from the front and back but also from the side. Gait should be carefully observed since a large proportion of patients have abnormal gait [4], especially those with spine kyphosis. Abductor muscle weakness and LLD will result in a limping gait and make the trunk sway when the patient walks.

After this inspection, anatomic landmarks such as the anterior superior iliac spine (ASIS), pubic symphysis, great trochanter, and iliac crests should be identified. The inguinal ligament extends from the ASIS to the pubic symphysis, and the pulse of the femoral artery can be palpated below its midpoint. When we passively rotate the hip of a patient with severe arthritis, we might feel friction between the femoral head and acetabulum. Establishing the range of motion (ROM) of both hips and the other joints is an essential next step. Hip flexion/extension, abduction/adduction, and internal/external rotation should be measured with the patient in the supine position. We measure not only the passive ROM but also the active ROM. Relative LLD is measured from the umbilicus to the medial malleolus, which corresponds to patients' perceptions of LLD (Fig. 7.1). However, the real LLD is measured from the ASIS to the medial malleolus. When LLD is measured, both lower extremities should be in the same position to avoid bias. All joint surgeons should carefully assess muscle strength before THA, especially that of the abductors, which include the gluteus medius and minimus muscles.

We further recommend the following specific tests for the hips:

7.2.1 Thomas Test

This test is used to assess a potential hip flexion contracture. Patients should be in a supine position and must have no spine lordosis. The examiner flexes the patient's contralateral hip and knee towards the patient's abdomen. The test is positive if the other leg is passively raised during this maneuver, which means the patient has a hip flexion contracture (Fig. 7.2). Subsequently, the raised leg should be lowered. The positive result is reinforced if the lumbar spine becomes lordotic or the pelvis tilts anteriorly in the process.

7.2.2 Trendelenburg Test

This test is used to assess the strength of the hip abductor muscles. The examiner asks the patient to stand on the affected leg only and observes them from behind. Normally, a person can stand on one leg for at least 60 s without the contralateral pelvis dropping below the level of the pelvis at the site of the standing leg (Fig. 7.3). A drop on the contralateral side is a positive test and may result, for example, from hip pain, dislocation, or a coxa vara.

Fig. 7.1 Relative LLD measurement from the umbilicus to the medial malleolus
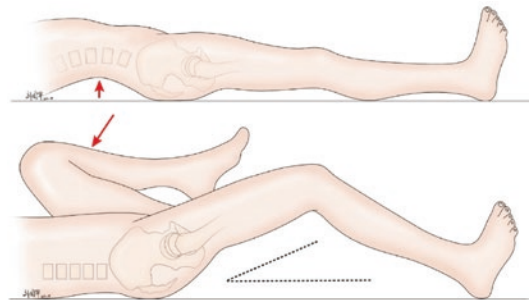
Fig. 7.2 Thomas test
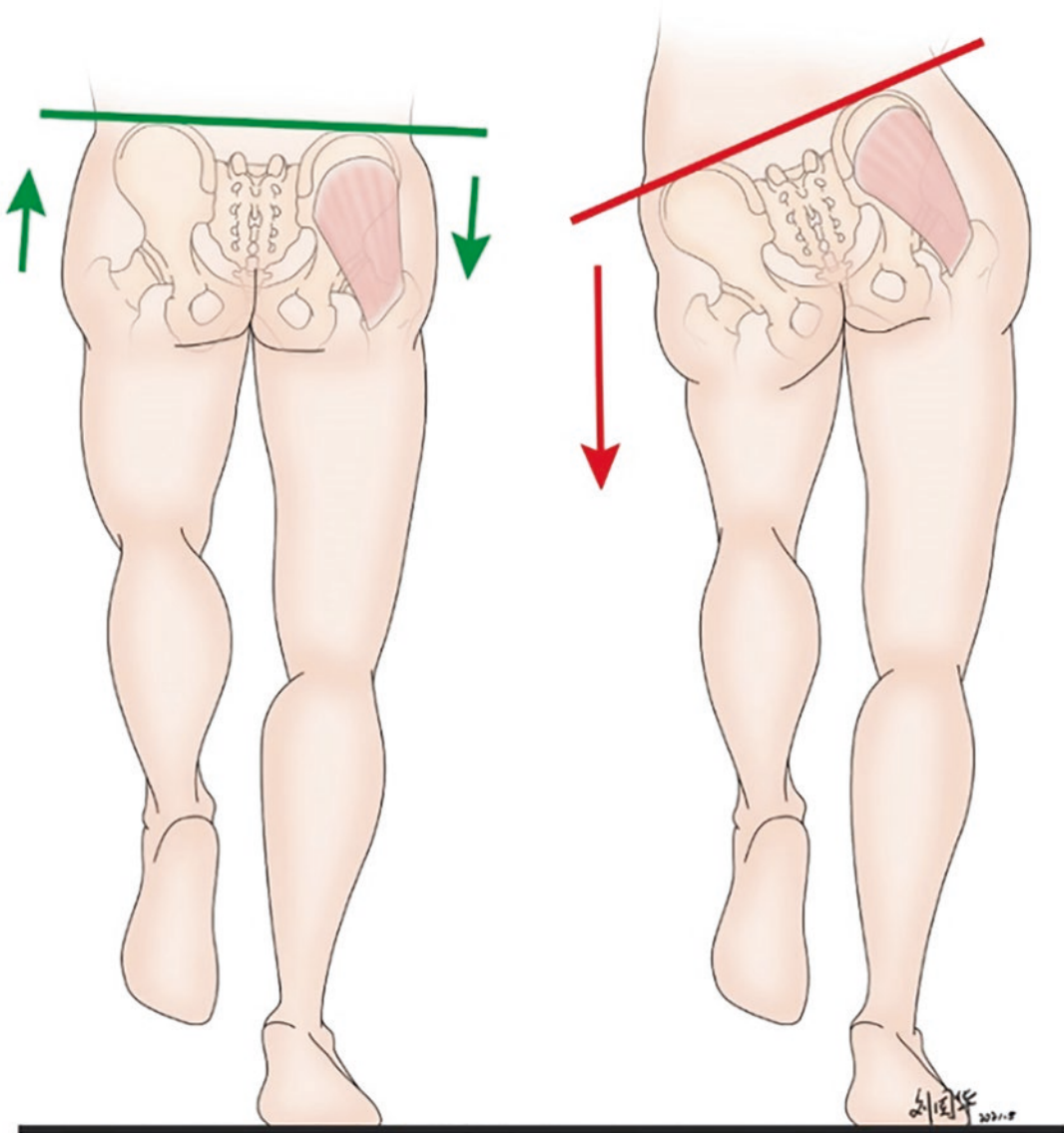
Fig. 7.3 Trendelenburg test: left side is negative, right side is positive

7.3 Radiographic Evaluation

Radiography is the most important imaging examination for orthopedic surgeons. It helps confirm the clinical history and physical examination and make the final correct diagnosis. Radiographic imaging does not only inform the diagnosis but also provides information on biomechanics, such as femoral neck length, offset, and acetabular or femoral anteversion. As precision medicine is coming, we do preoperative templating based on radiographic images.

Before evaluating preoperative radiographs, we should ensure that high-quality radiographs are obtained.
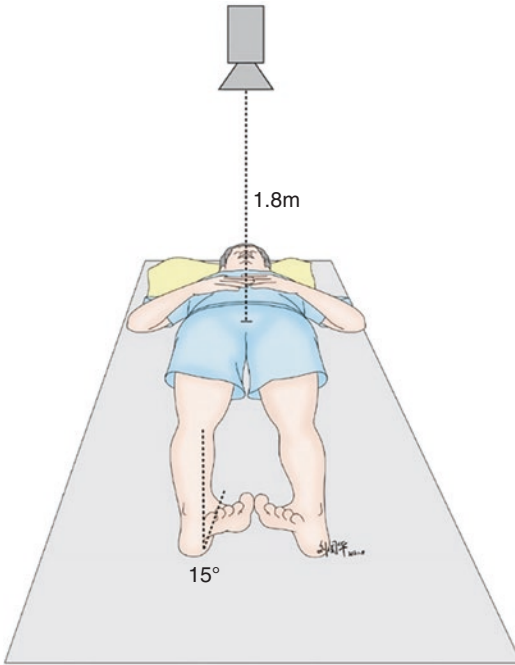
Fig. 7.4 The standard of taking hip a X-ray. Radiographic tube should have 1.8 m distance and center to the pubic symphysis while the lower extremity should be at 15° internal rotation to compensate for the femoral anteversion

The radiographic tube should be at a distance of 1.8 m and center on the pubic symphysis. The lower extremity should be in 15° internal rotation to compensate for femoral anteversion (Fig. 7.4). There is controversy about whether standing or supine hip X-ray assessments should be used preoperatively [5].

Spinopelvic motion influences pelvic tilt. Anterior pelvic tilt decreases acetabular anteversion and inclination, whereas posterior pelvic tilt increases them [6]. In our practice, we use an EOS imaging system to evaluate spinopelvic motion when patients move from standing to sitting. We strongly recommend the routine use of lateral spinopelvic radiography from standing to sitting if EOS is unavailable. We will discuss how to target patient-specific safe zones based on preoperative imaging data in Chap. 25.1.3. Computed tomography can provide more detailed information and is often used in cases with a substantial anatomic variation. In patients with developmental dysplasia of the hip, it may be used to measure femoral anteversion [7] and complete patients' preoperative assessment (Fig. 7.5).
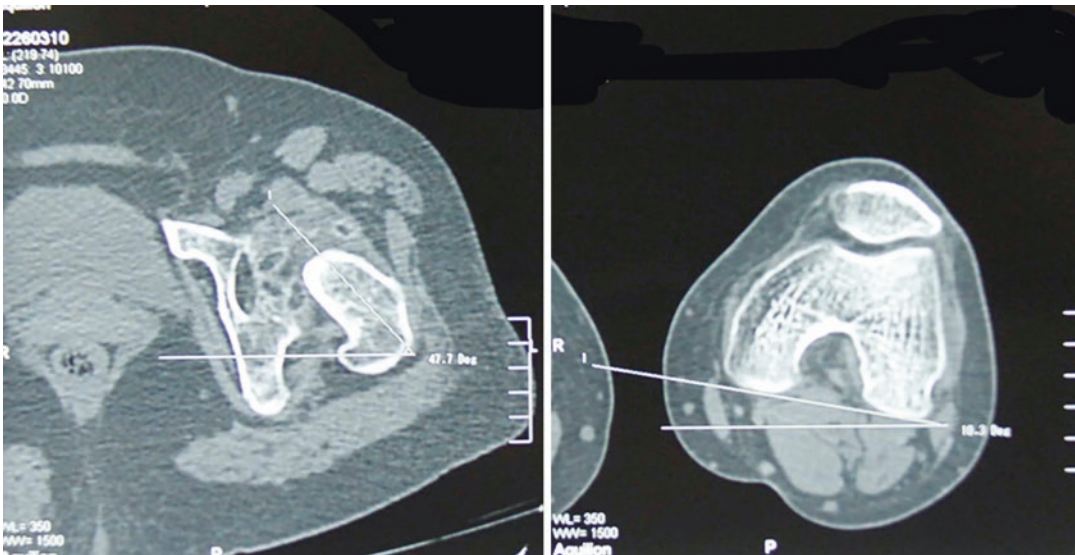
Fig. 7.5 Using preoperative CT scan to evaluate femoral anteversion. Left side shows how to measure the femoral neck angle while the right side shows how to measure the angle between the posterior condylar axis and horizontal line. The difference between the two angles is the femoral anteversion

7.4 Preoperative Templating

THR refers to total hip reconstruction, not total hip replacement. The reestablishment of normal hip biomechanics is the primary goal of joint surgeons [8]. Our preoperative templating focuses on restoring the hip joint center with the reconstruction of femoral offset and equalizing limb length.

Most surgeons start with templating the acetabular side first, and we follow this approach in THA. The primary goal in positioning the acetabular component is to place it just lateral to the lateral side of the pelvic teardrop, with an inclination of 40°. The lateral cup margin should be in the superolateral area of the acetabulum. In developmental dysplasia of the hip, the acetabulum is sometimes shallow. In these patients, we can medialize or place the cup cranially for better bone coverage. With the improved quality of porous coating, a maximally 30% lack of lateral coverage should be accepted. We use these surgical techniques to reconstruct the hip center as close as possible to its anatomic position (Fig. 7.6). Watts et al. [9] reported a higher incidence of aseptic loosening and cup revision when the postoperative hip center was more than 10 mm superior or lateral to the anatomic hip center.

On the femoral side, we template the femoral component based on the plain anteroposterior X-ray. We measure the femoral canal to determine whether the metaphyseal and diaphyseal areas fit the femoral component well. This determines the size of the stem to use and where to cut the femoral neck (Fig. 7.7).

After templating the acetabular and femoral sides separately, we obtain the rotational centers for the two sides. We measure the distance between these two centers in the horizontal and vertical directions. If the femoral center is medial and superior to the acetabular center, the gap between them represents the amount of soft tissue that should be released, and
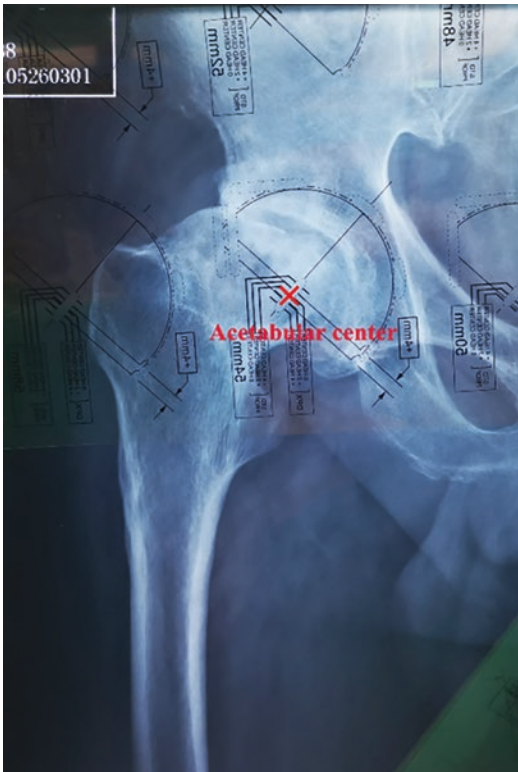

Fig. 7.6 Templating of the acetabular side
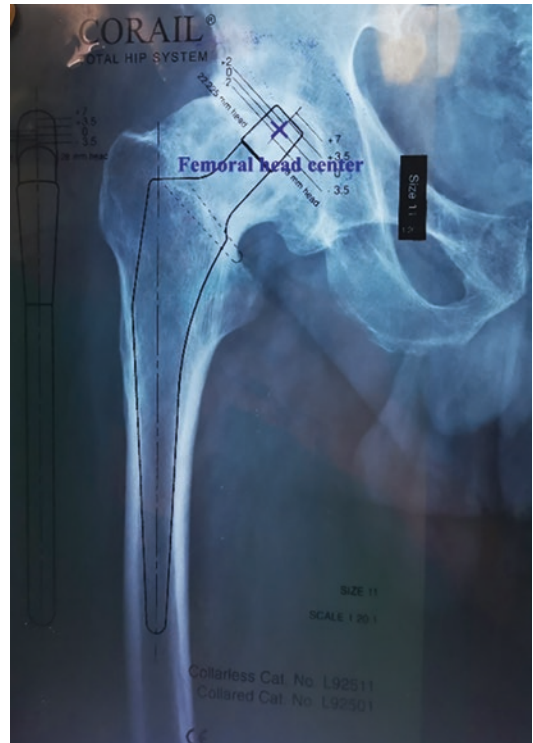
Fig. 7.7 Templating of the femoral side

Fig. 7.8 The vertical distance between femoral head center and acetabular center is how long we will lengthen the leg

the vertical distance indicates by how much we need to lengthen the leg (Fig. 7.8). If the femoral center is lateral to the acetabular center, we may use a high offset stem. Alternatively, a longer femoral neck could also compensate for this incongruency, but we should be cautious of leg lengthening. If the femoral center is inferior to the acetabular center, it means that the hip joint will be lax. In this situation, we should use a larger femoral head or longer femoral neck to elevate the femoral center to avoid hip instability.

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Postoperative Radiological Assessment After Total Hip Arthroplasty

8

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Key Points

1. It is recommended to follow a systematic protocol to evaluate radiographies after THA so that we do not miss important findings.
2. In patients after THA, we usually assess four aspects: the patient's overall condition, the characteristics of the prosthesis, the component position, and any potential complications.
3. Radiographic manifestations of component loosening, heterotopic ossification, periprosthetic fractures, and osteolysis are introduced in this chapter.

Hip and pelvic X-ray imaging occupy a central position in the auxiliary examination of hip joint diseases. With the increasing popularity of computed tomography (CT) and magnetic resonance imaging (MRI) in recent years, the role of pelvic X-rays in hip assessment seems to be challenged. However, through careful reading of the plain pelvic film, the surgeon can discover subtle abnormalities and provide substantial diagnostic information for evaluation after total hip arthroplasty (THA).

8.1 Sequence of Radiographic Evaluation of the Hip

It is important for every surgeon to learn how to systematically read X-rays after THA. Before reading the film, we note the patient's occupation, identity, and the date of the image, and we identify the left and right leg. Then, we assess the quality of the film and the X-ray transmission and determine whether the film shows the entire prosthesis, whether the left and right sides are symmetrical, and whether there is pelvic or femoral rotation or tilt. A standard set of X-ray images after THA should include the anteroposterior pelvis view and lateral views of the affected joint showing the full length of the prosthesis.

In patients after THA, we usually assess four aspects: the patient's overall condition, the characteristics of the prosthesis, the component position, and any potential complications.

8.2 Patient's Condition

Sometimes, the diagnosis underlying the THA can be identified on the pelvis film. If there has been no replacement on the contralateral side, it will provide some hints, such as femoral head necrosis, osteoarthropathy, or acetabular dysplasia. Sometimes there may also be some hints on the THA side, such as the hip, the acetabulum,

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the greater trochanter of the femur, or the proximal femur having internal fixation nails and steel wires, suggesting that there may have been a fracture of the greater trochanter during the operation. If there is a screw canal visible in the proximal femur, we consider whether this had been a failure of internal fixation that was converted to THA. Very small bones and prostheses may indicate congenital disease or bone dysplasia. Characteristic changes in the sacroiliac joints and lumbosacral vertebrae or in the obturator shape from an approximate circle to an upright oval on the pelvic anteroposterior film may allow the diagnosis of ankylosing spondylitis. Of course, there are many further characteristic changes in the film indicating that every patient is different.

8.3 Characteristics of the Prosthesis

We should know the characteristics of commonly used prostheses. It is important to understand the fixation method of the prosthesis, the characteristics of the acetabulum and femoral stem components, and the correct position of the entire joint. The fixation methods are mainly bone cement and biological fixation. Nowadays, bone cement is usually treated with barium salt or zirconium oxide, which are visible on X-rays. However, some of the previously used types of bone cement may not be visible. The surface of cementless prostheses may appear rough on X-ray films because they may have porous surfaces or hydroxyapatite coatings or pearl surfaces. We should also pay attention to factors such as the shape and size of the prosthesis, the diameter of the femoral head, and modularity.

8.4 Component Position

When assessing the acetabulum, we first determine whether the position of the acetabular cup (including horizontal and vertical angles) is ideal. The inclination of the acetabular prosthesis, the acetabular opening, is shown as a narrow ellipse on the anteroposterior X-ray film, which is called the "ring sign." The angle formed between a line through the long diameter of the ring and the line connecting the teardrops on both sides (or the line connecting the ischial tuberosities) is the inclination angle. If the inclination angle is too large, the stress concentration will accelerate the wear in polyethylene components, increase the penetration rate, and may cause femoral head fractures in ceramic-polyethylene joints. The anteversion of the cup is difficult to measure on the anteroposterior film accurately but usually inferred from the shape of the prosthetic metal marking ring. When the shape is a narrow oval, the cup is slightly tilted forward or backward. If the ring is rounded, it indicates a large anteversion angle (Fig. 8.1).

The vertical position of the acetabulum is measured as follows: if the opposite side is healthy, the distance from the bottom of the teardrop to the center of the hip joint in the vertical plane on the opposite side can be measured; a similar vertical distance of the acetabular cup center can be measured in the replaced side to calculate the difference from that in the healthy side. For horizontal position, the bottom of the acetabular cup usually aligns with the bottom of the teardrop, and the medial acetabulum wall is close to the outer edge of the teardrop. The horizontal position of the acetabular cup must not exceed the Kohler line medially, and the inward protrusion is the indigo bulge.

In the assessment of the femoral stem, attention should be given to whether there is a varus malposition. We can distinguish between early bone cement techniques and more recent cement techniques by assessing any cement emboli at the distal end of the prosthesis. The cementing technique is critical to the longevity of a THA. In 1992, Barrack et al. proposed an evaluation standard for bone cement techniques based on X-ray (Fig. 8.2) [1]:

1. Complete "white-out" of the bone-cement interface.
2. < 50% radiolucency of the bone-cement interface
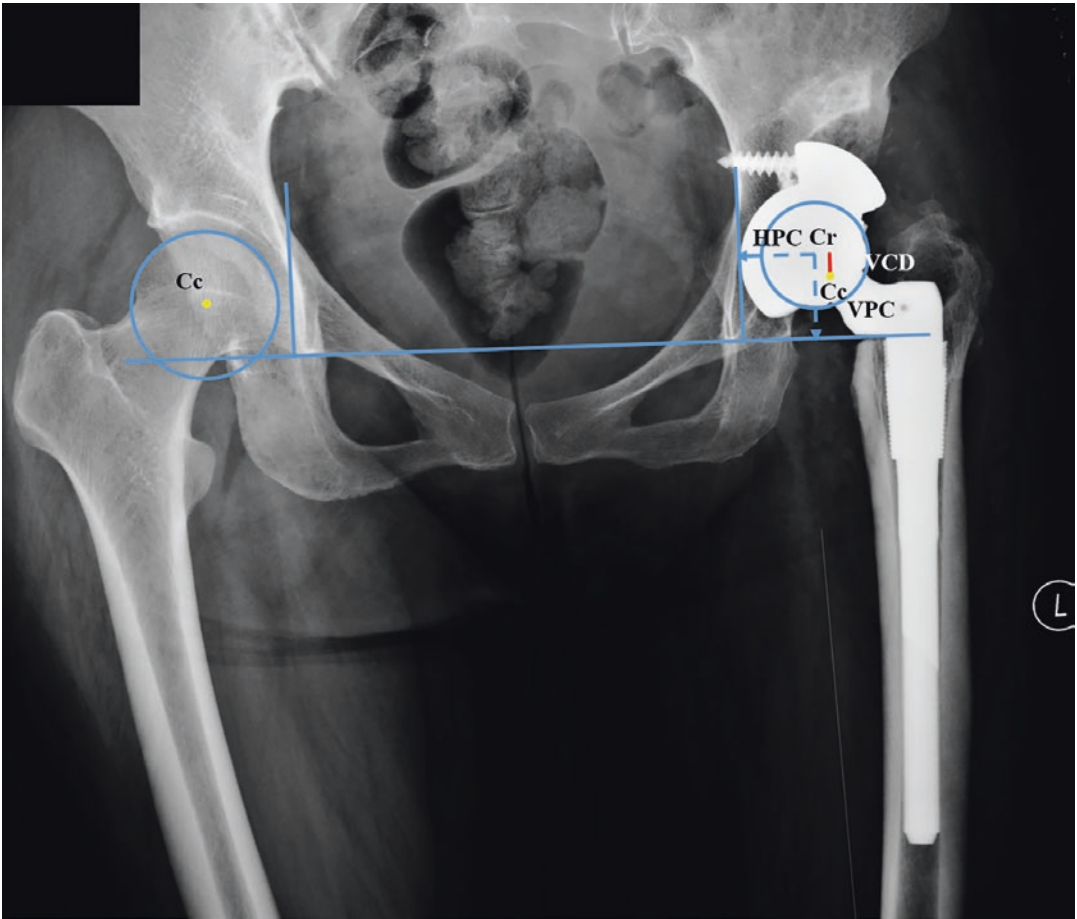3. 50–99% radiolucency AND/OR

Fig. 8.1 Assessment of the hip center of rotation, offset, and leg length. *Cc* Center of the contralateral side, *Cr* Center of the reconstructed side, *HPC* Horizontal position of the cup, *VCD* Vertical cup difference
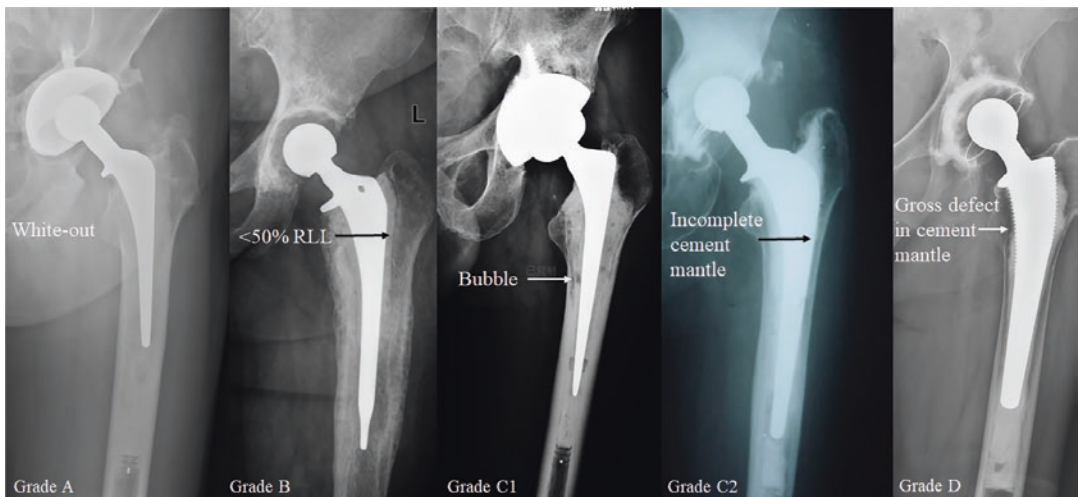

Fig. 8.2 Classification of cementing technique

- *C1: Bubble/void.*
- *C2: Area of incomplete cement mantle (<1 mm).*
4. 100% radiolucency on any view AND/OR
   - *Cement not extending beyond the tip.*
   - *Gross cement mantle defect.*

Early stability is very important in cementless stems. The pressure fit between the stem and the medullary cavity is the most critical factor for early stability. We should check how far the stem fills the proximal femur and the diaphyseal cavity, that is, the pressure fit between the stem and medullary cavity. Femoral stems with extensive porous surfaces are designed for distal fixation. If the stem is not properly press-fitted in the distal diaphysis, the early stability of the prosthesis is not good, and the failure rate is high. Sometimes, there may be observations that can reflect intraoperative problems, such as large bones (autogenous or allogeneic bone) or a metal block filling fixed with screws in the acetabulum, which may reflect a defect or dysplasia of the acetabulum. If there is a steel wire or a band around the proximal end of the femur, a crack or fracture occurred during the insertion of the prosthesis.

8.5   Complications

Complications after THA may include component loosening, heterotopic ossification, periprosthetic fractures, osteolysis, and dislocations.

8.5.1   Component Loosening

Aseptic mechanical loosening of the femoral stem and acetabular prosthesis is the primary cause of failure after THA, accounting for approximately 20% of all revisions. Wear and tear of prosthetic components, poor initial stability, failure of fixation, and patient characteristics (age and weight) are all contributing factors to aseptic loosening. Although the continued improvement of prosthesis design has reduced mechanical loosening in general, the incidence still varies greatly among different institutions. At present, the diagnostic criteria for femoral stem and acetabular prosthesis

loosening on X-rays are still not unified, but specific imaging features can be used to predict the possibility of revision surgery in the future.

8.5.1.1 Loosening of Cemented Stems
Harris et al. [2] defined the loosening criteria for cemented stems as follows:

1. Possible loosening: a translucent line around 50–99% of the stem in any view.
2. Suspicious loosening: 100% translucent line around the stem in any view.
3. Absolute loosening: The prosthesis is displaced (stem-cement or cement-bone interface), or the stem or bone cement is broken (Fig. 8.3).

There are two design concepts for cemented femoral stems: force-enclosed and composite beam stems. The imaging standards for identifying a failure of the two stems are different. Theoretically, the composite beam stem should not subside in the cement sleeve, whereas the highly polished tapered force-enclosed stem is designed to subside slightly in the cement sleeve and regains stability by transforming the shear force into hoop stress.

When highly polished tapered stems subside in the cement sleeve, the translucent line of the prosthesis-cement interface can often be seen around the shoulder of the stem, reflecting the subsidence distance of the stem. The subsidence rate decreases with time. The normal subsidence rate is 1 mm in the first year and 1 mm over the next 10 years. Usually, the stem does not subside more than 2 mm [3].

In the case of composite beam stems, the probability of long-term success is only 5% if they are displaced 2.6 mm or more 2 years after surgery [4]. If the prosthesis is displaced 2 mm or more at that time, and there is a translucent line of more than 2 mm, the possibility of revision within 10 years is 50%. If there is only either of these signs (displacement or translucent line), the need for revision within 10 years will be reduced to 25% [5].

Other adverse imaging manifestations associated with prosthesis failure in cemented stems include [6]:

- Newly appearing bright areas, especially at the cement-bone interface,
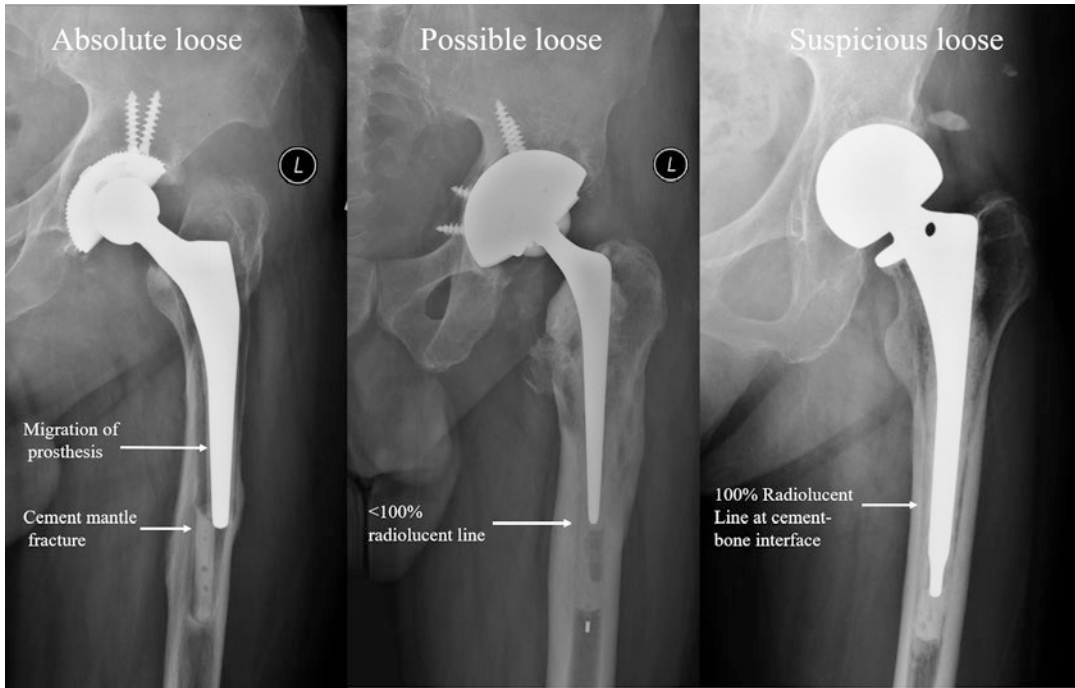
Fig. 8.3 Radiographic assessment of cemented stem loosening
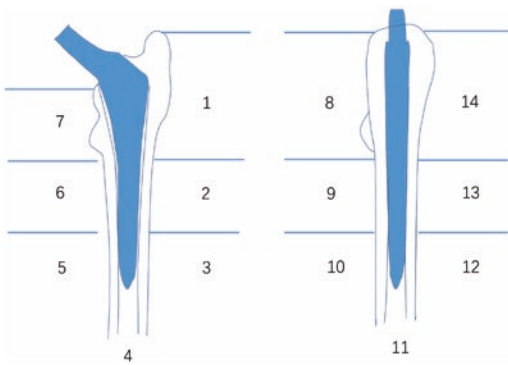
Fig. 8.4 Schematic illustration of the Gruen zones of femoral stems after total hip arthroplasty

- Translucent area that appears immediately after surgery or within 1 year,
- Separation of the bone cement-bone interface, especially if occurring in the Gruen I and II [7] zones (Fig. 8.4).

A narrow (<2 mm) translucent line surrounding the stem, frequently with obvious osteosclerotic lines next to it, is a normal manifestation in cemented stems. It results from a reaction between the cement and adjacent bone and represents the development of a fibrous membrane at the cement-bone interface. This fibrous membrane gradually stabilizes within 2 years after surgery. A translucent line of less than 2 mm that does not progress during the 2 years after the operation is not a sign of loosening, but a wider (≥2 mm) and progressive complete transparent line at the cement-bone interface indicates loosening [8]. A displacement (including rotation) of 3 mm or more of an acetabular prosthesis is considered a failure [6].

8.5.1.2 Loosening of Cementless Stems

The criteria for loosening are different for cementless prostheses. Engh et al. [9] used various classification systems to evaluate the stability of cementless femoral prostheses, which they divided into three categories (Fig. 8.5):

1. Osteointegration: no reactive sclerosis lines in the porous surface area, new bone formation in the endosteum, and porous surface (spot welds).
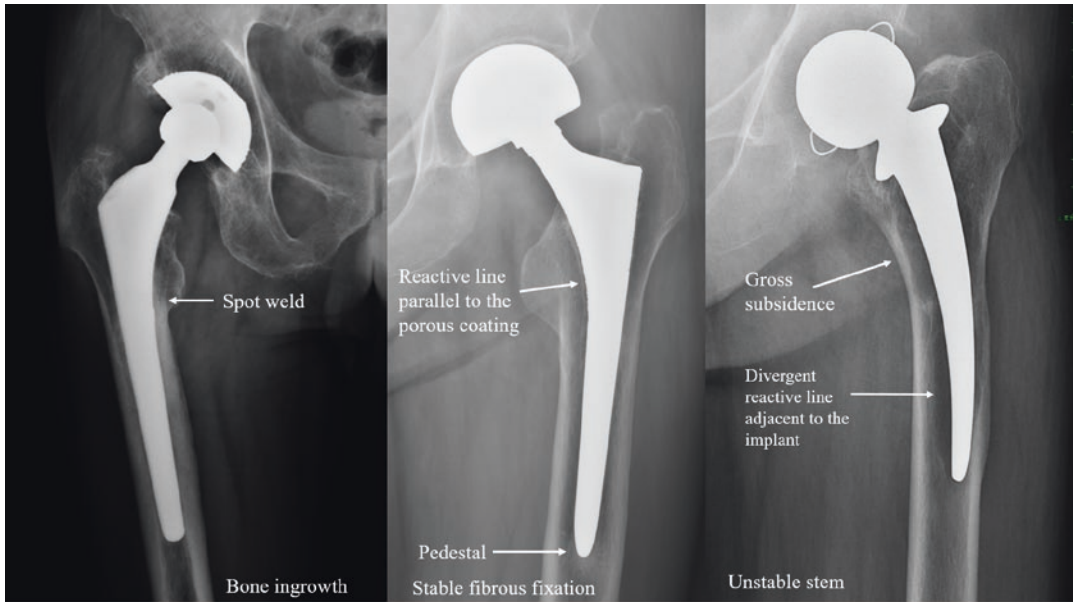
Fig. 8.5 Radiographic assessment of cementless stem stability

2. Fibrous stable: reactive hardening lines (but no progress) in the porous surface area, no prosthesis subsidence.
3. Unstable: prosthesis displacement (subsidence, inversion, eversion, and oblique), particles on the porous surface shell off.

Other imaging features that represent osteointegration include no translucent lines, stress shielding, femoral calcar resorption, and thickening of the bone cortex at the distal end of the stem.

Similar to cemented prostheses, translucent lines with a width of less than 2 mm that have not progressed 2 years after surgery can be regarded as normal. Such translucent lines are often accompanied by thin reactive hardening lines, indicating the presence of fibrous ingrowth into the prosthesis. Although fibrous ingrowth is not the same ideal result as bone ingrowth, it can provide sufficient stability (fibrous stability in the Engh classification [10]).

Occasionally, sclerosis of new bone tissue in the medullary cavity can be seen below the stem tip, which is called the "pedestal sign." It presents the response of the bone to the subsidence of the prosthesis. If the stem is considered stable based on other imaging signs, then the pedestal sign is not a concern. However, when there are signifi-

cant translucent lines around the stem at the same time, the pedestal sign may be a sign of loosening [9]. In proximally coated prostheses, an independent, narrow translucent line around the distal uncoated area results from fretting of the distal end and is acceptable (and often accompanied by reactive hardening) as long as there is osteointegration of the coated part [10].

8.5.1.3 Loosening of Cemented Cups
The DeLee and Charnley criteria for the loosening of cemented cups are based on the observation that the risk of loosening increases with the number of zones with a radiolucency width of >2 mm at the cement-bone interface (Fig. 8.6).

- Three zones: 94% loosen
- Two zones: 71% loosen
- One zone: 7% loosen
- Type 4: socket migration
  Different from femoral loosening, cup loosening rarely occurs at the cup-cement interface.

8.5.1.4 Loosening of Cementless Cups
The signs of osteointegration of acetabular cups include the absence of translucent lines, medial stress shielding, presence of superolateral buttress bone, radial bone trabeculae, and an inferomedial
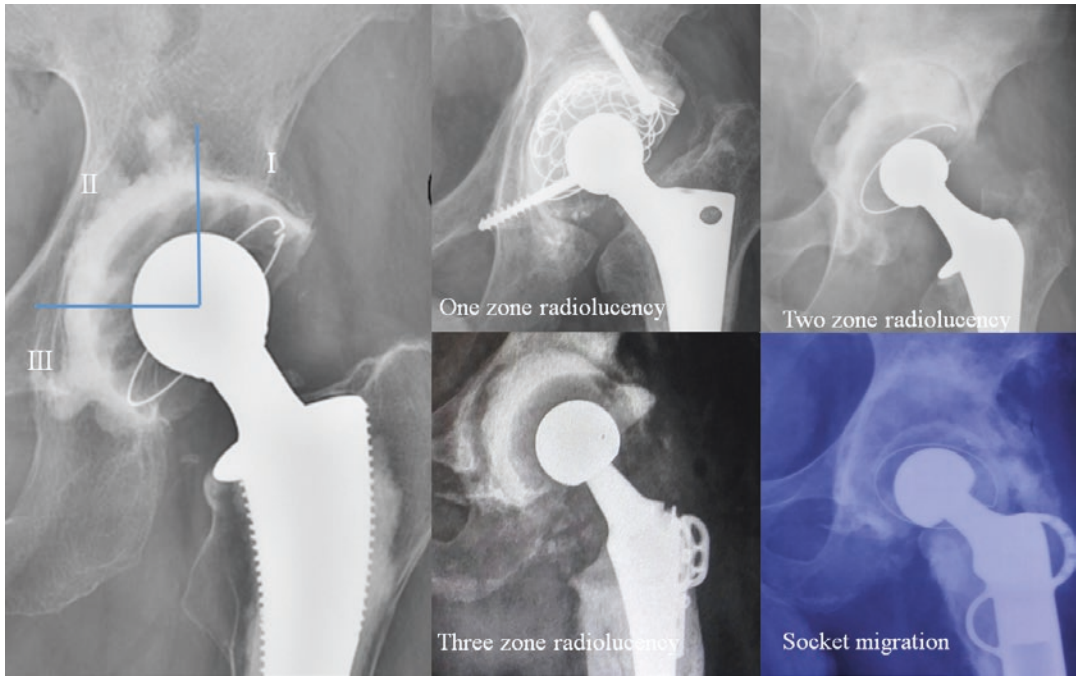
Fig. 8.6 Radiographic assessment of a cemented cup

buttress [11]. Translucent lines of more than 1 mm width and in multiple areas are considered clinically significant. Stress shielding is manifested as a decrease in bone density around the medial aspect of the cup, and supporting bone formation conceptually corresponds to the "welded spot" on the femoral side. These signs usually appear 2–3 years after THA, and 97% of the cups with three to five of these signs showed bone ingrowth, whereas 83% of the cups that did not show any of the above signs were found to be loosening [11].

The criteria for loosening of a cementless cup are:

- Component migration
- Change in the opening angle >8°
- Change in cup position of >3 mm
- Component fracture
- Shedding of porous coating
- Halo around screws

Other imaging findings associated with cup loosening include new or progressive translucent lines or the appearance of translucent lines

in all three zones 2 years after surgery. In addition, a displacement of a metal cup of ≥3 mm indicated loosening. It should be noted that small residual gaps that exist immediately after surgery will usually disappear within 2 years, and this kind of translucency has no clinical significance [12].

8.5.1.5 Digital Tomosynthesis for Assessment of Component Loosening

Radiographs are usually confusing because of the low spatial resolution for depth. Conventional CT cannot be used to detect spot welds, in spite of its improvement in spatial resolution, as the metal artifacts severely blur the metal-bone interface. Furthermore, the increased risk of radiation exposure is another major concern that impedes the routine application of conventional CT.

Digital tomosynthesis is a novel technique which can improve depth resolution and minimize metal artifacts. In comparison with conventional tomography, a series of images are obtained

in a single sweep of scan with a lower radiation dose. The original data are then reconstructed using various mathematical algorithms. There are several reconstruction strategies developed to generate artifact-reduction images. In a recently introduced algorithm, digital tomosynthesis with metal artifact reduction (TMAR) successfully reduced structure overlapping and metal artifacts and limits radiation exposure (Fig. 8.7).

Studies have investigated the efficacy of tomosynthesis in the diagnosis of complications after joint replacement. Minoda et al. [13] developed an osteolysis model (average size, 0.7 mm^3) after knee arthroplasty and a translucent line model (width 2 mm), using pig knee joints. The sensitivity and specificity of tomosynthesis were 85.4% and 87.2%, respectively, and those of CT were 61.5% and 64.1%, respectively, while plain film and MRI failed to detect bone defects. Our serial studies found that tomosynthesis substantially improved the accuracy of diagnosing prosthesis loosening. We added digital tomosynthesis to our diagnostic standard of artificial joint prosthesis loosening, which increased the accuracy of our diagnosis of prosthesis stability to 82% (X-ray film, 44%; CT, 39%) [14]. The sensitivity of detecting osseointegration was 74% for TMAR compared with 50% for X-ray and 36% for CT [15]. The overall sensitivity for the detection of radiolucent lines of ≤2 mm width using digital tomosynthesis of 63.3% meant an improvement of 58.2 ± 3.1% (95% CI, $p < 0.001$) compared with radiography and of 21.7 ± 7.1% (95% CI, $p < 0.001$) compared with CT [16]. The radiation dose was reduced by 84% compared to that of CT [14]. Professor Daniel I. Rosenthal [17] commented, "It will not be surprising if tomosynthesis with metal suppression becomes a routine tool to investigate orthopedic hardware."

8.5.1.6 Single-Photon Emission Computed Tomography for Assessment of Component Loosening

Emerging nuclear medicine technologies, such as single-photon emission computed tomography (SPECT-CT) and positron emission computed tomography may have more clinical applications
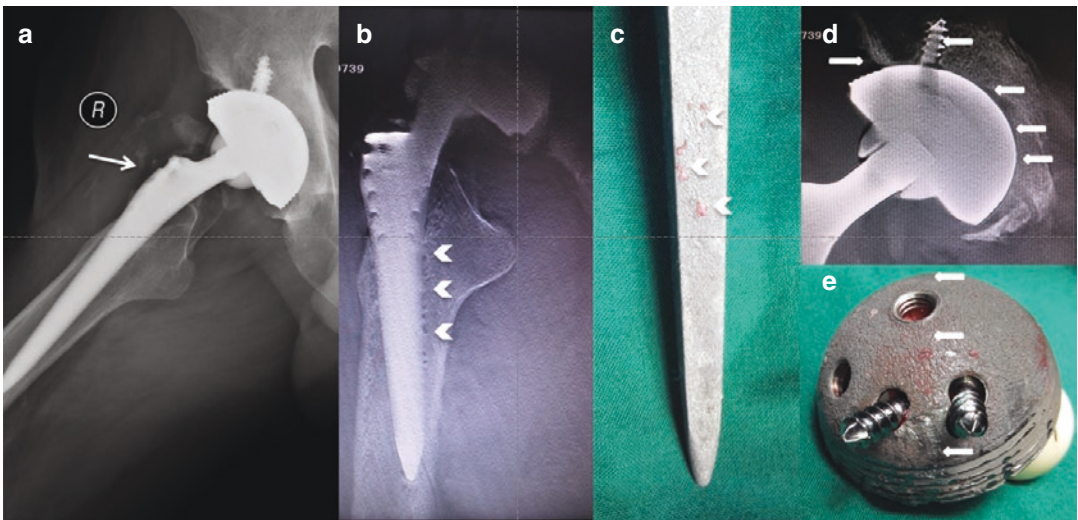
Fig. 8.7 An example of digital tomosynthesis. (**a**) Preoperative radiograph shows possible subsidence with severe osteolysis of the greater trochanter (thin arrow). (**b**) Digital tomosynthesis showing good osteointegration. (**c**) Retrieved stem shows evidence of bone ongrowth corresponding to the medial side of the stem in figure **b** (arrowheads). (**d**) Preoperative digital tomosynthesis shows uninterrupted radiolucent lines around the cup and screws. (**e**) Retrieved cup shows no signs of bone ongrowth (thick arrows). TMAR tomosynthesis with metal artifact reduction, CT computed tomography

in the future in the arena of THA. In the study of Abele et al. [18] in 2015, the sensitivity of SPECT-CT in diagnosing aseptic loosening of prostheses after THA was 100.0%, the specificity was 96.0%, and the positive predictive value was 92.9%, providing new options for the diagnosis of aseptic loosening in the future.

8.5.2 Heterotopic Ossification

Heterotopic ossification occurs in 30–50% of patients who develop heterotopic ossification after THA. The most common symptom is joint stiffness, but about 70% of patients with heterotopic ossification are asymptomatic. Using plain X-ray and CT, calcification shadows can be observed several weeks after THA, and joint ankylosis may occur as early as 12 weeks postoperatively [19]. A triphasic bone scan is the most sensitive imaging method for the early detection of heterotopic ossification. The blood-flow and blood-pool phase images can show increased tracer uptake 1–4 weeks before X-ray detection [20].

The most widely accepted classification system for heterotopic ossification developed by Broker et al. [19] comprises four grades:

- Grade I: bone islands in the soft tissue around the hip joint.
- Grade II: osteophytes arising from the pelvis or proximal femur with at least 1 cm of distance between the opposing bony surfaces.
- Grade III: osteophytes arising from the pelvis or proximal femur with a distance of less than 1 cm between the opposing bony surfaces.
- Grade IV: complete ankylosis.

8.5.3 Osteolysis and Bone Defects

Osteolysis mediated by wear particles is one of the main sources of translucent areas around the prosthesis. Although particles from any material of the prosthesis can induce phagocytosis by tissue cells, polyethylene wear particles are the most important pathogenic factor. Polyethylene or any other particles can enter the bone-prosthesis or cement-bone interface via joint fluid. Consequently, osteolysis can occur anywhere around the prosthesis.

The imaging findings in these cases are sometimes subtle and can be easily confused with aseptic loosening and infection. A lobulated endosteum (endosteal scalloping) is a typical feature. CT has advantages over plain X-ray films [21]. Previous studies have reported that plain X-ray films underestimate the degree of osteolysis by at least 20%, and more than 83% of the osteolysis on the surface of prosthetic cups will be missed using a single plain X-ray, whereas the diagnostic accuracy of CT is high [22, 23]. In another study, Walde et al. [24] used an osteolysis model in cadaveric bone and found a diagnostic sensitivity of 52% for plain X-ray, 75% for CT, and 95% for MRI. Owing to the tomographic characteristics of CT and MRI, they can also quantify the degree of any bone defects.

8.5.4 Periprosthetic Fractures

Periprosthetic fractures (Fig. 8.8) are relatively common complications with an incidence after THA of almost 1%. Fractures are often associated with loosening, stress shielding, or trauma. The Vancouver classification can be used to classify these fractures [25]:

- Type A fractures are located in the trochanter area.
- Type B fractures are located near the shank or shank tip.
  - Type B1: the stem is not loosening.
  - Type B2: the stem is loosening.
  - Type B3: the stem is loosening with a severe bone defect.
- Type C fractures are located more distally to the shank tip.

In conclusion, X-ray imaging is an important method for evaluating THA outcomes. Regular follow-up after THA to obtain serial radiographs is essential. It requires years of clinical practice to achieve the ability to evaluate radiographs effi-

Fig. 8.8 An example of Vancouver type B1 of periprosthetic fractures of the hip

ciently. However, the introduction of advanced technologies, such as digital tomosynthesis, SPECT-CT, and metal-reduction MRI, may affect the learning curve of making a radiological assessment.

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Critical Techniques for Total Hip Arthroplasty

9

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Key Points

1. "A surgeon needs to have an eagle's eyes, a woman's hand, and a lion's heart" (Len Wright).
2. Before starting acetabular reaming, it is important to expose the entire circumference of the acetabulum and the transverse acetabular ligament, provided they are present.
3. More and more attention is paid to the sagittal spine-pelvis-femur balance. The ability of the lumbar spine to compensate for the limited hip range of motion in the sagittal position and the anteversion of the femur both have an impact on the functional safe zone of the acetabular cup in the middle pelvis.

Surgeons who want to perform a successful total hip arthroplasty must internalize several critical surgical principles and techniques. The critical and essential techniques are summarized below.

9.1 Preoperative Planning

This aspect is described in detail in the previous chapter and will not be repeated here, but the author still wishes to refer to preoperative planning as a core principle of successful surgery.

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Preoperative planning includes many aspects, such as template measurement, leg length recovery, selection of the most suitable offset, anticipating difficulties that may be encountered during surgery, and how to deal with them, to name but a few. Beyond these technical features and considering the individual patient, it also includes the choice of the surgical intervention and methods, damage control, and more. If surgery is likened to a battle, preoperative planning represents the strategic dimension and fundamental decision-making, and the importance becomes self-evident.

The care applied to all details in the planning before surgery can never be too much. It represents a rehearsal in the surgeon's mind before the actual operation. The more complicated the operation, the more extensive and detailed it should be.

9.2 Exposure

In hip replacement surgery (as in most orthopedic surgery), adequate exposure can be seen as one of the most important and fundamental technical principles. Regardless of which surgical approach is used, what type of hip prosthesis is chosen, whether it is a straightforward primary replacement or complex revision surgery, if the surgical site is not well exposed, it may affect the smooth running of the operation and the clinical outcomes. Good exposure is half the success of any operation.

When surgeons expose the surgical site, special attention should be paid to the protection of both hard and soft tissues. Good exposure should never come at the expense of excessive tissue damage. In the quote, "A surgeon needs to have an eagle's eyes, a woman's hand and a lion's heart" (Len Wright). The concept of avoiding any unnecessary injury during surgery, together with decisive decision-making and accurate judgment, constitutes the foundation of damage control, which is an important aspect of the currently much discussed enhanced recovery after surgery.

Of note, a "small incision" does not necessarily mean small trauma. The author prefers the definition, "large enough to not need a larger incision" over "small to the extent that it cannot be smaller." This is the most appropriate definition of a small incision, highlighting the necessity of good exposure while minimizing tissue damage.

9.3   Acetabular Side Operation

Before starting the reaming of the acetabulum, it is important to expose the entire circumference of the acetabulum and the transverse acetabular ligament, provided it is present. This will determine whether the next step of the procedure can proceed smoothly and whether the prosthesis implantation will be accurate.

9.3.1   Depth of Acetabular Reaming

The acetabulum should be reamed deep to its inner wall, which corresponds to the outer edge of the teardrop on the anteroposterior radiograph of the pelvis. Adequate depth is important. Otherwise, there is a risk of lateralizing the cup and insufficient bone coverage of the cup, resulting in a poor cup inclination or anteversion and other unsatisfactory results. Especially for cases with obvious osteophytes, any osteophytes around the acetabulum and in the inner wall may affect the correct assessment of the depth of the reaming. If the surgeon is not sure about the required depth, fluoroscopy or radiography can be used to facilitate this assessment intraoperatively.

9.3.2   Acetabular Reaming

The reaming technique may vary from one surgeon to the other. Some surgeons use a small reamer to ream to the appropriate depth initially and then increase the size of the reamer along the edge of the transverse acetabular ligament gradually until an appropriate bone bed is created. Other surgeons choose a reamer that is two to three sizes smaller than the anticipated cup size based on the preoperative measurement to begin the concentric reaming, while again others perform the reaming under fluoroscopy (e.g., arthroplasty through an anterior approach). During reaming, the author recommends paying careful attention to the acetabular edge, especially the bone stock of the anterior and posterior walls, to avoid out-of-line reaming, especially in cases with bone structure malformations of the acetabular walls, such as developmental dysplasia of the hip. The ultimate goal is to obtain a bone bed of just the right size, reasonable positioning, good bleeding, and good coverage of the cup.

9.3.3   Management of Periacetabular Osteophytes

Excessive osteophytes around the acetabulum need to be removed; otherwise, impingement between the osteophytes and the prosthesis may occur, resulting in dislocation and other complications. In order to differentiate between the osteophytes and normal bone, the transverse acetabular ligament can serve as a reference. A line along the outer edge of the transverse ligament around the acetabulum may provide orientation. Any bone outside that line can be regarded as osteophytes and should be carefully removed. Placement of the cup can also be attempted before removing the osteophytes to provide protection and a reference line to avoid removing normal bone.

9.3.4   Choice of the Size of the Metal Acetabular Cup

Several reference points may be used to select the correct size of the acetabular cup: (1) Reaming until a hemispherical bone bed with reasonable position-

ing and good bleeding and coverage is obtained. This is the main reference for choosing an appropriate acetabular cup size. (2) Preoperative template measurement can be used as a reference. (3) The surgeon can measure the size of the femoral head before starting reaming as a reference for the final size of the cup. The latter should usually be 4–6 mm larger than the diameter of the femoral head.

9.3.5 Acetabular Cup Orientation

There is a certain safety range for the placement angle of the acetabular cup. The safety range that was given by Lewinnek et al. [1] is 15 ± 10° of anteversion and 40 ± 10° of inclination. The incidence of dislocations for cups placed at angles outside the safe area is about four times that of those within the safe area.

In general, the following methods can be used to determine the optimal angle of cup placement:

1. Most joint prosthesis manufacturers provide angle guide rods or angle-measuring device such as a gradienter connected to the cup handle.
2. The transverse acetabular ligament can also be used as a reference. The anteversion of the cup should not be less than that of the transverse acetabular ligament. Provided that the bone bed reaming depth and size are adequate, the lower edge of the cup will be close to the inner edge of the transverse acetabular ligament, allowing the surgeon to estimate the inclination of the cup.
3. Referring to the bony anatomy of the acetabulum, the front edge of the metal cup should usually not come to lie above the anterior wall of the acetabulum, while the cranial edge of the metal cup should not be lower than the edge of the upper wall of the acetabulum.
4. Some authors refer to the sciatic notch acetabular angle because it is relatively constant [2].
5. Intraoperative fluoroscopy or radiography is used for confirmation, mostly for total hip arthroplasty through an anterior approach.

However, Abdel et al. [3] showed that 58% of patients with a hip dislocation had an acetabular

angle within the safe zone described by Lewinnek. Therefore, Tezuka et al. [4] proposed that the concept of a "functional safe zone" is superior to Lewinnek's method of predicting hip stability. In recent years, more and more attention has been paid to the sagittal balance of the spine, pelvis, and femur. The morbidity of the lumbar spine and pelvis in the sagittal plane and the degree of anteversion of the femur both have an impact on the functional safe zone of the acetabular cup. Therefore, the functional safe zone varies from patient to patient.

Preoperative evaluation of the sagittal spine-pelvis-femur balance theoretically allows a relatively accurate calculation of the functional safe zone in each patient, and robotic surgery may further facilitate determining the individual functional safe zone. In addition, the coronal balance of the spine, pelvis, and femur will also affect the functional safe zone of the acetabular cup. In short, preoperative simulation allows to accurately evaluate both the individual motion of the lumbar spine, pelvis, and femur and their combined movements as well as main trunk muscle function, and, therewith, the ideal postoperative balance that should be targeted. However, achieving this postoperative target balance during the operation still needs more comprehensive theory, more accurate techniques, and calls for more research on this topic.

Finally, no matter what method is used, it is necessary to repeatedly confirm the stability of the hip joint before closing the wound.

9.4 Femoral Side Operation

Arthroplasty on the femoral side mainly involves the following aspects: stability and anteversion of the femoral prosthesis and offset and length of the leg.

9.4.1 Stability of Femoral Prosthesis

Cementless femoral stems with proximal fixation are being used more and more frequently in clinical practice. The preparation of the femoral medullary cavity is particularly important for the cementless stem to obtain press-fit and meet the stability requirements of anti-subsidence and anti-rotation.

The location of the femoral medullary opening should be accurate. It is important to emphasize that the direction of the rasp should be consistent, meaning straight in and straight out until the appropriate size is achieved, and the twist test is negative. The medullary cavity should be prepared until it is consistent with the shape of the femoral stem.

9.4.2 Stem Anteversion

The head and neck of a normal femur have a defined anteversion angle, generally within a range from 0 to 15°. The insertion of the femoral prosthesis following the anatomical direction at the calcar level, using the posterior cortex of the femoral neck as a marker, will usually maintain the anteversion within the normal range. In the case of proximal femoral abnormalities, such as hip dysplasia, where the femoral anteversion is significantly larger than the normal range, it may be considered to use a modular stem or a Wagner-type stem to adjust the anteversion. The most commonly used stems are the S-ROM® (DePuy Synthes, West Chester, PA, USA) and Wagner® Cone stem (Zimmer Biomet, Warsaw, IN, USA).

9.4.3 Offset

It is important to take careful template measurements before surgery to understand the patient's individual femoral offset. The restoration of offset is not only helpful to ensure the normal performance of the abductor muscle but also related to leg length restoration. If the patient has a large femoral offset, lengthening the leg may help to maintain the stability of the hip joint during the operation. Therefore, the femoral offset of each patient should be carefully measured before surgery, and a stem with a high offset should be prepared if necessary.

9.4.4 Leg Length

Leg lengthening is one of the main reasons for dissatisfaction after a hip replacement [5]. There are several possible reasons for leg lengthening

(usually referring to the absolute length) after hip replacement: First, the soft tissue around the hip joint is too tight postoperatively. Second, the offset of the prosthesis has been decreased compared to the original femoral offset, and the stability of the hip joint is maintained by lengthening the leg. Third, an excessive release of soft tissues around the hip joint was performed, resulting in leg lengthening in order to restore proper joint tension. Fourth, the prosthesis has a poor position and joint stability. Compromise is made by the surgeon to increase joint tension.

The following reference methods can be used to assess leg length intraoperatively:

1. Check the tension of the joint capsule, test the range of motion of the hip joint, and avoid excessive tightness of the joint and contracture of the hip joint during the operation.
2. Use leg length marks, such as a Kirschner wire inserted above the acetabulum, and compare with the intraoperative drawing lines.
3. The legs are placed in the same position on the operating table, and the patellae and calcanei are compared by bringing them to touch.
4. Fluoroscopy or radiography is performed to compare the positions of the lesser trochanters.

In summary, accurate placement and orientation of the prosthesis, restoration of the natural offset, and reasonable release of soft tissue are the basis for avoiding leg lengthening. Intraoperative verification with the surgeon's preferred methods can further reduce the occurrence of leg lengthening after total hip arthroplasty.

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Minimally Invasive Posterolateral Approach to Total Hip Arthroplasty

10

Jing Tang

Key Points

1. The posterolateral approach is suitable for primary and revision hip arthroplasty in most cases.
2. The standard incision can be extended if required by the intervention or shortened according to the experience of the surgeon.
3. The protection and reconstruction of the periarticular soft tissue can effectively improve the clinical outcome and reduce joint dislocations after arthroplasty.

The posterolateral approach to total hip arthroplasty (THA) is widely used [1–4]. It can fully expose the acetabulum and proximal femur, but the incision can also be extended to further increase the exposure according to the procedural or surgeon's needs. Therefore, it is suitable for most cases of THA in clinical practice. With the continuous accumulation of experience and the improvement of techniques, the length of the incision has been further shortened, and the tissue damage caused by the operation has been further reduced [5].

The minimally invasive posterolateral approach is widely used in our hospital, mostly through an 8–10 cm long incision. Here, we describe the different steps of this approach.

10.1 Surgical Technique

Both general and epidural anesthesia can be selected. The patients are routinely placed in the lateral position, and it is very important to keep the lateral position stable. If the position of the patient is not fixed firmly and changes during the operation, it will directly affect the surgeon's judgment of the position of the prosthesis. This misjudgment might lead to surgical errors, joint dislocation, and other adverse consequences. There are many ways to maintain the lateral position during surgery. We use a lateral positioning plate to secure the patient's position during surgery. The lateral positioning plate can be fixed very reliably and is hard to move. It can be used even in obese patients. By using this plate we can keep the patient in the fixed lateral position as much as possible and avoid moving them during surgery (Fig. 10.1).

Routine disinfection is performed, and a sterile operation sheet is applied. The incision is located above the middle and posterior part of the greater trochanter (Fig. 10.2). The incision length is usually 8–10 cm. One-third of the incision lies above the proximal part of the greater trochanter, and two-thirds of the incision lies above the distal part. The subcutaneous tissue is incised down to

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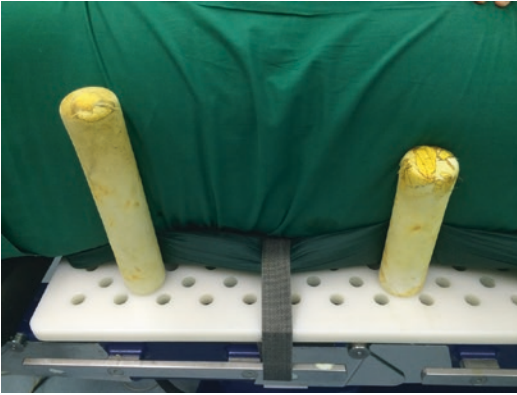Beijing Jishuitan Hospital, Beijing, China

Fig. 10.1 The lateral positioning multiholed board to secure the patient's position. The back of the column is against the sacrum, and the front is against the pubic symphysis. The columns control the position parallel to the operating table. After the board is fixed, the body position can be maintained

Fig. 10.2 Location of the incision above the greater trochanter. The length of the incision is adjusted according to the difficulty of the operation

the deep fascia under simultaneous meticulous hemostasis. After exposure of the deep fascia, we confirm the correct incision position again, especially in obese patients. The iliotibial band should be severed over the middle and posterior part of the great trochanter to expose the proximal part of the gluteus maximus muscle, and blunt dissection is performed in the direction of the incision. The bursa of the greater trochanter is opened to expose the tissue behind the greater trochanter. The hip

Fig. 10.3 The tendon of the external rotator muscle is clearly visible in most patients. The insertion of the external rotator muscle is incised, and the muscle is pulled outward to expose the deep joint capsule

joint is then rotated slightly internally, and the gluteus medius muscle is pulled superiority with a retractor. The fat tissue on the surface of the external rotator muscle is removed. Commonly, there are arteries in the fat tissue that enter the hip joint, which is electrocuted. After the external rotator muscle is exposed, the piriformis and gluteus minimus muscles are identified, and a sharp retractor is placed between them so that the gluteus minimus can be gently pulled proximally. The assistant rotates the hip joint internally, and electrocautery is used to slowly dissect the external rotator muscle. After it is completely incised, the hip joint capsule is exposed (Fig. 10.3).

It is helpful to keep the tendon as long as possible so that it can be reconstructed and sutured to the piriformis muscle to maintain the soft tissue tension [6]. During the incision of the capsule, attention should be paid to the direction of the incision, and the capsule structure should be preserved so that it can be used for the repair and suture when closing the joint. A retractor is placed on the neck of the femur inside the capsule, and the femoral head is dislocated by flexion and internal rotation of the joint. If the proximal part of the quadratus femoris muscle is tight, it can be loosened to prevent injury to the muscle during the dislocation of the femoral head.

After fully exposing the femoral neck, the osteotomy template is used to help determine its direction and position and confirm whether the length of the bone is appropriate by touching the tip of the lesser trochanter. Next, the osteotomy of the femoral neck is performed, and the femoral head is dislocated. The leg is then brought into extension on the operating table, and slight internal rotation can help expose the acetabulum. A retractor is placed anteriorly of the acetabulum to pull the proximal femur anteriorly. We then insert a 4.0 mm pin vertically into the posterior aspect of the inferior ramus of the ischium and another one in the anterior and superior aspect of the acetabulum to facilitate its exposure (Fig. 10.4). It is normally not necessary to identify the sciatic nerve, and the artery is retracted together with the posterior soft tissue. Another retractor is placed under

Fig. 10.5 Positioning of acetabular prosthesis assisted by a locator. With the patient in the lateral position, the proximal femur should be fully pulled anteriorly by the anterior retractor. The acetabular component's camber angle is 45° when the locator is vertical to the ground. The anteversion of the acetabular prosthesis is about 20° when the angle ruler of the locator is parallel to the long axis of the trunk

Fig. 10.4 Acetabular exposure. Two pins are used: one at the back in the ischial ramus and another in the anterosuperior part of the acetabulum. A retractor is placed in the anterosuperior part of the acetabulum to block the proximal femur and another retractor at the lower part of the acetabulum between the transverse ligament of the acetabulum and the joint capsule

the transverse ligament of the acetabulum. The acetabular labrum and the residuum of the ligament are removed. The acetabulum is now fully exposed and can be reamed. After reaming to the right size, we place the acetabulum prosthesis in the ideal position using a guide [7] (Fig. 10.5).

When the proximal femur is exposed, the assistant adducts internally rotates and flexes the hip joint, so that the lower leg is perpendicular to the floor, which allows observing the femoral anteversion (Fig. 10.6). The proximal femoral bone is exposed with a retractor. The femur canal is opened and gradually expanded to a suitable size. If necessary, we use fluoroscopy to confirm whether the trial stem has the right size and is in the right position. We then place the trial head and attempt the reduction of the hip joint. The range of motion of the hip joint has to be satisfactory without dislocation, and the legs should be of equal length. The trial stem is then removed, and the corresponding femoral prosthesis and head are implanted. The greater trochanter should be protected during the placement of the stem (Fig. 10.7). We suture the posterior capsule and reconstruct the piriformis tendon insertion to the great trochanter before closing the wound.

Fig. 10.6 Three retractors are used to expose the proximal femur. The assistant positions the lower leg perpendicular to the ground. A double tip retractor was placed under the proximal femur, a retractor is placed inside the femoral canal, and the other retractor is placed proximally to retract the gluteus medius muscle
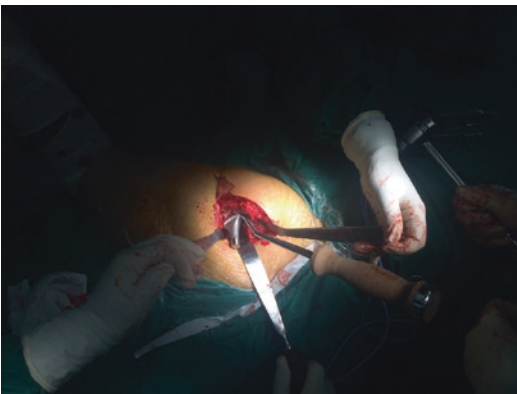
Fig. 10.7 The use of femoral percussion apparatus with eccentric moment. This can prevent the greater trochanter from excessively pressing outward when the greater trochanter is blocked, resulting in a greater trochanter fracture

10.2   Postoperative Rehabilitation

The length of time until weight-bearing is allowed postoperatively depends on the intraoperative situation. If the prosthesis is stable, and the patient has good bone quality and is not morbidly obese, the patient is allowed to walk with partially weight-bear on crutches on the first postoperative day.

The posterolateral approach requires severance of the external rotator muscle and opening of the posterior joint capsule. Even if reconstruction and suturing are performed before closing the wound, it is necessary to limit the activity of the hip joint in the early postoperative period [8]. Hip flexion is limited to avoid soft tissue tears caused by excessive activity since this will reduce the posterior stability of the joint and increase the risk of dislocation. Generally, if the intraoperative range of motion test of the joint showed stable conditions, hip flexion is allowed up to 90° after the operation, which helps during the postoperative rehabilitation, especially regarding squatting, putting on shoes and socks, and other activities. But at the same time, it is also necessary to prevent excessive hip extension [9–11].

Depending on patients' individual condition, they may progress to one crutch only within 2 weeks to 1 month after the operation and discard the crutch entirely after 1 month.

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Minimally Invasive Direct Anterior Approach for Total Hip Arthroplasty

11

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Key Points

1. With the direct anterior approach, the accumulation of experience allows surgeons to reduce the length of the incision gradually.
2. Sufficient soft tissue release reduces tissue damage during surgery.
3. Surgeons starting to use this approach should be patient and cautious to avoid complications.

The direct anterior approach (DAA) to total hip arthroplasty is used by an increasing number of doctors worldwide because of its advantages [1, 2]. These are minimal invasiveness, quick recovery, and good outcomes with regard to joint stability [3]. The DAA has been adapted to the operating habits of local surgeons in different countries and regions. Some surgeons prefer the anterolateral approach, which splits the anterior third of the gluteus medius muscle, to facilitate exposure and simplify the technique. Surgeons who favor minimally invasive surgery directly enter the hip joint through the gap between the sartorius and tensor fasciae latae muscles and retain the integrity of the abductor muscles and posterior soft tissue structures.

The DAA can be performed with the patient supine, which makes this approach an attractive option. The supine position is stable, and the length of both legs can be conveniently determined and compared. It avoids the problem of intraoperative position changes frequently encountered when patients are placed in the lateral position. Maintaining a stable lateral position during surgery is also challenging in obese patients, who are continuously increasing in number. In patients with a pelvic or spinal deformity, the lateral position might cause intraoperative judgment errors. Finally, the dislocation rate after total hip arthroplasty through the anterior approach was shown to be lower than that of the posterior approach.

The surgical approach is a critical step in any operation that influences the intervention's success [4]. In contrast, surgical approaches are selected depending on the patient's individual situation. On the other hand, choosing a familiar approach can reduce the technical difficulty for the surgeon and reduce the trauma inflicted on tissues compared to those of less familiar approaches. With increasing experience, surgeons are able to expand the indications and complete various complex operations through the approach they are most familiar with [5].

It is generally recommended that the first hip replacement in patients without obvious anatomical deformities can be performed through the minimally invasive DAA in the supine position.

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These patients include those with necrosis of the femoral head, osteoarthritis, and mild dysplasia of the hip joint.

Contraindications for the DAA include obesity, stiffness, severe deformities and dysplasia of the hip, previous hip surgery, and revision arthroplasty [6]. However, with increasing experience and improved surgical techniques, some of these contraindications are not absolute. For example, the DAA may be used in some obese patients if the operation is not too technically demanding.

An appropriate extension of the incision should be considered when needed to improve exposure and will help to prevent complications.

11.1 Surgical Technique

Adequate anesthesia is important to ensure a smooth operation. General anesthesia is recommended to enable anesthesiologists to optimally control muscle relaxation and reduce surgical trauma and facilitate the operation. Adequate muscle relaxation is helpful in exposing the proximal femur, especially in patients with a tight tensor fasciae latae muscle or strong gluteus medius muscle.

The advantage of the supine position is that the patient's position is stable during the operation, which helps to avoid misplacement of the prosthesis that might be caused by changing body positions if patients lie on their side. This advantage is more obvious in obese patients and patients with pelvic and lumbar deformities. At the same time, it is easier to compare the length of the legs. From the anesthesiologist's perspective, the supine position facilitates maintaining a patient's cardiopulmonary function and avoiding dislodgement of the tracheal tube or laryngeal mask that may occur in the lateral position.

After anesthesia induction, but before disinfection, anatomical landmarks of the hip joint are marked on the skin, such as the outline of the proximal part of the greater trochanter and the anterior superior iliac spine. The skin incision is marked starting 3 cm distally and 3 cm laterally to the anterior superior iliac spine, extending over approximately 8–12 cm (Fig. 11.1). This is fol-

Fig. 11.1 The skin incision lies between the sartorius and tensor fasciae latae muscles. This gap can be palpated in most patients. The length of the incision is about 9 cm and can be extended as needed

lowed by routine disinfection and application of a sterile operation sheet and plastic adhesive drape.

The skin and subcutaneous tissue are incised down to the fascia lata. The space between the tensor fasciae latae and the sartorius muscles is exposed, and the fascia is incised approximately 1 cm laterally of the gap. The gap between the tensor fasciae latae and sartorius muscles is widened by blunt separation, and a sharp retractor is placed around the superior aspect of the femoral neck and used to pull the sartorius muscle medially. The deep fat tissue is carefully separated, and the branches of the lateral femoral *circumflex vessels* are identified and treated carefully (Fig. 11.2).

A blunt retractor is placed under the femoral neck to prevent the superficial fat tissue from obstructing the view of the femoral neck, and the rectus femoris is properly released, while another retractor is placed on the front edge of the acetabulum.

The femoral neck is then exposed through a T-shaped capsulotomy. The retractor tip is placed inside the joint capsule anteriorly and posteriorly of the femoral neck. The osteotomy in the femoral neck is performed with a saw according to the preoperative templating. The greater trochanter should be protected to avoid a fracture, and the acetabulum should not be damaged with the saw (Fig. 11.3). External rotation and traction of the extended leg will enable dislocation of the femoral head.

The acetabulum is now exposed by inserting a retractor superiorly, in front of, and inferiorly to

Fig. 11.2 After incising the skin, the gap between the sartorius and tensor fasciae latae muscles is bluntly dissected. The ascending branch of the lateral circumflex femoral artery is identified, carefully separated, and ligated or electrocuted. Note: Sometimes, the lateral circumflex femoral artery has two branches, which have to be carefully dissected. If the vessel is not handled properly and injured, it is difficult to treat the bleeding because the vessel retracts, resulting in massive intraoperative bleeding or postoperative hematoma

Fig. 11.3 The femoral neck is exposed while protecting the surrounding soft tissue with a retractor. Osteotomy of the femoral neck is performed in slight internal rotation of the leg

the acetabulum so that the labrum and residual transverse ligament can be resected under vision. At this time, the retractor under the acetabulum can be replaced by a double-tip retractor, which is conducive to exposing the acetabulum (Fig. 11.4).

Fig. 11.4 The acetabulum is exposed with three retractors, one at the anterior edge of the acetabulum, another one at the superior edge of the acetabulum, and one below the transverse ligament. Note: The incision in the anterior joint capsule should be extended to the anterior edge of the acetabulum for release. The inferior joint capsule is often tense and needs release

The smallest reamer available is used to ream the acetabulum as a start, and the reamer size is then gradually increased. Attention should be paid to the direction and depth of reaming. Generally, reaming is performed at 45° to the longitudinal axis of the body and at 15° to the operating table (Fig. 11.5). The anterior and posterior walls of the acetabulum should be fully exposed to avoid excessive reaming.

After reaming to the right size, the acetabular prosthesis is implanted. One or two screws are used to fixate the cup and achieve good initial stability. Then, the corresponding liner is inserted.

Prior to preparing the femoral side, the operating table is tilted by approximately 30° toward its end to raise the head and lower the feet. The proximal femur is further exposed by adduction and external rotation combined with soft tissue release. It is generally necessary to release the joint capsule in the greater trochanter region. If the exposure is still insufficient, the insertion point of the external rotator muscle should be released, too (Fig. 11.6). Adequate and sufficient release reduces the technical difficulties in open-

Fig. 11.5 The direction of the acetabular reaming generally refers to the plane of the operating table. The reaming method is the same as that in the posterolateral approach, but the direction is different. Surgeons need to pay attention to prevent the acetabulum from superiorly shifting and protect the anterior wall of the acetabulum. If the direction of reaming is not ideal, it is often because the three retractors do not provide sufficient exposure. Therefore, their position should be adjusted and the release of the soft tissue should be extended
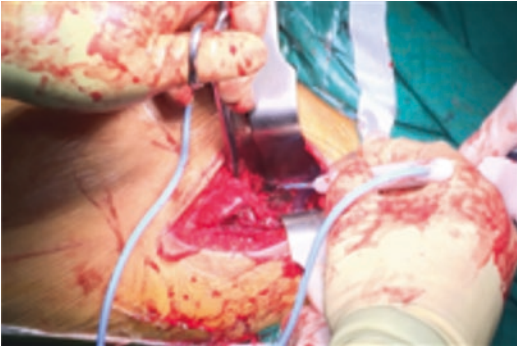
Fig. 11.6 Treatment of the femoral side. At this time, the distal end of the operating table needs to be folded down by about 30°. The folding angle can be increased or decreased according to need and the exposure achieved. The release is performed at the posterior joint capsule of the greater trochanter and the insertion points of some external rotators
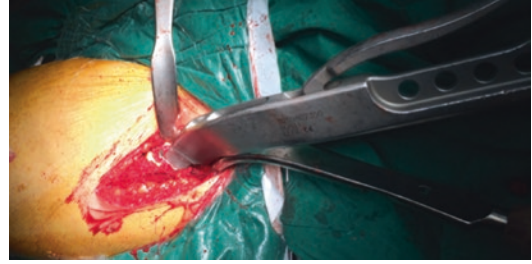
Fig. 11.7 Proximal femoral reaming using an eccentric femoral holder. The use of a femoral holder with an eccentric moment and a femoral beater can prevent injury of the tensor fascia latae muscle

ing the femoral canal and avoids the prosthesis penetrating the femoral medullary cavity. After the release, a retractor is placed under the greater trochanter to lift the proximal femur. Another retractor is placed medially on the proximal femur to pull it out of the incision. The position of the leg can be adjusted as needed to optimize exposure, for example, by further adduction and external rotation. If the patient's muscles are strong, the anesthesiologist should administer muscle relaxants at this time to relieve muscle tension. The proximal femoral canal should be opened with a box osteotome close to the trochanter to prevent the prosthesis from being implanted in varus.

The use of a femoral holder with offset can facilitate the exposure of the proximal femur and reduce the risk of prosthesis penetration (Fig. 11.7). The trial stems are used one by one starting from the smallest stem to arrive at the correct size. If necessary, fluoroscopy may confirm whether the trial stem is in the right position [7] (Fig. 11.8a, b).

The next step is the reduction with a trial femoral head. The hip joint is moved through the entire range of motion to test its stability, and the leg length is compared. If the joint range of motion is satisfactory without a dislocation tendency, and there is no leg length difference, the corresponding prosthetic stem and head are implanted. Finally, the wound is closed.
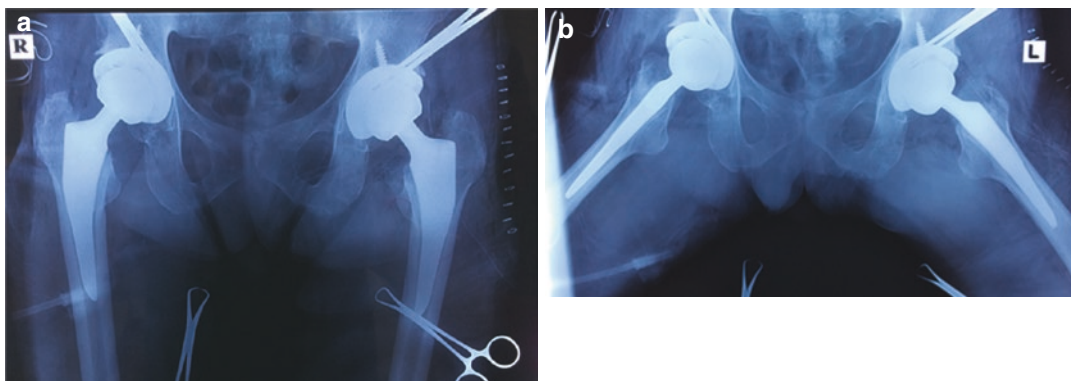
Fig. 11.8 (**a**, **b**) Intraoperative anteroposterior and lateral radiographs can be used to determine the position, size, and length of the prosthesis

11.2   Postoperative Rehabilitation

The length of time until weight-bearing is allowed postoperatively depends on the intraoperative situation. If the prosthesis is stable and the patient has good bone quality and is not morbidly obese, they are allowed to partially weight-bear on crutches 1–2 days after the operation.

The DAA only opens the anterior capsule without severing any muscles around the hip joint. Therefore, it is not necessary to limit the range of motion of the hip joint, and there is no risk of posterior dislocation.

Depending on the patient's individual condition, they may progress to a single crutch within 2 weeks to 1 month after the operation and discard the crutch after 1 month [3, 8].

11.3   Complications

The potential complications of the DAA are as follows:

1. Fracture: A greater trochanter fracture, proximal femoral fracture, or prosthesis perforation may occur if the exposure of the proximal femur is not ideal, the direction of the canal opening is wrong, the size of the prosthesis is too large, surgeons pursue a tight fit at all cost,

the bone is osteoporotic, and for further reasons [6, 9, 10]. Good exposure is the key to correct implantation of the prosthesis stem and to avoiding intraoperative fracture.

2. Tensor fasciae latae muscle injury: This may be caused by muscle tightness, patients with strong muscles, an incision that is too short, not using a femoral holder with offset, insufficient exposure of proximal femur, and other reasons [11]. Therefore, if there are difficulties during the operation, it is recommended to perform a further soft tissue release and request the anesthesiologist to increase the muscle relaxation.

3. Injury to the lateral femoral cutaneous nerve: This may be related to an incision that is too medial, the hook is pulled medially with too much force, the operating time is too long, or the suture roughly include the nerve. If the incision is in the correct position, the hook should protect the nerve from damage. Injury to this cutaneous nerve will leave patients with numbness in the lateral thigh [12].

4. Erroneous positioning of the prosthesis: Surgeons who start using this approach are prone to positioning errors, such as excessive acetabular protrusion and varus implantation of the femoral prosthesis. Intraoperative fluoroscopy or radiography can avoid incorrect positioning of the prosthesis.

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The Surgical Approach and Outcomes of Total Hip Arthroplasty

Jing Tang

Key Points

1. The surgical approach is only a technique that does not determine the outcomes of total hip replacement.
2. Any approach that is fully mastered by the surgeon and that minimizes tissue trauma will have good clinical results.
3. While each has its own advantages and disadvantages, it is the level of familiarity and skill of surgeons that affect the clinical outcome and the occurrence of complications.

At present, there are many approaches to total hip arthroplasty [1]. They can be roughly divided into three types according to the different directions of the approaches, they are anterior, posterior, and lateral approaches. The posterolateral and direct anterior approaches are commonly used in our hospital. These two approaches are described in the previous two chapters. Other surgical approaches, such as the anterolateral, lateral, and two-incision approaches, are widely used in other hospitals and by other surgeons, who obtain excellent clinical results with these [2–4]. Therefore, although the different surgical approaches may all have their specific advantages and disadvantages in theory, the decisive factors in practice are the surgeon's familiarity with the chosen surgical approach and their level of surgical skill and mastery of the technique [5, 6]. Experience, skill, and good surgical techniques are critical for obtaining excellent clinical results.

It seems to be a false proposition that there is one surgical approach that is most suitable for a specific case or that surgeons will choose the most appropriate surgical approach for each patient. Surgeons tend to use the approach they are most familiar with to solve all the problems they encounter, including uncomplicated, complex, primary, and even revision total hip arthroplasty [7, 8]. Once a surgeon has mastered a surgical approach, they will have become less familiar with other surgical approaches. Therefore, they tend to use the approach they are most familiar with, rather than the approach that, theoretically, appears most suitable for the individual patient.

Therefore, the critical point we want to make here is that the approach is nothing but a surgical technique. High-level surgical techniques and skills are the true keys to a successful operation. Any approach has theoretical advantages, but it will bring unnecessary problems for the surgeon and potential complications for patients if the surgeon is unfamiliar with it [9–11].

Learning a new surgical approach or changing specific aspects of the surgical approach a surgeon is familiar with often requires paying the price, which is commonly known as the "learning

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curve". Before proficiency is achieved, there may be numerous minor or significant complications, and both surgeon and patient will pay for the new surgical approach [9, 12, 13]. Therefore, under the premise of not rejecting new technologies and methods, surgeons must give their best to reduce the potential of complications. At the same time, they must strive to move smoothly and quickly through the learning curve to become proficient in the new technique. In reality, that is very difficult to achieve. The success of this undertaking depends on the difficulty of the surgical approach itself, the learning ability, surgical skills, and character of the surgeon, the cooperation of the assistant, and the complexity of the conditions in the patient population. However, in the interest of our patients, it is vital that as surgeons, we give our best to train ourselves and move quickly through the learning curve of a new surgical approach. We believe that it is possible to avoid complications and surgical risk to patients.

We are of the opinion that any surgical approach that results in the least tissue trauma, the smallest incision, the least bleeding, the best prosthesis position, the ideal recovery, in the hands of a skilled surgeon, and the best clinical outcomes compared to those of other approaches provides the best service to the patient. There is no clinical evidence that one surgical approach per se is superior to another. In the hands of skilled surgeons with expertise and sufficient experience, each surgical approach may achieve nearly perfect clinical results. Consequently, there is no need to change an approach that works well in the hands of a surgeon to achieve the ultimate clinical effect. Instead, we should pay attention to the continuous improvement of our surgical techniques, the deep-rooted concept of minimally invasive surgery, and pursue maximal benefits for our patients. Only in this way can we achieve the best surgical outcomes and thereby achieve the ultimate purpose of the surgical profession.

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Part III

Complex Primary Total Hip Arthroplasty

Total Hip Arthroplasty for Developmental Dysplasia of the Hip. Part 1: Crowe I–II

13

Songjie Ji and Jing Tang

Key Points

1. Epidemiology and classification of developmental dysplasia of the Hip.
2. Typical anatomical deformities of acetabulum and femur in DDH.
3. Preoperative plan and surgical technique for I-II DDH.

13.1 Introduction

Osteoarthritis secondary to developmental dysplasia of the hip (DDH) is a common orthopedic condition [1]. DDH is a congenital disorder in infants and children. Early detection and nonoperative management have been shown to be effective in preventing secondary osteoarthritis [2]. The incidence of osteoarthritis (OA) secondary to DDH shows considerable geographic and ethnic variation [3]. Regardless of whether or not patients have undergone nonoperative treatment in their early childhood, patients often develop hip pain when they reach a certain age. The anatomical and biomechanical alterations of the acetabulum, femur, and pelvis in DDH predispose to the development of hip OA [4]. A radiological evaluation will demonstrate hip joint degeneration and bony abnormalities. Some patients show

subluxation or complete dislocation of the hip joint. These patients are usually relatively young, mostly 40–60 years old, with some being only between in their twenties. Thus, their lifestyle is comparably active, posing high requirements on function, and they need a good survival of the implant. So, they are in need of surgical treatment to either improve their joint function or to achieve normal joint function and mobility in the first place, so as to pursue a normal life and work.

The principles of total hip arthroplasty (THA) in DDH are the same as those of THAs for other OA causes: The normal biomechanics of the hip should be restored as much as possible. At the same time, the various anatomical abnormalities often increase the difficulty of the operation. It is critical to evaluate these abnormalities meticulously before surgery. This generally entails a careful examination of the clinical manifestations and the findings on medical imaging, including radiography and computed tomography (CT). Surgeons require comprehensive clinical experience and a thorough understanding of hip anatomy and surgical techniques. Only the integration of knowledge with highly developed surgical skills permits performing high-quality THA in DDH patients.

13.2 Typical Deformities

The acetabulum and femur of DDH patients are abnormal. The true acetabulum is characterized by insufficient depth, a thin anterior wall,

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reduced bone mass, and also bone defects. The true acetabulum may be shallow and have full contact with the femoral head, partly in contact with a false acetabulum, or extremely small, shallow, and triangular, showing a complete loss of congruency with the femoral head [5]. Anteriorly, bone stock is limited, often with segmental wall defects. The bone stock is usually rearranged posteriorly [6], and the femoral head is only insufficiently covered by the acetabulum [7]. Commonly, compensatory hyperplasia, thickening, and hypertrophy of the labrum and joint capsule are found. Depending on the length of a patient's history, osteophytes will have formed around the acetabulum, while the bone defects will be aggravated as a result of long-standing weight bearing on the acetabulum [8]. It is critical to estimate the difficulty of the operation preoperatively and select the most appropriate way to reconstruct the rotation center of the hip joint. Femoral hypoplasia with loss of the metaphyseal flare is often present, with a narrow and straight intramedullary canal

[9]. Many patients have marked femoral anteversion and torsion and a short neck, with a coxa valga and lower offset than these of a normal femur [6, 10]. The CT manifestations in patients with dysplasia of the hip include a shallow acetabulum, poor matching between the acetabulum and femoral head, a thin anterior wall, and superior lateral defects (Fig. 13.1). The preoperative CT is helpful to evaluate the degree of bone defects, regardless of whether the anterior wall and posterior wall are intact or not, and the bone stock of the acetabular floor. In patients with a long history of the disease, severe degeneration, and hyperplasia, numerous osteophytes around the acetabulum may have formed (Fig. 13.2). These need to be removed during THA, paying attention not to damage the normal residual structures of the hip joint. Removal of osteophytes can release the capsule and reduce the impact on the hip joint after the operation. Most of the time, osteophytes are removed after the acetabular prosthesis is placed (Fig. 13.3).
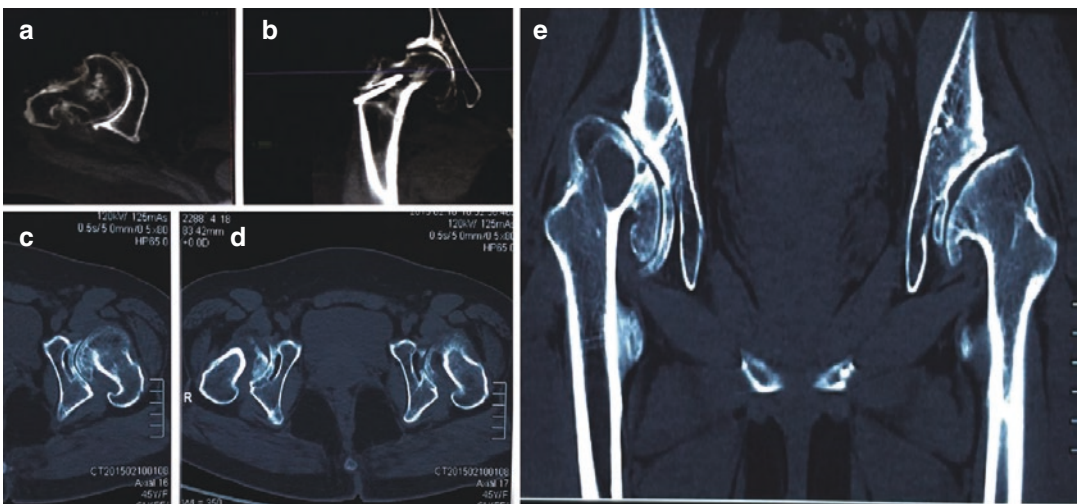
Fig. 13.1 Computed tomography in developmental dysplasia of the hip. (**a**) This CT shows a shallow acetabulum, poor matching between the acetabulum and femoral head, a thin anterior wall, and a superior lateral defect. (**b**) femoral head dislocate from acetabulum. (**c**, **d**) femoral anteversion is abnormal. (**e**) CT findings in severe cases showing extensive osteophyte growth around the acetabulum, femoral head dislocate from acetabulum

13.3   Classification

Many classifications of DDH have been proposed. The most popular are the Hartofilakidis and Crowe classifications. The Crowe classification [11] divides DDH into four types according to the degree of dislocation of the femoral head from the true acetabulum (Fig. 13.4). The teardrop and the inner edge of the femoral head and neck are reference points in this classification, and the height of the femoral head is the reference height.

- Type I is a subluxation of less than 50% of the vertical diameter of the femoral head;
- Type II is a 50–75% subluxation of vertical diameter of the femoral head;
- Type III is a 75–100% subluxation of vertical diameter of the femoral head;
- Type IV is a more than 100% subluxation of the femoral head.

The disadvantage of this quantitative classification is that it focuses on the degree of displacement of the femoral head and does not consider the anatomical abnormalities of the acetabulum. It requires a pelvic radiograph, presents some

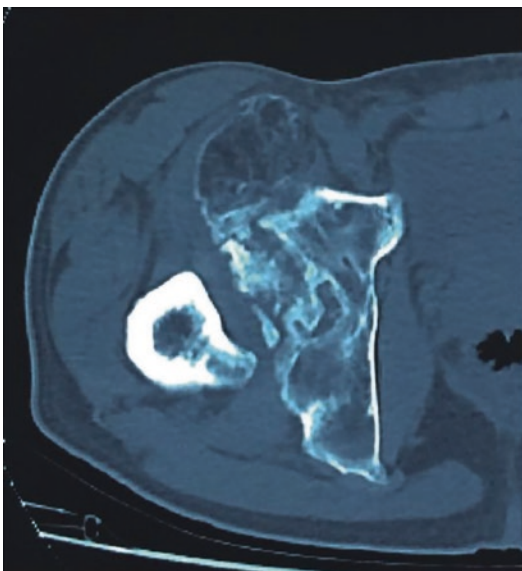**Fig. 13.2** Computed tomography in developmental dysplasia of the hip. A large osteophyte in ventral acetabulum is visible
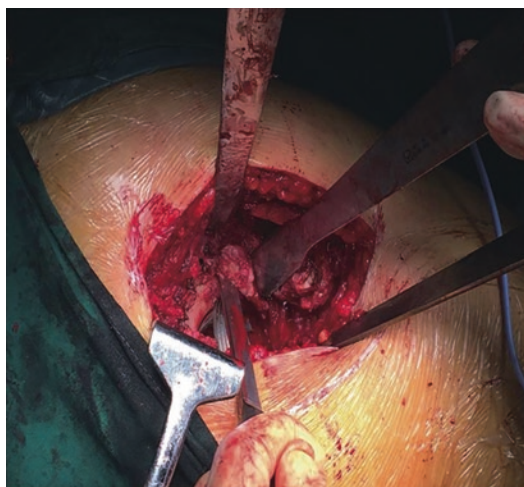

Fig. 13.3 Intraoperative image during total hip arthroplasty. The removal of periacetabular osteophytes is shown
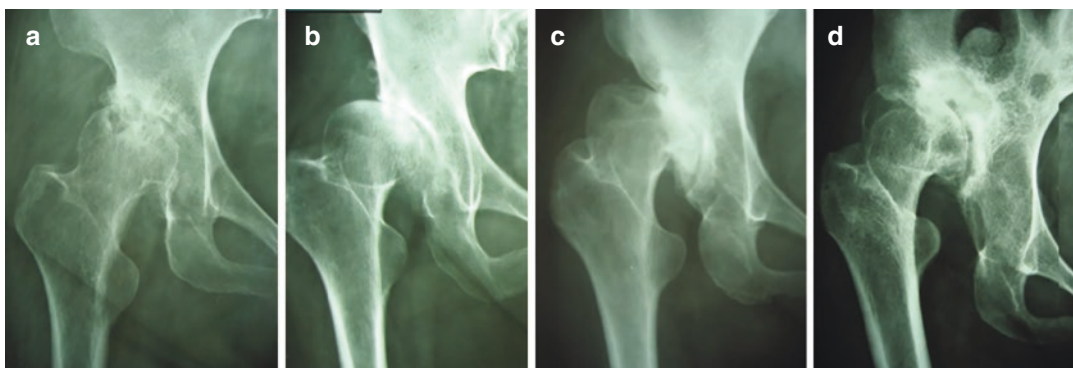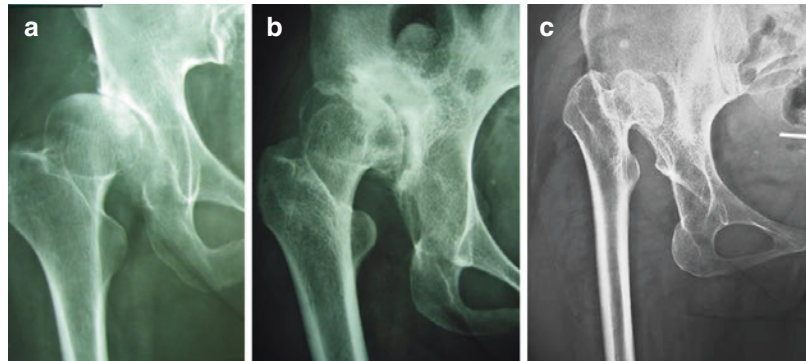

Fig. 13.4 Crowe classification of developmental dysplasia of the hip. (**a**) Type I; (**b**) Type II; (**c**) Type III; (**d**) Type IV

Fig. 13.5 Hartofilakidis classification of developmental dysplasia of the hip. (**a**) Type A; (**b**) Type B; (**c**) Type C

difficulties in defining the landmarks, and does not explain the underlying pathology. Furthermore, it is not very helpful in preoperative planning.

The Hartofilakidis classification [12] is more practical than the Crowe classification. As a qualitative classification, it explains the underlying pathology and anatomic variations. It distinguishes three types (Fig. 13.5):

- Type A: Dysplasia, the femoral head is located within the true acetabulum;
- Type B: Low dislocation, the femoral head is located within the false acetabulum. The lower lip of the acetabulum adjoins or overlaps the upper lip of the true acetabulum;
- Type C: High dislocation, the femoral head has migrated posteriorly and superiorly and has no contact with the true or false acetabulum. This type can be further divided into two distinct subtypes, based on the presence (C1) or absence (C2) of a false acetabulum [13]. Revision rates are higher in C2 than C1 [14]. The femur in C2 has a smaller neck-shaft angle, higher migration index, shorter femoral neck, and higher position of the greater trochanter [15].

13.4 Surgical Planning

Surgeons should use standard anteroposterior and lateral radiographs for templating [16]. Most of the time, the mean mediolateral diaphyseal diameter of the femoral canal is smaller than the anteroposterior in all DDH types. Therefore,

small and even smallest diameter implants (e.g. 38 mm) are needed. CT with 3D reconstruction is performed to evaluate any wall deficiencies, the socket size, and bone stock of the true acetabulum. Furthermore, the anteroposterior acetabular diameter is crucial in cup size selection [17]. Leg-length discrepancy and decreased acetabular anteversion compared with normal population correlate with advanced disease [18]. Templating is performed to choose the type and size of the implant, and the success of DDH reconstruction will depend on the correct choice of the implant. However, intraoperative findings may change implant requirements. Preferably, the acetabular component which has a hemispherical porous shell with multiple holes for screw fixation is used. Even if seldom needed, augments, buttress, and equipment for structure bone grafts should be prepared preoperatively.

A variety of femoral components should be available to address both routine and complex cases. Since increased anteversion is a common finding even in mild DDH (I, II), modular implants that allow rotational adjustment are useful. Modular stems such as those in the S-ROM® Modular Hip System (DePuy Synthes, Raynham, MA, US) are well suited for DDH. The S-ROM® is a cementless modular cylindrical prosthesis system. The titanium alloy stem is polished distally with splines around a coronal slot to reduce stem stiffness. Additionally, there are proximal standard and calcar height and offset options. It offers porous-coated or hydroxyapatite-coated sleeves designed to convert hoop and shear stresses to compressive forces at the sleeve-bone interface. Cerclage cables, femoral plates, and

screws should be available in case they are needed. Biant et al. reported the average 10-year clinical and radiographic results of 28 hips with Crowe III or IV DDH and a technically difficult primary hip arthroplasty using the cementless modular S-ROM® stem [19]. None of the S-ROM® stems had been revised or were loose at the latest follow-up.

Cemented prostheses fare less well in DDH. Stans et al. [20] reported the results of a cemented prosthesis in 70 Crowe type III hips in patients with secondary OA after an average of 16 years postoperatively, showing aseptic loosening of 40% of the femoral stems. Eleven stems had been revised, including four because of an infection and two following component fractures. Klapach et al. [21] reported on the long-term follow-up of cemented THA in 65 hips with Crowe II, III, and IV DDH.

13.5 Surgical Technique

Surgeons performing THA in DDH need to have sufficient experience, not only to correctly determine the location of the true acetabulum but also to master the technical demands of the reconstruction. The preoperative imaging examination allows evaluating the bone stock and the intactness of the anterior and posterior wall of the acetabulum. If the bone stock of the inner wall of the acetabulum is sufficient and the anterior wall is intact, the operation is relatively easy. If the inner wall of the acetabulum is thin and the anterior wall is weak or has defects, the operation becomes difficult. In this case, the key is to protect the anterior wall during reaming. A small cup has to be used and reaming should not go beyond a distance of approximately 2–3 mm from the inner cortex to leave sufficient bone stock for potential future revision surgery. Surgeons should aim to achieve 75–80% coverage of the cup.

The principles of reconstruction in DDH are:

1. Aiming to reconstruct the acetabulum in the correct position and avoid moving the rotation center cranially. It is critical to determine the ideal rotation center, which can be measured on preoperative radiographs as follows: If the contralateral hip is normal, the position of its acetabular center determines the height of the center of the reconstructed hip. If both sides are abnormal, the ideal rotation center can be found by drawing Ranawat's triangle.

2. Aiming to maximize the contact area between the prosthesis and the host bone to facilitate bone ingrowth and obtain stable and reliable long-term fixation.

3. Using the largest cup possible, which can increase the liner thickness, increase the diameter of the femoral head, and reduce the dislocation rate.

It should be underlined that the position of the acetabular fossa should be determined first, and thereafter a small reamer can be used to expose the bottom of the acetabular fossa. Following that, surgeons should gradually enlarge the size of the cup to find the most appropriate size.

The following three reconstruction methods are recommended in Crowe type I–II DDH:

1. *Deepening of the acetabulum.* In patients with sufficient acetabular bone stock, this method is mostly used and saves time. After identification of the true acetabulum position, it is important to expose the entire circumference of the acetabulum and the transverse acetabular ligaments. In DDH patients, the ligaments are generally a certain mark of acetabulum. The inner wall of the acetabulum is reamed with a small reamer, for example, 38 mm. The depth of reaming is determined by the inner wall of the acetabulum, which corresponds to the lateral edge of the teardrop on the radiograph. If the depth is insufficient, it is likely to lateralize the cup and result in inadequate coverage. In general, the anterior wall is very thin but relatively hard in Crowe type I–II. If the anterior and posterior walls cannot provide sufficient support to stabilize the cup, the acetabulum may be too shallow. In that case, reaming can be performed to deepen it appropriately, even if at the cost of slightly penetrating the inner wall. In complex cases, fluoroscopy can be used intraoperatively to

Fig. 13.6 Total hip arthroplasty in developmental dysplasia of the hip in Crowe type I–II. (**a**) Preoperative radiograph. Rotation center is up migration. (**b**) Postoperative image, rotation center is normal
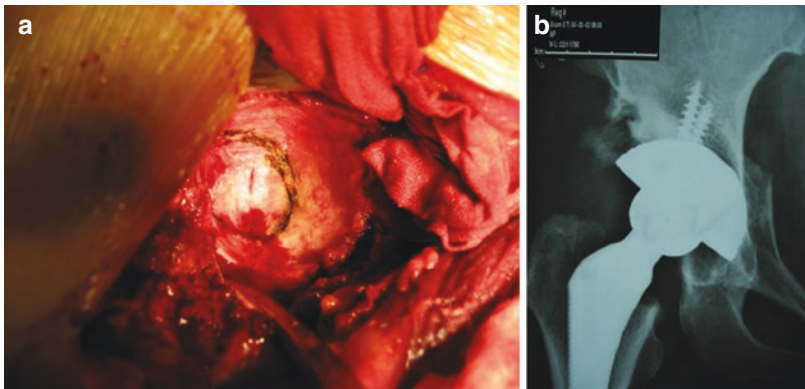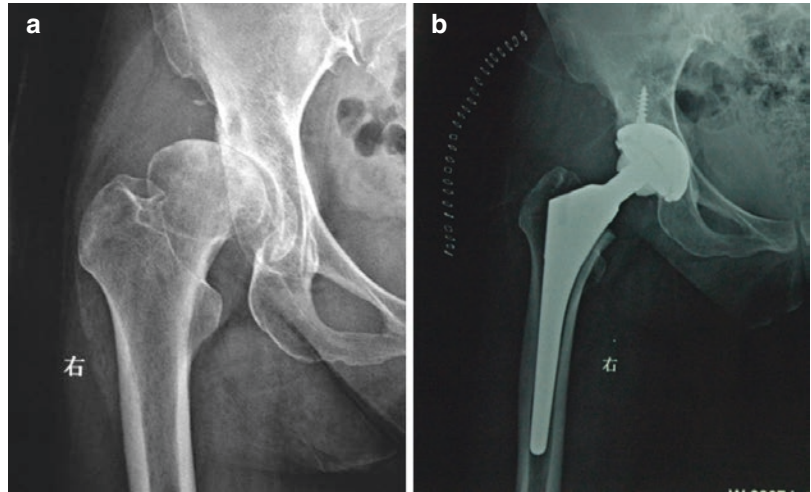
Fig. 13.7 Total hip arthroplasty in developmental dysplasia of the hip in Crowe type I–II. (**a**) Intraoperative image of the inner wall osteotomy. (**b**) Postoperative image shows the block from a part of the inner wall is kept

support the surgeon's judgment. Once the stability of the anterior and posterior wall has been secured, the bone fragments harvested during reaming can be implanted into the acetabular floor, and screws may assist fixation of the prosthesis (Fig. 13.6).

2. If the above method cannot obtain stable conditions, an inner wall osteotomy may be performed. Surgeons use the osteotome to cut a circle of about half the diameter of the inner wall and then carefully advance the central bone block into the pelvis while still keeping contact between the bone block and the acetabulum. This allows to deepen the acetabulum, preserve the bone stock of the inner wall, and obtain stable fixation (Fig. 13.7).

3. If the acetabular bone stock measured on the preoperative images is insufficient, defects are severe, and acetabular coverage is poor, autologous femoral head grafting or an appropriate type of metal augments can be used to supplement the superolateral defects (Fig. 13.8).

The femoral side reconstruction of the dysplastic hip is equally important. In this case, the offset of the femoral head can be reconstructed by using a conventional prosthesis, carefully avoiding a leg-length discrepancy. The femoral anteversion is calculated on preoperative imaging and confirmed intraoperatively. Usually, a CT measurement is used for the preliminary calculation (Fig. 13.9). If the anteversion is too large, it

Fig. 13.8 Total hip arthroplasty in developmental dysplasia of the hip in Crowe type I–II. (**a**) Preoperative radiograph show acetabular bone stock is insufficient, (**b**) Structural bone grafting is used to recover bone stock of acetabulum

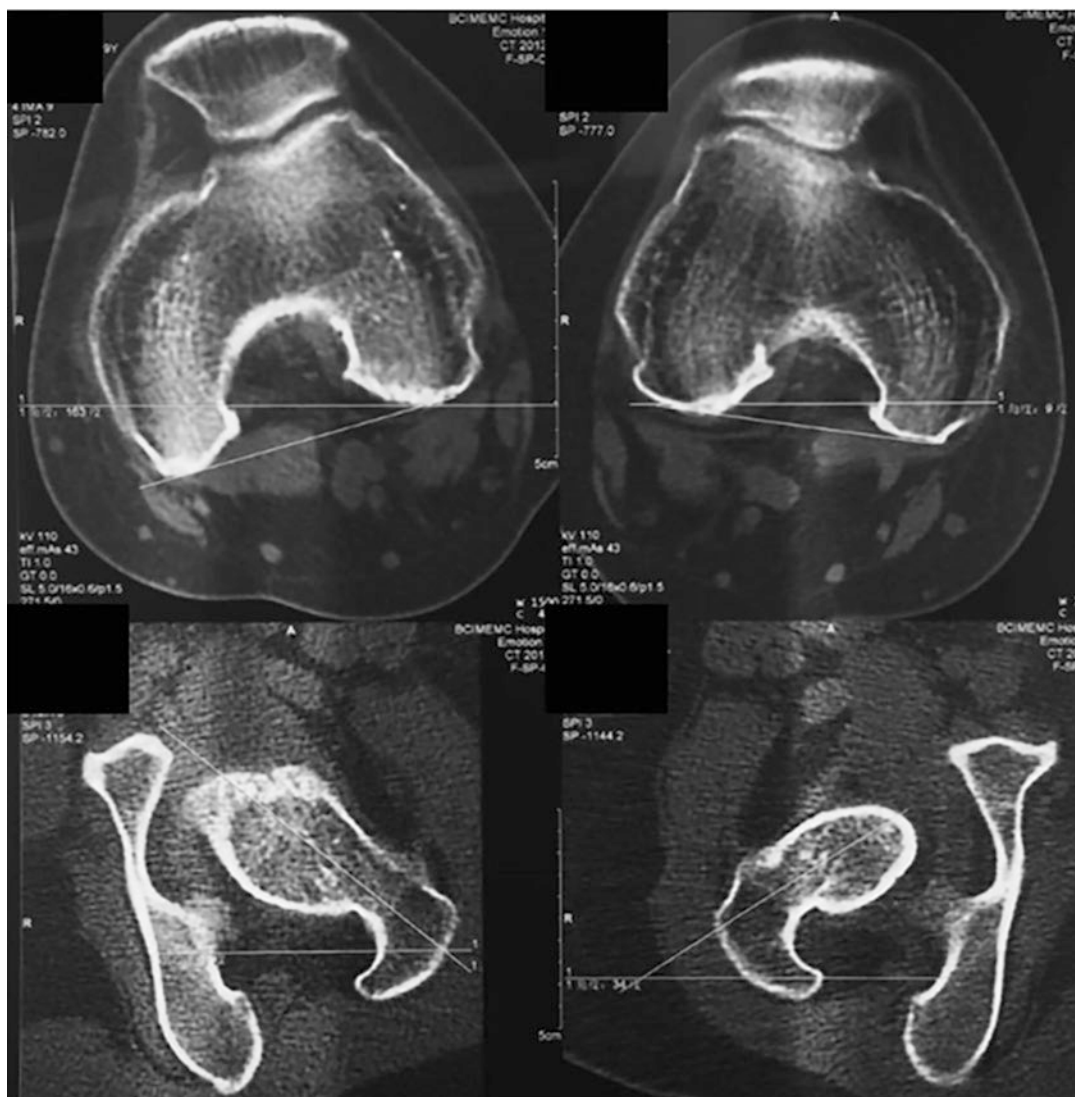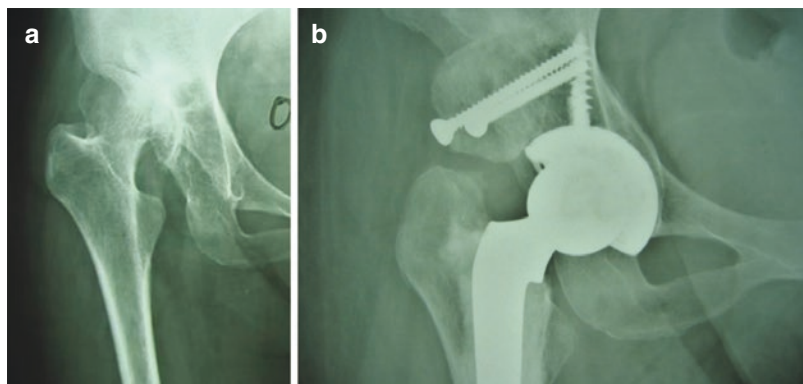**Fig. 13.9** Measurement of femoral anteversion on computed tomography prior to total hip arthroplasty in developmental dysplasia of the hip in Crowe type I–II. The line of the posterior edge of the femoral condyle was used as a reference to measure the relative Angle of the femoral neck relative to the level of the posterior edge of the femoral condyle

needs to be adjusted by using a modular prosthesis. It should be noted that the femoral anteversion calculated using CT preoperatively can be used as a reference but sometimes is not consistent with the actual anteversion measured during the operation. The reasons may be measurement errors, inaccuracy in CT, or an improper decubitus position during scanning. If the femoral anteversion is considerably increased, for example, >30°, a modular prosthesis should be used to adjust the anteversion, such as the S-ROM® prosthesis. However, in Crowe I–II, a monoblock prosthesis is usually sufficient to perform THA.

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Total Hip Arthroplasty for CROWE Type III Developmental Dysplasia of the Hip

14

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Key Points

1. Preoperative planning is critical in CROWE type III developmental hip dysplasia. Reconstructing the ideal hip rotation center will accurately restore the length of the leg.
2. A good understanding of the anatomical variations and excellent surgical technique are preconditions to ensure the success of total hip arthroplasty.
3. High-quality surgical techniques can avoid a number of complications, but patients with this type of dysplasia still have a high incidence of complications.

Developmental dysplasia of the hip (DDH) crowe type III denotes serious dysplasia, with a 75–100% subluxation and cranial displacement of the femoral head [1]. The abrasion of the acetabulum which was abnormally weight-bearing with the femoral head for years reduces its bone stock, especially in the weight-bearing area, making total hip arthroplasty in these patients relatively difficult [2, 3]. Some patients have a very rigid hip or a history of hip surgery, which renders the operation even more difficult.

In this chapter, we mainly discuss the surgical reconstruction methods in patients with CROWE III DDH.

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14.1 Surgical Technique

14.1.1 Acetabular Reconstruction

Generally, the reconstruction methods for CROWE III DDH are similar to those for CROWE I and II described in the previous chapter, and the method used in most cases is also similar. Mainly three methods are used to reconstruct the rotational center of the hip, and these are deepening of the acetabulum, inner wall osteotomy, and bone grafting [4, 5].

However, the specific features of CROWE III DDH are that the defect is more severe, and the dislocation of the femoral head is higher than what is observed in CROWE I and II DDH. Therefore, compared to CROWE I and II, the acetabular defect is larger, and a satisfactory bony coverage can frequently not be obtained [6]. Therefore, other methods need to be used to increase the bony coverage and initial stability of the acetabulum in CROWE III.

Current recommendations for the acetabulum reconstruction in CROWE III DDH still include a non-cemented acetabulum prosthesis. In patients with very limited bone mass, a multi-hole acetabulum cup with porous coating should be used for reconstruction. Screws are routinely used and absolutely indicated in these cases. Generally, if the acetabular prosthesis is relatively stable, the use of one screw is acceptable. If instability is more severe, we recommend using two or three

screws to reinforce the acetabulum and achieve good initial stability of the acetabular prosthesis.

When preparing the acetabulum, attention must be paid to protect the anterior wall. Because of the severe dysplasia in CROWE III, patients always have anterior wall defects, and it is very important to ream the acetabulum carefully and avoid damaging the anterior wall.

Regardless of the size of the defect, the acetabulum prosthesis should principally be placed in the ideal hip center [7]. In our clinical practice, we accept only a minimal cranial shift. The reconstruction method should be selected according to the size of the acetabular defect. If the defect is relatively small, no specific treatment is required. If the defect is severe it can be filled with a bone graft, usually harvested from the femoral head. If the defect extends beyond an area covering 30% of the acetabular prosthesis, we recommend using augmentation to fill the defect and firmly fix the acetabular cup. It is not recommended to use large bone blocks to fill extensive defects since these are not reliable and may cause long-term bone resorption, ultimately leading to failure of the arthroplasty.

It is common practice to choose the augment according to the size of the defect. The shape of premanufactured augments is not always appropriate because of the variety of defect sizes and shapes. Consequently, we need to either choose the correct size and appropriate type of the augment or create an augment that fits the shape, size, and location of the defect. This treatment is equivalent to designing a personalized acetabular prosthesis (Fig. 14.1). The augment and the prosthesis are connected with cement, and the augment is then fixed together with the prosthesis to the host bone with screws. In the early postoperative stage, the acetabular prosthesis stability is maintained by the screws. In the long term, bone ingrowth into the prosthesis and augment obtains lasting stable fixation.

The choice of available augment sizes is limited, and we need to pay careful attention to the augment size. It is important to avoid excessive augmentation, which will irritate the gluteus medius muscles and surrounding soft tissue, resulting in discomfort to the patient. The surgeon should test for any obvious friction intraop-

Fig. 14.1 The acetabulum augment was shown to deal with the defect

eratively after placing the augment and treat the surrounding soft tissue as needed.

In the case of augmentation and a multi-hole acetabular prosthesis, screws are needed to assist in adequate fixation. If the prosthesis is very stable, it is not necessary to limit the patient's weight-bearing activities after the operation. According to individual stability, the patient can walk under the protection of crutches after the operation.

Deepening the acetabulum and the other methods described will meet the needs of most of these patients, and only a few patients will require an augment or bone graft. Whether a bone graft or augmentation are chosen will depend on the surgeon's personal preferences and access to these methods.

14.1.2 Femur

Femoral reconstruction in DDH is also important and depends on the presentation in the individual case. Generally, two situations are distinguished:

1. Mild dysplasia of the femur with normal or slightly increased anteversion less than 30°: In this case, the height of the femoral head can be reconstructed using a conventional prosthesis. Surgeons should avoid using a high-offset prosthesis that may cause difficulties during reduction or increase the length of the leg compared to the other side [8].

2. Abnormal femoral anteversion can be evaluated by preoperative imaging (Fig. 14.2). However, any measurement using radiographs or computed tomography will have errors and needs to be confirmed during surgery [9].

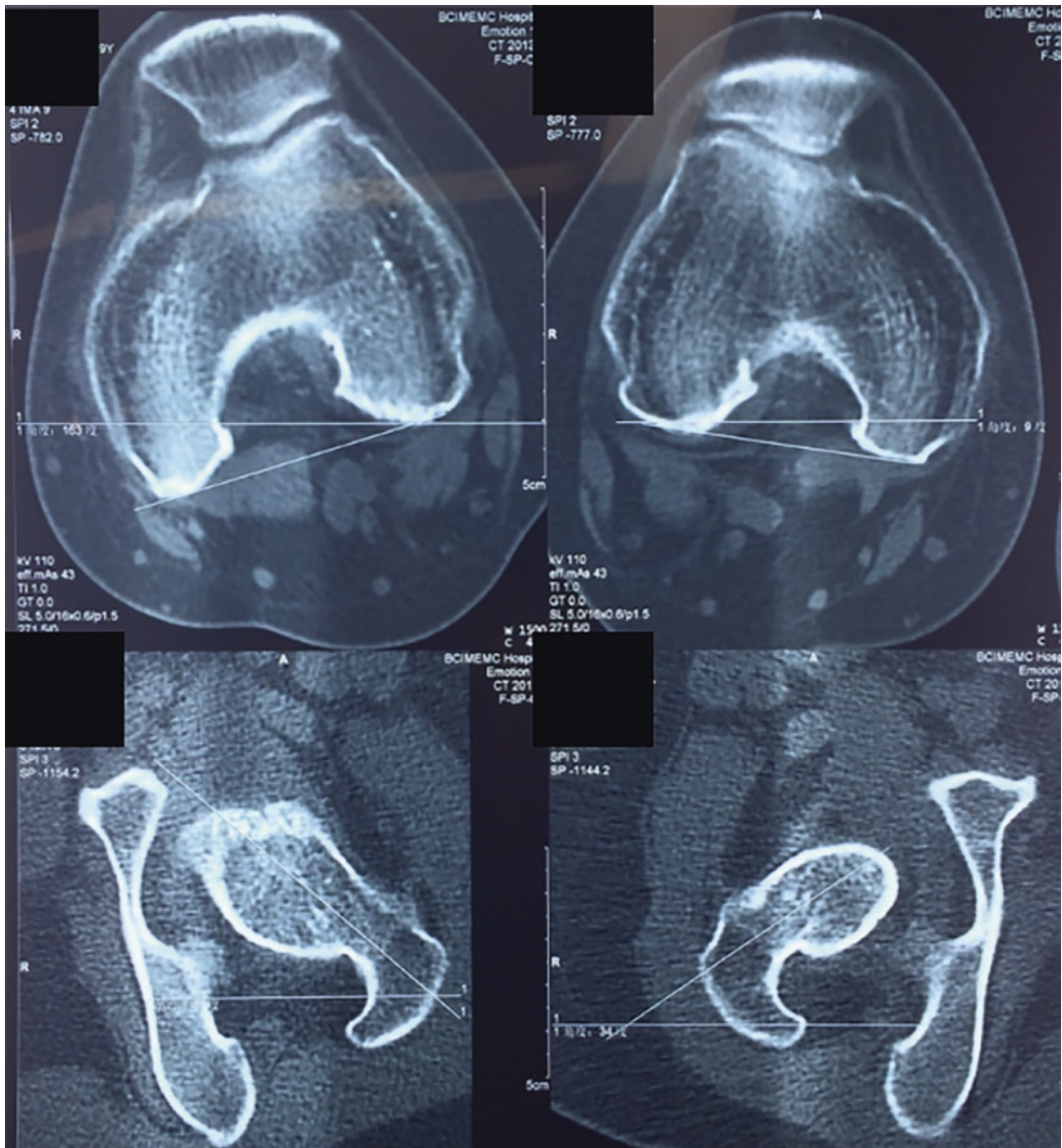In patients with a femoral anteversion of more than 30°, we recommend using a modular pros-

Fig. 14.2 The femoral anteversion angle needs to be calculated before operation, usually it can be preliminarily calculated by CT image measurement

thesis, such as the S-ROM® Modular Hip System to correct the anteversion angle.

Given that the dislocation is not very high in CROWE III DDH, the femur generally does not require a shortening osteotomy to achieve reduction [8, 10]. However, careful preoperative evaluation, especially the measurement of leg length, is needed. We usually measure the absolute leg length using a preoperative full-length radiograph. If the absolute leg length on the affected side is longer than 1 cm than that of the healthy side, we may consider a shortening osteotomy to achieve a symmetrical leg length after the operation [11].

14.2 Postoperative Rehabilitation

The rehabilitation methods for patients with DDH depend on the intraoperative situation and reconstruction method used in the individual patient. As long as the prosthesis is fixed firmly and stable, bedrest to wait for bone ingrowth is not recommended. In general, if sufficient bone has been established on the acetabular side during the operation, either in the form of an allogeneic or autogenous bone graft, patients can walk early. However, we recommend partial or no weight-bearing on the affected side. Full weight-bearing is not allowed until 6–8 weeks after surgery.

If there was no large bone defect, and the prosthesis is stable, patients can walk with weight-bearing according to the standard rehabilitation process after primary hip replacement.

Patients with DDH generally have a long history, and muscle atrophy from disuse is common. Consequently, they benefit from long-term rehabilitation after surgery to achieve normal joint function to the extent that is possible.

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Total Hip Arthroplasty in Crowe IV Developmental Dysplasia of the Hip

15

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Key Points

1. The typical abnormalities in a dysplastic Crowe IV hip include a hypoplastic and triangular-shaped acetabulum and a narrower and straighter femoral canal than that in non-dysplastic hips.
2. The altered anatomy poses a challenge to total hip arthroplasty (THA) in Crowe IV developmental dysplasia of the hip (DDH).
3. True acetabulum reconstruction is preferred, and a subtrochanteric femoral shortening osteotomy is usually needed.

The high hip dislocation in Crowe IV DDH patients poses great challenges for surgeons because the bony anatomy is severely deformed, and the surrounding soft tissue is contracted. Consequently, THA in these patients is technically demanding. Extensive soft tissue release, special implants, and subtrochanteric femoral shortening osteotomy are usually required. Detailed preoperative evaluation and planning and meticulous surgical technique are required to achieve long-term survival and satisfactory clinical results.

15.1 Anatomy

The true acetabulum in a Crowe IV hip is markedly hypoplastic because of the insufficient stress stimulation during its development. The typically triangular-shaped acetabulum often has poor bone stock and shows a small diameter and excessive anteversion. The bone deficits are mostly located anteriorly and anterosuperiorly [1]. The acetabulum is shallow, and the medial wall is less thick in Crowe IV than in the other Crowe DDH types [2]. However, the hypoplastic true acetabulum can still accommodate a small-diameter acetabular component without additional augmentation in most cases (Fig. 15.1).

The typical femoral deformities in a Crowe IV hip include a narrower and straighter femoral canal, excessive anteversion, an increased neck-shaft angle, and a more posteriorly located greater trochanter than non-dysplastic hips [3]. The proximal femur is dislocated more superiorly, and the femoral canal is narrower with a smaller canal flare index in Hartofilakidis type C2 than in type C1 (Fig. 15.2) [4].

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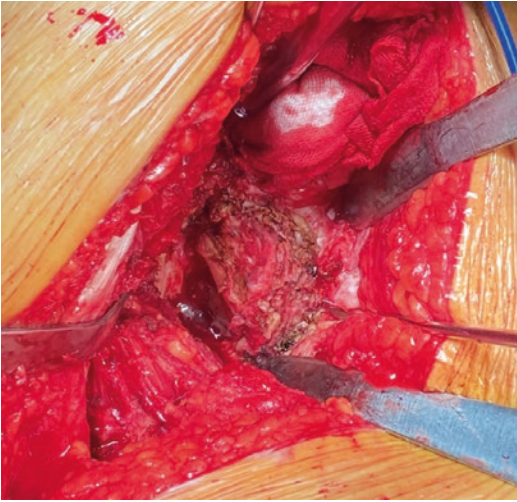
Fig. 15.1 Intraoperative view in a 41-year-old female with a Crowe IV hip dysplasia who was treated with THA. The triangular-shaped acetabulum has poor bone stock and a small diameter. The cranial part of the hypoplastic true acetabulum is covered by protruding osteophytes

Fig. 15.2 Preoperative radiograph of a 35-year-old female with a Crowe IV hip dysplasia. The femoral canal is narrow and stovepipe-shaped

15.2 Clinical Outcomes

Although satisfactory outcomes have been reported, the complication rate after THA in Crowe IV DDH is relatively high because of the characteristics of these patients, such as young age and the specific anatomic abnormalities of the hip [5, 6]. Common complications include intraoperative femoral fracture and nerve injury,

postoperative dislocation, osteotomy site nonunion, and implant loosening [7–10]. Sofu et al. [11] performed 87 THAs in patients with Crowe IV DDH. Nerve injury was observed in two hips (2.3%), femoral osteotomy nonunion in two hips (3.6%), and postoperative dislocation in six hips (6.9%). Aseptic cup loosening was seen in four hips (3.6%), and aseptic femoral component loosening in four hips (3.6%). Revision arthroplasty was performed in 12 hips. Necas et al. [12] evaluated the outcomes of THA with subtrochanteric shortening osteotomy, using the S-ROM stem for Crowe IV DDH in 28 hips. Complications were observed in seven cases (25%). Intraoperative periprosthetic fractures were observed in four hips (14.3%), whereas three hips (10.7%) required revision surgery that was due to recurrent dislocation in two hips (7.1%) and aseptic stem loosening in one case.

15.3 Surgical Technique

The patient is immobilized in the lateral position, and the pelvis is fixed firmly by posts placed against the sacrum and pubic symphysis. The posterior approach is preferred. The longitudinal incision extends more distally than usual, as the femur is cranially displaced, and subtrochanteric osteotomy is often needed. The skin and subcutaneous fat layers are incised successively. The deep fascia is dissected proximally between gluteus maximus and tensor fascia lata, the muscle fibers are separated bluntly, and the iliotibial band is dissected distally. The short external rotators are exposed and detached before the joint capsule is exposed and capsulotomy is performed.

Femoral neck osteotomy is performed according to preoperative planning. The thickened and elongated superior capsule is resected, while the anterior capsule should be retained as much as possible to maintain anterior stability. A part of the posterior capsule is reserved for capsule repair. A Hohmann retractor is placed against the anterior wall of the acetabulum to pry the proximal femur anteriorly, and the true acetabulum is identified by tracing the pedicle of the joint cap-

sule. The constricted inferior capsule is dissected, and another retractor is placed under the obturator margin of the acetabulum. Consecutively, a Steinmann pin is placed anterosuperiorly to the acetabulum and another one into the ischium to fully expose the acetabulum.

15.3.1 Acetabular Reconstruction

After resection of the remaining labrum, the entire rim of the acetabulum is exposed. In most instances, the anterior wall is thin and the posterior wall is relatively thick. The sclerotic osteophyte covers the upper margin of the true acetabulum and should be removed to expose the cotyloid fossa. Acetabulum reaming starts slightly backward using the smallest reamer. The acetabulum should be reamed to the inner floor. Then the acetabulum is further enlarged, carefully avoiding over-reaming of the anterior and posterior walls. Reverse reaming is often needed to preserve cancellous bone while enlarging. The true acetabulum can accommodate a small-diameter cementless acetabular component with adequate press-fit in most cases. After that, the acetabular component is additionally fixed with screws to achieve primary stability (Fig. 15.3).

15.3.2 Femoral Reconstruction

A S-ROM modular stem is routinely used for femoral reconstruction in Crowe IV hips. A subtrochanteric femoral shortening osteotomy is needed if more than 4 cm of leg-lengthening is expected or if the reduction is too tight. The first step of femoral preparation is distal reaming to achieve cortical contact. This is followed by proximal and calcar reaming to accommodate the metaphyseal sleeve. Subsequently, trial sleeve and stem are inserted into the femur with proper anteversion, and trial reduction is performed.

The surrounding soft tissue is contracted in Crowe IV hips, often hindering trial reduction even after extensive soft tissue release. In that case, a subtrochanteric femoral osteotomy is performed about 2 cm distal to the sleeve. Then, the stem trial is reinserted into the proximal femur, and trial reduction is performed. The distal femur is pulled distally to measure the length of the overlap between the proximal and distal femur parts. The distal femur is then shortened by 1 cm less than that length. The femoral trial stem is reinserted through the proximal femur into the distal femoral canal. Trial reduction is attempted again, and soft tissue tension and joint stability are evaluated. If trial reduction fails, or the sciatic

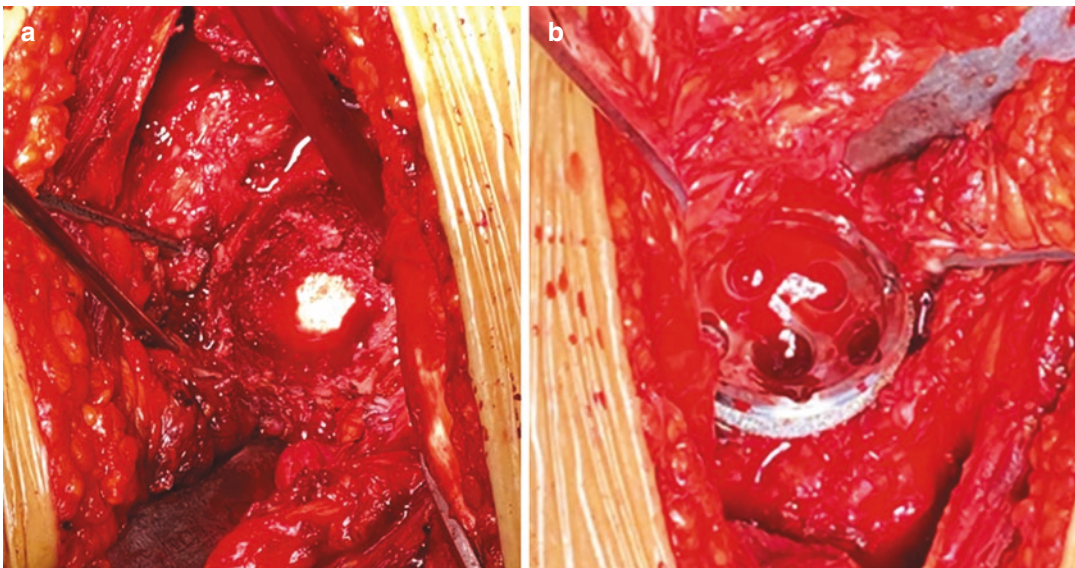**Fig. 15.3** Intraoperative view during total hip arthroplasty in Crow IV. (**a**) The acetabulum is enlarged, carefully avoiding over-reaming. (**b**) A small-diameter cementless acetabular component is implanted with adequate primary stability

nerve bundle is too tight, more bone may need to be resected from the distal femur.

Before prosthesis implantation, the stem-canal fit and torsional stability are carefully checked. Prophylactic cerclage can be used on the proximal and distal fragments to prevent intraoperative fractures. The prosthetic sleeve is impacted into the metaphysis, and the stem component is tapped into the femoral canal with proper anteversion until it fully seats into the sleeve and the osteotomized fragments are in direct contact. The resected femoral bone fragments may be reimplanted around the osteotomy to promote bone healing. After joint reduction, joint stability throughout the full range of motion should be ensured (Fig. 15.4).

Fig. 15.4 Radiograph after THA in a patient with Crowe IV DDH. Intraoperatively, a subtrochanteric femoral shortening osteotomy was performed distal to the sleeve. A prophylactic cerclage was used on the distal fragment to prevent an intraoperative fracture. The resected femoral bone fragments were reimplanted around the osteotomy

15.4 Challenges During THA in Crowe IV DDH

Several major challenges are faced when performing THA in Crowe IV DDH. Owing to the poor bone stock and small true acetabulum, acetabular reconstruction is difficult. A high hip center reconstruction presents an alternative choice and is theoretically less technically demanding. However, the most abundant bone stock is located around the true acetabulum, especially in the posterior column. The ischium, pubis, and the superior posterior bone provide good primary stability. High placement of the socket means less cup coverage and less dependable bone support. A high hip center increases the risk of cup loosening and hip dislocation as it increases the acting force on the hip and decreases the safe range of motion [13–15]. Therefore, the high hip center reconstruction results in less favorable clinical results and decreases long-term implant survival. Thus, true acetabulum reconstruction should be performed whenever possible.

Another common error in acetabular reconstruction is the over-reaming of the acetabulum to enable the use of a cup with a larger diameter than that of the true acetabulum. Inadequate stress stimulation of the true socket during skeletal development and after skeletal maturity almost always results in a small and osteoporotic acetabulum. Over-reaming leads to further bone loss thus weakening the primary stability of the prosthesis. Reverse reaming is often required during the deepening of the acetabulum to preserve as much bone stock as possible, and a small-diameter acetabular component (38–44 mm) is usually selected in Asian patients. Supplementary screw fixation is obligatory to guarantee the stability of the acetabular component. Chu et al. [16] described the outcomes of cementless THA for Hartofilakidis type C DDH in 48 patients. True acetabular reconstruction was performed in all cases. Postoperatively, one dislocation occurred and was successfully treated with closed reduction. No cup loosening or other major complications were observed.

True acetabular reconstruction in Crowe type IV DDH results in a relatively lower hip center and considerable leg-lengthening compared with the preoperative situation, which may lead to difficulties in hip reduction and risk of sciatic nerve injury. Therefore, subtrochanteric femoral shortening osteotomy is often necessary to facilitate joint reduction and nerve protection while preserving the proximal femoral anatomy [7]. The narrow and straight femoral canal limits the implant selection for femoral reconstruction. A modular metaphyseal sleeve femoral stem is preferred since the modular design accommodates the metaphyseal and diaphyseal mismatch of the femur and helps to achieve press-fit in the proximal metaphysis and rotational stability in the femoral diaphysis. Furthermore, surgeons need to consider the morphological differences between Hartofilakidis type C1 and C2. Patients with type C2 hip may require more non-sprouted sleeves and thinner stems, and require more extensive shortening of the femur compared with type C1 [17].

15.5 Summary

The severe deformation of the acetabulum and femur makes THAs in Crowe type IV DDH patients considerably more difficult than conventional primary THAs. Meticulous preoperative planning and flawless surgical technique are prerequisites for successful THA in this situation. High hip center acetabular reconstruction and acetabular over-reaming should be avoided. Subtrochanteric femoral shortening osteotomy with a modular metaphyseal sleeve stem is needed in most instances for femoral reconstruction.

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Total Hip Arthroplasty After Previous Periacetabular Osteotomy

16

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Key Points

1. The radiographic examinations are necessary to perform a comprehensive preoperative evaluation and preparation.
2. Extensive soft tissue release, extended trochanteric osteotomy may be required in some patients to avoid unnecessary tissue damage and facilitate the exposure of the acetabulum.
3. We recommend a posterolateral approach to reduce the complexity of exposure.
4. The specific abnormalities of the bony structures determine the selection and correct positioning of the components.
5. The proximal femoral periprosthetic fracture is the most common intraoperative complication.
6. Leg-length differences (LLD), stiffness, and limping were the main postoperative complaints.

Developmental dysplasia of the hip (DDH) is recognized as a major cause of pain and activity limitations that predispose patients to early age arthritic changes [1]. Symptomatic patients with DDH may benefit from joint-preserving procedures. Periacetabular osteotomy (PAO) repositions the acetabulum to improve the articular cartilage coverage of the femoral head [2]. It may optimize the anatomic and biomechanical rela-

tionships between the acetabulum and femoral head, improving pain and function in the majority of these patients [1, 3].

The efficacy of pain relief PAO has been proven in several mid- and long-term studies [4, 5]. However, more than 70% of patients develop progressive osteoarthritis after PAO and 60% of patients undergo total hip arthroplasty (THA) or other procedures to relieve pain and improve joint function.

In the knee, previous surgery to preserve the joint has been shown to compromise the results of subsequent total knee arthroplasty [6–8]. Different from those studies about knee preserved surgery, the clinical outcomes of THA after PAO were proven to be similar to those in patients without prior osteotomy [9–11]. The complexities inherent in THA for these patients, especially aspects of intraoperative tissue preservation and appropriate prosthesis selection, were not sufficiently addressed by previous studies [9, 10], and the reasons for patients' postoperative complaints were not analyzed thoroughly.

Consequently, we reviewed the clinical and radiographic outcomes of the patients who underwent THA after PAO at our institution, with particular attention to the intraoperative details. In this chapter, we aim to address the following points: (1) How to perform a comprehensive preoperative evaluation and preparation in patients scheduled for THA after PAO? (2) How can we achieve proper exposure and choose the right

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approach? (3) Prosthesis selection and implantation; (4) Intraoperative damage control and perioperative complications; (5) Main postoperative complaints.

16.1 Preoperative Evaluation and Preparation

Accurate and timely diagnosis, comprehensive preoperative evaluation, use of the most appropriate procedures and techniques, and adequate surgical skills can achieve satisfactory clinical outcomes of THA after PAO.

The course of DDH after PAO can mostly be evaluated and classified according to the system described by Crowe [12] for DDH (Fig. 16.1).

However, as a consequence of the complex changes after PAO, some cases may only be described as "unclassifiable."

Radiography and computed tomography (CT) are the commonly used medical imaging examinations in this situation. We perform a detailed physical examination to be able to anticipate any difficulties associated with exposure intraoperatively. Almost 30% of the patients at our hospital showed a retroverted acetabulum and an abnormal femoral neck anteversion angle on preoperative CT scans.

The details of the exact surgical technique used during PAO and the radiographic examinations described above [13, 14] are helpful to perform a comprehensive preoperative evaluation and preparation.
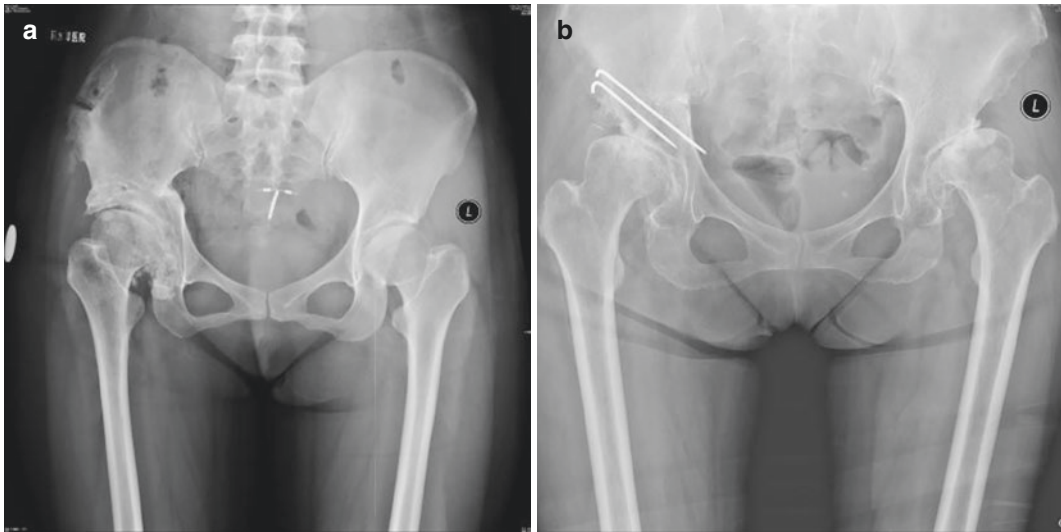
Fig. 16.1 The Crowe classification of developmental dysplasia of the hip (DDH) after periacetabular osteotomy. (**a**) DDH Crowe type I; (**b**) DDH Crowe type II; (**c**) DDH Crowe type III; (**d**) DDH Crowe type IV; (**e**) Unclassifiable
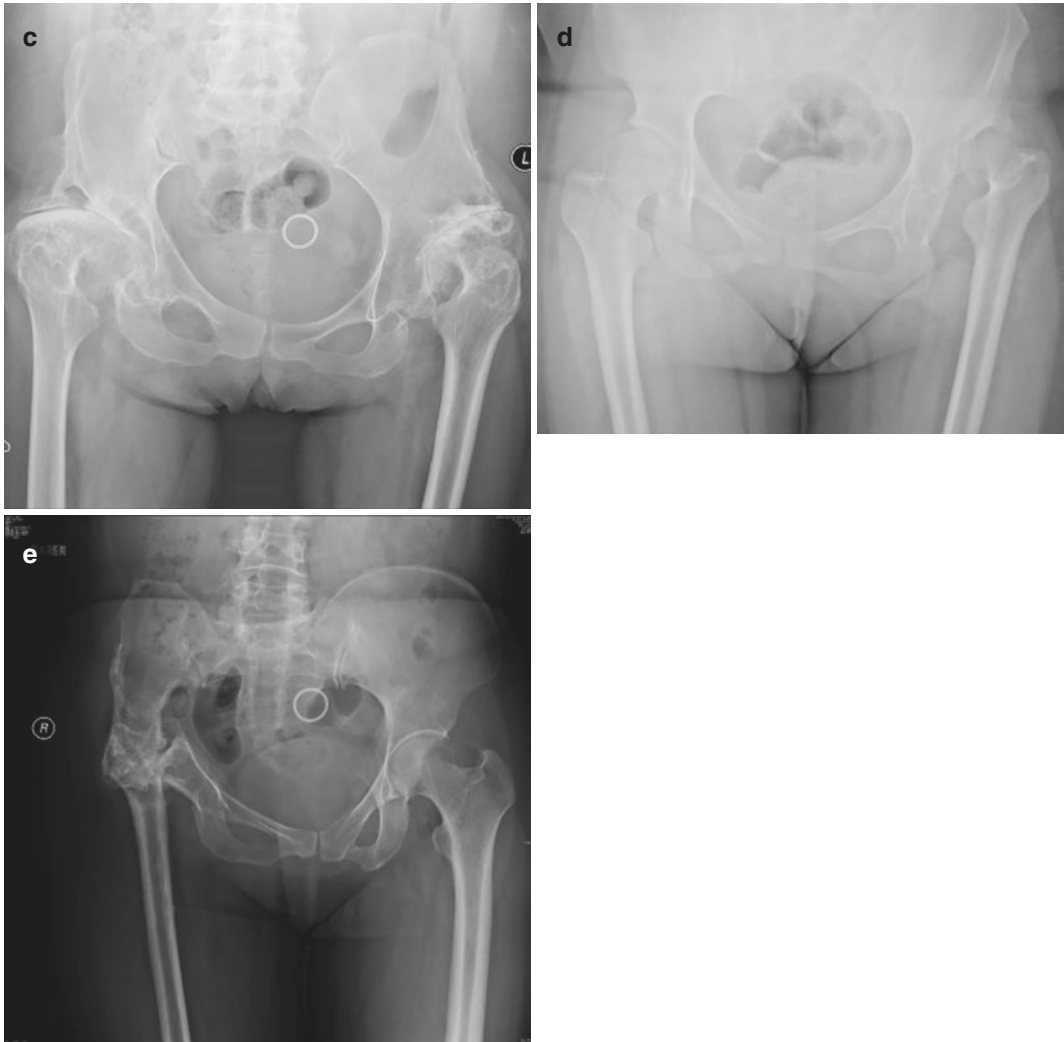
Fig. 16.1   (continued)

16.2   Exposure and Approach

Intraoperatively, difficulties in adequate exposure and the substantial variation in the anatomical structures may present substantial challenges for surgeons. After PAO, some hips may be extremely difficult to expose and show various degrees of dislocation because of abnormalities of the bony structures and dense scar tissue. We recommend a posterolateral approach to reduce the complex-ity of exposure. Extended trochanteric osteotomy may be required in some patients to avoid unnec-essary tissue damage and facilitate the exposure of the acetabulum. We also perform an extensive soft tissue release, such as the release of the glu-teus maximus insertion, gluteus minimus muscle, and capsule, in almost 60% of cases. Adductor tenotomy is not necessary for most patients because it has frequently been performed during PAO.

16.3 Prosthesis Selection and Implantation

Prosthesis selection and implantation present another technical challenge during THA in these patients. As mentioned above, almost 30% of patients at our hospital showed a retroverted acetabulum and an abnormal femoral neck anteversion angle on preoperative imaging, which was usually confirmed during the intraoperative exploration. The specific abnormalities of the bony structures determine the selection and correct positioning of the components. Preoperative CT scans of the proximal femur and acetabulum on both sides play an important role in recognizing the complex anatomy of the hip. Careful comparison with the normal contralateral hip will help prevent malpositioning of the acetabular component. Robot-assisted surgery is becoming increasingly popular in cases with extremely complicated periacetabular deformities and deficiencies. Augmentation to reconstruct the acetabulum is not necessary in most patients, even in those with severe deformities of the posterior acetabular wall or Crowe III. Sufficient cranialization of the rotation center and an appropriate size of the acetabular component may achieve better coverage and stability of the prosthesis. A trabecular metal acetabular cup is a recommendation in cases with periacetabular deformity and deficiency.

Some of our patients showed evidence of subtrochanteric osteotomy performed at the time of PAO. Malunion, stenosis of the medullary cavity, and an abnormal femoral neck anteversion angle are typical observations in these cases. Without sufficient broadening of the medullary canal in the stenotic area, malposition or overfitting of the femoral component may occur. Sometimes, we use a local osteotomy to improve malalignment or correct the stenosis. A wedge-shaped osteotomy may be a better choice in cases of proximal femoral malunion compared to transverse osteotomy. A tapered or modular femoral prosthesis is an appropriate option to achieve optimal matching, decrease the fracture risk, and correct the femoral torsion.

16.4 Intraoperative Damage Control and Perioperative Complications

The abnormal periacetabular structure and the need for extensive soft tissue release result in high blood loss and transfusion rates and long operation times in patients undergoing THA after PAO [10]. In our view, careful evaluation of the abnormal bony structures and proper soft tissue release remain the best way to reduce tissue damage during surgery and the risk of preoperative infection. A proximal femoral periprosthetic fracture was the most common intraoperative complication in our patients and had to be fixed with wires or plates. Medullary canal stenosis, proximal femoral malunion or deformity, and periacetabular soft tissue tension are risk factors for an intertrochanteric fracture.

We did not observe a higher dislocation risk in our patients after PAO than after the common THAs. The main problems we observed during revision are instability caused by soft tissue release and component malposition. However, excessive soft tissue release may decrease soft tissue tension and increase the risk of dislocation [11, 15, 16], even if the components are correctly positioned.

16.5 Main Postoperative Complaints

Based on the functional and radiological data in previous studies [4, 5], patients who have undergone PAO can achieve acceptable clinical outcomes of THA. Leg-length differences (LLD), stiffness, and limping were the main postoperative complaints that showed different degrees of relief during long-term follow-up. A subtrochanteric osteotomy performed because of difficult component reduction or proximal femoral deformity are risk factors for LLD. Moving the hip rotation center cranially to achieve better coverage and stability of the prosthesis as well as malpositioning of components may also induce LLD [17]. Furthermore, some patients complained of

LLD without showing significant radiographic discrepancies. The perceived LLD in the patients in this series may be transient and partially resolve from the second postoperative year. Joint stiffness is mainly induced by a tightness of the periacetabular soft tissue or postoperative immobilization. Only rarely, patients complain of substantial stiffness.

Therefore, we intend to pay more attention to controlling soft tissue tension intraoperatively and avoiding long-term immobilization in the future. Different degrees of postoperative limping were observed in 33% of patients in our series, which may be the consequence of previous periacetabular osteotomies, excessive soft tissue release, and LLD [15, 17, 18].

Previous studies have shown that THA can be performed with acceptable outcomes and improvement in functional scores in most DDH patients after PAOs [4, 5, 9]. However, the technical challenges in our patients during THA with PAO may lead to more blood loss and higher blood transfusion rates, prolonged operation times, and higher complication and revision rates than those without. Careful evaluation of the abnormality of the acetabular and proximal femoral anatomy, tissue preservation, and appropriate prosthesis selection are key to achieving acceptable outcomes.

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Total Hip Arthroplasty in Hip Ankylosis

17

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Key Points

1. Hip replacement in patients with hip ankylosis is a major challenge for joint surgeons because of the severely limited range of motion, poor soft tissue compliance, weak abductors, muscle imbalance, and a high risk of perioperative complications.

2. In hip joint ankylosis, contamination of the surgical site during disinfection and draping is more likely than in routine hip replacements. Both legs should be disinfected at the same time.

3. During the cutting of the femoral neck in situ, injury to the normal acetabular bone, especially the anterior acetabular wall, should be avoided. If neck exposure proves difficult, sliding or extended osteotomy of the greater trochanter can be considered.

4. Considering the retroversion of the pelvis and the relative hyperextension of the hip joint postoperatively, the cup should be placed with a relatively small anteversion to avoid posterior impingement and anterior dislocation.

17.1 Introduction

Hip ankylosis refers to a fusion of the hip joint with a limited range of motion. Hip replacement in this situation is a major challenge for joint surgeons because of the severely restricted hip motion, poor soft tissue compliance, weak abductors, muscle imbalance, and high risk of perioperative complications. Hip stiffness can be caused by a number of factors, including previous infection, surgery, or trauma, heterotopic ossification, ankylosing spondylitis, rheumatoid arthritis, and severe osteoarthritis. Any hip replacement in these patients requires careful management throughout the entire perioperative period, including preoperative preparations, intraoperative body position, anesthesia, disinfection and draping, and surgical approach and technique [1, 2].

17.2 Perioperative Management

The preoperative examination must evaluate the patient's physical condition, nutritional status, and fitness for surgery. For patients with specific diseases, such as inflammatory joint disease, attention should be paid to their medication to establish whether it needs to be adjusted and how well it controls the disease. Consulting with a specialist is recommended when necessary. Furthermore, discussing the risk and optimal method of anesthesia with the anesthesiologist

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preoperatively is essential. Furthermore, since the physical activity and ability to be mobilized are limited in these patients, and they might have been confined to the bed for long, it is important to examine the skin condition to identify potential sores and other issues [2].

Furthermore, in patients with spinal deformities, such as ankylosing spondylitis, anesthesia is difficult, and the pre- and intraoperative management should be carefully planned by an anesthesiologist [3].

The abductors can be assessed by palpating the muscles during contraction when asking the patient to elevate the leg in the lateral decubitus position. Furthermore, preoperative ultrasound may help to evaluate their volume. Previous surgical history around the abductors may indicate poor abductor function and a high risk of postoperative dislocation.

Most ankylosed hips can be reconstructed with cementless stems, except in cases where the femur is extremely osteoporotic. In patients with stove-piped femoral canals, cementless distal fixation stems instead of porous-coated proximal fixation stems should be considered.

Evaluation of the spine and pelvic-femoral sagittal balance is important in patients with significant spinal deformities. Patients with ankylosing spondylitis and obvious kyphosis of the fused lumbar spine are common. Both the pelvis and lumbar spine in these patients have lost their mobility and lost their ability to compensate for the limited hip range of motion, which may result in posterior impingement and anterior instability after hip replacement. Therefore, these patients require consultation with spine surgeons to discuss the optimal treatment strategy, including the order of spine and hip surgery.

It is important to evaluate the characteristics of hip ankylosis in the individual patient as it relates to intraoperative positioning, surgical approach, disinfection, and draping. The posterior approach may be considered if the patient has a hip contracture and internal rotation deformity, and the anterior approach may be considered if the patient has restricted extension and external rotation.

17.3 Intraoperative Patient Positioning and Surgical Technique

The commonly used approaches are the posterior approach, anterior approach, or combined approach with one incision. As described, the optimal surgical position should be adopted according to the characteristics of a patient's ankylosis. If the patient has a hip contracture and internal rotation deformity, the posterior approach can be considered, and a lateral decubitus position can be adopted. If the patient has restricted extension and external rotation, the anterior approach can be considered, and the supine position can be adopted.

In patients with severe scarring and adhesions around the previous infected hip joint, two approaches though one incision can be considered, and part of the Harding approach is adopted [4, 5].

It should be noted that the contralateral hip and spine should be appropriately supported and padded during patient positioning, as any stress concentration in these areas resulting from inappropriate positioning may easily lead to fractures.

In hip joint ankylosis, especially with a severely limited range of motion, contamination of the surgical site during disinfection and draping is more likely than during routine replacements. It should be considered to disinfect both lower extremities at the same time. The range of motion of the hip usually improves after femoral neck osteotomy. This is an opportunity to recheck the draping and, if necessary, repeat the disinfection and optimize the draping.

Normally, after exposure of the neck of the femur, wedge bone cutting helps to achieve free movement of the lower limb. Surgeons should carefully protect the sciatic nerve during exposure. Particular attention should be paid to avoid injury to the normal acetabulum bone, especially the anterior acetabular wall, during the cutting of the femoral neck in situ. For patients with a short femoral neck or femoral head invagination, exposing the neck of the femur is difficult, and

there might not be enough space to cut the bone safely. In these situations, the surgeon can consider a sliding greater trochanter osteotomy or extended greater trochanter osteotomy [6, 7].

If the femoral head is fused with the acetabular bone or it is difficult to remove the femoral head, direct acetabular reaming can be considered. It is particularly important to have optimal surgical field exposure. Under normal circumstances, careful observation can identify the boundary of the anatomical edge of the acetabulum. During reaming, the surgeon should pay attention to the residual bone at the acetabular anterior and posterior walls to avoid excessive reaming. In ankylosing spondylitis, bone fusion of the hip joint is clinically common. In most cases, a trace of the oval fossa (with fat filling) can still be found when the acetabulum is reamed to a sufficient depth, and this will help to determine the inner wall of the acetabulum. If the bony acetabulum is particularly difficult to locate, intraoperative fluoroscopy can be used [8].

For patients with a longstanding hip joint ankylosis, the gluteus medius muscle is often weak, and the bone in the greater trochanter may be osteoporotic. Therefore, adequate exposure and gentle operation technique are warranted to protect these structures during surgery. Considering the retroversion of the pelvis and the relative hyperextension of the hip joint postoperatively, the cup should be placed with a relatively small anteversion to avoid posterior impingement and anterior dislocation.

17.4 Postoperative Management

Individual rehabilitation plans are made according to the details of the operation performed, including when to ambulate with weight-bearing and when to start muscle function rehabilitation.

In addition, these operations are often difficult and time-consuming. If the patient has comorbidities, such as rheumatic immune disease, the risk of postoperative infection is relatively high. Therefore, the prophylactic use of antibiotics should be discussed with the pharmacy physician [2].

In conclusion, total arthroplasty in hip ankylosis is relatively difficult. Therefore, it is critical to pay adequate attention and optimize all relevant factors during the perioperative period. In terms of the surgical technique, adequate exposure is particularly important, and meticulous care should be taken to protect important anatomical structures such as the sciatic nerve, gluteus medius muscle, and greater trochanter.

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Total Hip Arthroplasty After Hip Fracture

18

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Key Points
1. Total hip arthroplasty (THA) after a hip fracture is a challenging procedure.
2. During surgery, the problems mainly include poor exposure, hardware interference, abnormal anatomy around the hip joint, and poor bone quality.
3. Compared to patients with nontraumatic arthritis, patients with prior hip fractures show inferior clinical results and more complications after THA.

Hip fractures comprise acetabular fractures, femoral neck fractures, and intertrochanteric fractures. The incidence of hip fractures in China continues to increase with the rise in traffic injuries and the growing aging population. Although the success rate of hip fracture treatment has improved with the use of advanced surgical techniques in recent years, the proportion of patients who experience treatment failure and require further interventions remains high.

The main reasons for fracture treatment failure include posttraumatic arthritis, osteonecrosis of the femoral head, nonunion of the fracture, and internal fixation failure. In a large meta-analysis of 3670 acetabular fractures, the most common long-term postsurgical complication after open

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reduction internal fixation was posttraumatic arthritis (20%) [1]. The rate of osteonecrosis of the femoral head was 5.6%. In another study, the incidence of posttraumatic arthritis after prior acetabular fractures ranged from 10% to 60% and the incidence of femoral head osteonecrosis from 3% to 53% [2]. According to a systemic review, avascular necrosis occurs in 10%–45% of patients with femoral neck fractures [3]. Nonunion occurs in almost 20% of femoral neck fractures and is more common in elderly patients [4]. Intertrochanteric fractures are common in the elderly with poor bone quality, and their treatment is problematic because of the high failure rates of internal fixation. Nordin et al. [5] reported a failure rate of <16.7% (10/60) when patients with intertrochanteric fractures were treated with a dynamic hip screw (DHS). Kim et al. [6] reviewed 178 intertrochanteric fractures treated with DHS and found that 27.5% had radiographic failure. In unstable fractures in patients with osteoporosis, the failure rate was more than 50%. Reoperations were required in 8.3% of patients with intertrochanteric fractures who were treated with a percutaneous compression plate in another study [7]. Liu et al. [8] reported that 7% of patients treated with proximal femoral nail antirotation for intertrochanteric fractures underwent reoperations.

As one of the most established procedures in orthopedic surgery, THA may be an effective treatment for patients with posttraumatic arthri-

tis, osteonecrosis, nonunion, malunion, or failure of the fixation after the treatment of prior hip fractures. However, conversion THA after failed treatment of hip fractures is usually more difficult than primary THA in nontraumatic arthritis. According to the literature, THA after hip fractures, especially after acetabular fractures, often yields inferior results and has a higher complication rate than THA in nontraumatic disease. In a systemic review [9], 238 THAs in patients with posttraumatic arthritis after acetabular fractures were analyzed. After an average follow-up of 82 months, the Harris Hip Score (HHS) had improved from 41.5 preoperatively to 87.6. The median postoperative overall complication rate was 10.2% across three of the studies analyzed. The most common clinically significant complication was implant loosening, which varied from 2% to 24% in five studies. The median 10-year survival rate was 84% in five studies. In contrast, the 15-year cumulative revision rate of THA for osteonecrosis was 6.6% and the median HHS was 93 after 10 years in another study [10].

In this section, we focus on the preoperative preparation, surgical techniques, and postoperative rehabilitation in conversion THA after prior hip fractures. We also present the complications and outcomes of these procedures.

18.1 Preoperative Evaluation

18.1.1 Exclusion of Joint Infection

Since most patients with prior hip fractures were treated with surgery initially, the erythrocyte sedimentation rate and C-reactive protein level should be obtained to rule out infection. If these are elevated, preoperative aspiration of the hip joint may be necessary. Triple-phase bone scanning may be useful to exclude infection of the joint. When joint infection is confirmed, debridement and hardware removal should be performed first. A staged THA may be performed 6–12 weeks after the joint infection has been cleared.

18.1.2 Physical Examination

The physical examination begins with an inspection of the patient's gait that should include the presence of an antalgic gait or Trendelenburg gait and the use of assistive devices. The wound should be inspected for any evidence of infection or delayed healing. The location of the wound should be documented because wound healing may be affected when the prior incision is located within the THA approach. In patients with hardware involving the greater trochanter, palpation over the trochanter may identify prominent hardware and pain, for example, in the case of trochanteric bursitis. Compared to patients with primary osteoarthritis, patients with prior hip fractures usually have a smaller hip range of motion because of previous immobilization or surgery. We test the passive hip range of motion in the supine position and document the degrees of extension, flexion, abduction, adduction, internal rotation, and external rotation. Abductor function is particularly important and is assessed with the patient actively abducting the limb against the resistance exerted by the examiner. The abductor function is assessed in grades from 0 to 5. Limb length from the anterior superior iliac spine to the medial malleolus should be measured bilaterally and documented. Significant limb shortening often occurs in patients with untreated femoral neck fractures.

Symptoms of sciatic nerve damage should be noted and documented, especially in patients with prior acetabular fractures. In our clinical experience, the sciatic nerve is more likely to be secondarily damaged during THA when it was damaged in previous operations for acetabular fractures.

18.1.3 Radiographic Analysis

Radiographic analysis prior to surgery is important. It is helpful in selecting the optimal implant, instrument preparation, template measurement, and assessing the prognosis. An anteroposterior view of both hips and the frog-leg lateral view of each hip are necessary. The frontal view of the entire lower limb is helpful in measuring a potential leg length discrepancy. The obturator oblique view is used to evaluate the anterior column and posterior acetabular rim, and the iliac oblique view is used to evaluate the posterior column and anterior acetabular rim. Computed tomography is useful to (1) determine the state of fracture healing, (2) establish the relationship between the hardware and the articular surface or femoral canal, and (3) evaluate the location and degree of any bone defects. Magnetic resonance imaging is mostly unnecessary.

18.2   Implant Selection and Instrument Preparation

The implant selection in patients with prior hip fractures depends on several factors, including patient age, physical condition, prior surgical history, location or type of the fracture, bone quality, and severity of bone defects.

On the acetabular side, a highly porous cementless acetabular component is generally recommended. A multi-hole cup with a highly porous coating surface can be used when full stability is difficult to achieve initially because of insufficient host bone contact or poor bone quality. Augments may be needed when a patient has significant acetabular bone defects. In patients with pelvic discontinuity, the acetabular distraction technique proposed by Sporer et al. [11] is often useful, and an acetabular distraction clamp should be prepared in advance. If the patient is considered to be at high risk of dislocation, a constrained liner can be prepared.

On the femoral side, the component can be cemented or cementless. At our institute, mostly cementless femoral components are implanted because we believe that cementless femoral reconstruction achieves superior outcomes, provided that appropriate components are selected. For patients whose femoral canal was not involved in the fracture (e.g., nonunion of a femoral neck fracture), a regular proximally fixed cementless stem is suitable. Even in patients with severe osteoporosis, a single wedge cementless stem is a reliable choice (Fig. 18.1a, b). However, in patients with prior intertrochanteric fractures, we often choose a distally fixed cementless stem because a proximally fixed stem is unsuitable in malunion or nonunion of the proximal femur (Fig. 18.2a, b). We prefer modular distally fixed cementless femoral stems such as the Restoration® Modular Stem (Stryker Corporation, Kalamazoo, MI, US) because modular femoral stems fit both the proximal and distal canal. Wires, cables, or a cable plate system should be prepared if extended trochanteric osteotomy or internal fixation is foreseen. Allogenic cortical struts could be used if there are significant bone defects in the proximal femur. Although not all hardware should be removed, we always prepare matched removal tools for patients with hardware in situ. Tungsten burs that can cut screws or plates are sometimes necessary.
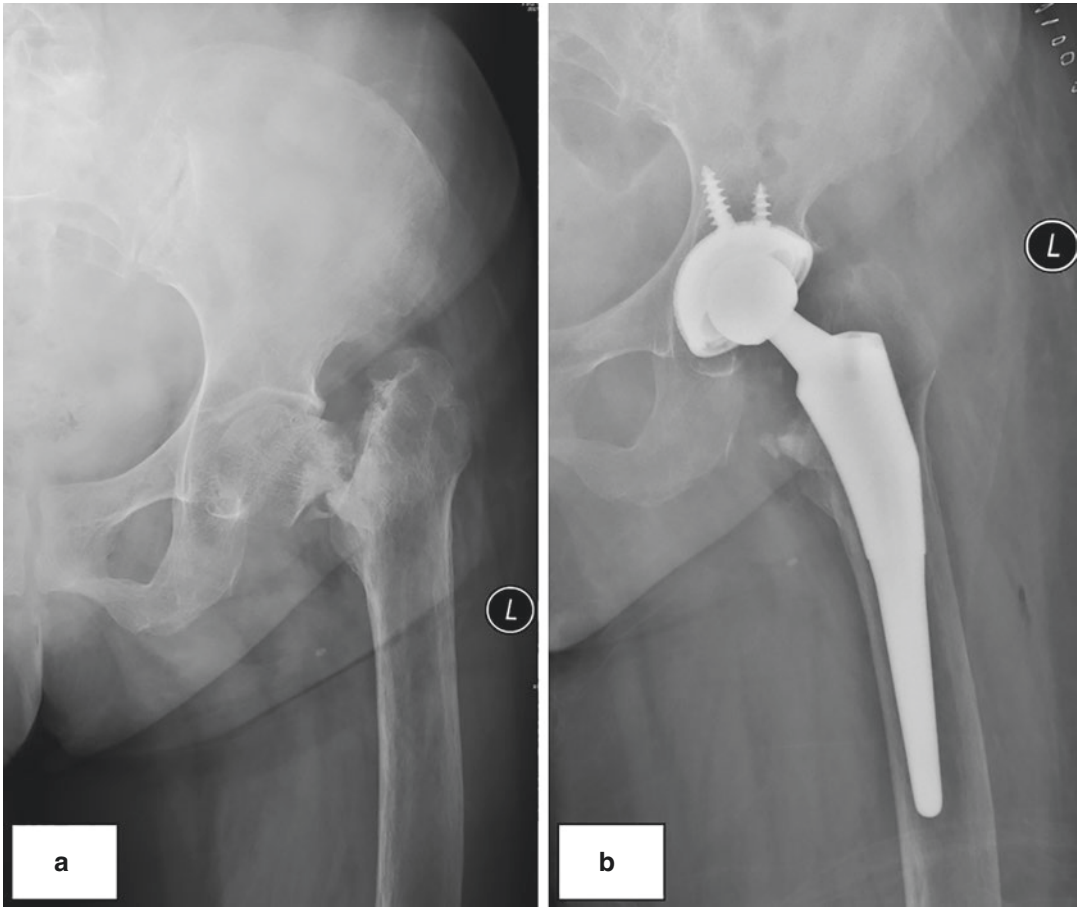
Fig. 18.1 (**a**) A 63-year-old lady suffered from pain and disability of the left hip since untreated femoral neck fracture. The radiography showed a Dorr C-type femoral canal on the left side. (**b**) A single wedge cementless femoral stem was implanted with excellent initial stability
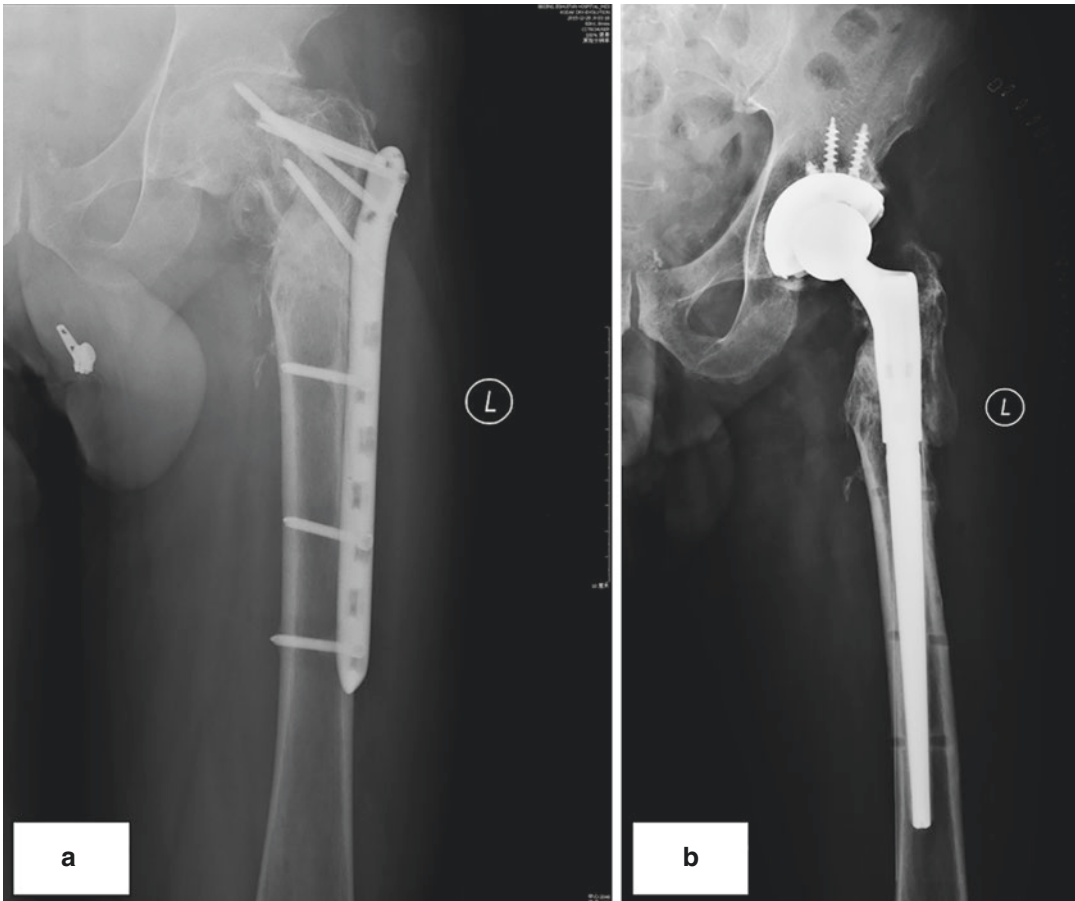
Fig. 18.2 (**a**) A-54-year-old man was diagnosed with posttraumatic arthritis of the left hip after ORIF of the intertrochanteric fracture 8 years ago. (**b**) A modular dis-tally fixed cementless femoral stem was used after removing the internal fixation devices during THA

18.3   Surgical Techniques

THA following a prior hip fracture may present significant technical challenges for surgeons compared to THA for primary osteoarthritis. Issues related to soft tissue exposure, hardware removal, fracture malunion and nonunion, bone defects, and abnormal muscle function may be encountered.

18.3.1 Soft Tissue Exposure

Adequate exposure is a prerequisite for successful THA. However, it may be difficult to obtain adequate exposure for patients with prior hip fractures because of adhesions and stiffness after the previous trauma and surgery. At our institute, most surgeons use the posterolateral approach to perform THA. This approach can be extended

either proximally or distally. Furthermore, we can also perform an anterior release or remove hardware from the anterior acetabulum via the anterior gluteus medius in the same incision. All soft tissue releases should be performed close to the bone to avoid neurovascular injury. We often ignore the previous incision when the time elapsed since the first operation exceeds 10 years. With shorter intervals, it has to be considered that the blood supply to the skin between the two incisions may be compromised. In cases that are difficult to dislocate, forceful internal rotation of the femur may cause fractures. We recommend that the superior and inferior portions of the capsule are released, and osteophytes are removed along the posterior rim of the acetabulum. In the case of a protrusion deformity or severe intra-articular fibrosis, we first cut the femoral neck in situ and then remove the femoral head with a corkscrew

or after dividing it into several pieces. Trochanteric osteotomy or extended trochanteric osteotomy may be a choice in complicated cases.

18.3.2 Hardware Removal

In our experience, hardware should only be removed when it interferes with the implantation of either of the components or causes discomfort. We found that removing the acetabular hardware frequently results in damage to nerves or vessels, and removing the femoral hardware may cause fractures. Removing as little hardware as possible avoids complications. When reaming an acetabulum in patients with hardware in situ, we often retain the plate and screws as long as they do not affect reaming and cup implantation (Fig. 18.3a, b). Screws may have to be removed if
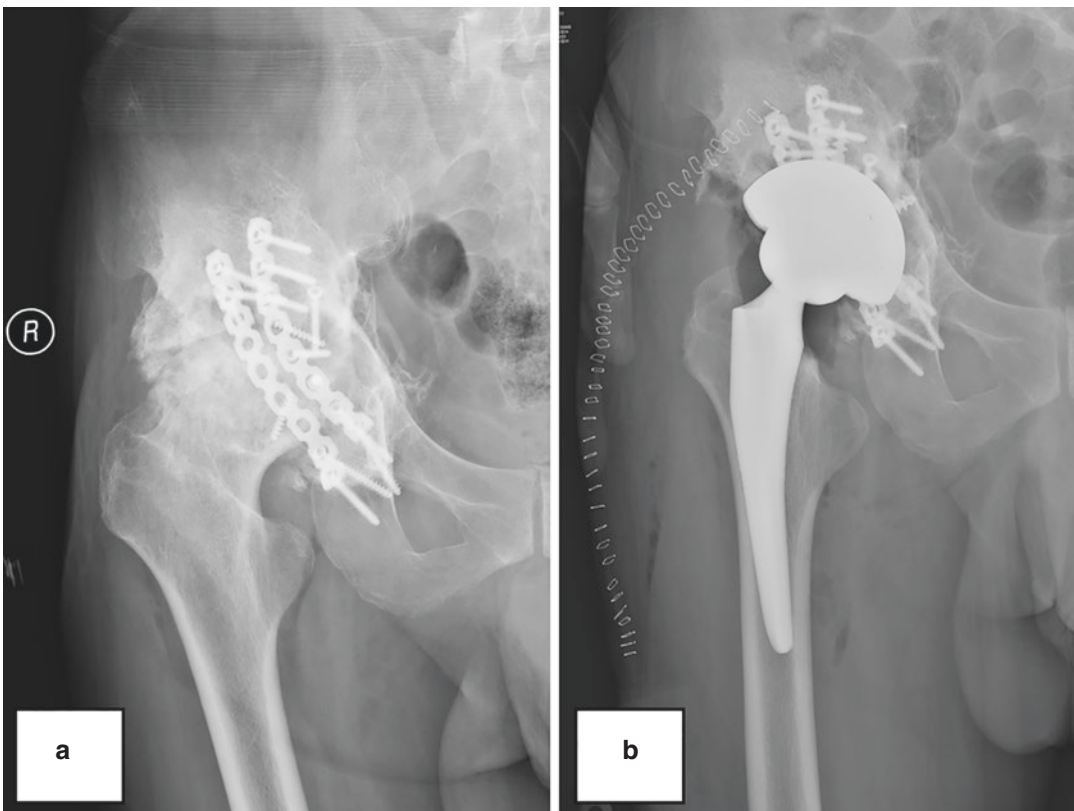

Fig. 18.3 (**a**) Anteroposterior radiograph of a 53-year-old man with posttraumatic arthritis of the right hip 8 years after open reduction and internal fixation for the

acetabular fractures. (**b**) A highly porous cementless acetabular component was implanted after removing some screws which hinder reaming and implantation

they are exposed to the acetabulum during reaming. When complete removal is difficult, we only remove the tips that are exposed in the acetabulum with a tungsten bur.

18.3.3 Reconstruction of the Acetabular Side

Reconstruction of the acetabular side may be challenging in patients with prior acetabular fractures and may confront surgeons with problems, such as poor bone quality, nonunion of the fractures, and bone defects.

Poor bone quality is often caused by disuse. We generally use cementless cups with highly porous surfaces, which provide greater friction between the metal and the host bone. Reaming should be performed very gently to avoid breaking through the dense subchondral bone into the softer cancellous bone. Screw supplementation is always recommended in these cases.

Acetabular nonunion may compromise the initial stability of the component. The approach to the required reconstruction is similar to that in revision THA. If the anterior and posterior columns are intact, a cementless cup is used, even with nonunion. If three stable points around the acetabular rim can be found or constructed by a plate, augment, or structural allograft, we also use a cementless cup, following the concept of the jumbo cup. If there is pelvic discontinuity, we ream the acetabulum and implant a trabecular metal multi-hole cup with 2–3 mm press-fit after distracting the acetabulum with a clamp as first proposed by Sporer et al. [11] If reconstruction with a cementless cup is not possible, a cup-cage system can be used to bridge gaps between parts of the acetabulum, followed by the implantation of a cemented cup.

Morselized cancellous bone grafts are a further option in patients with prior acetabular fractures. We crush the autogenous femoral head into 5-mm pieces to fill the bone defects. However, structural bone grafting is often unnecessary. In 14 of 31 THAs after fractures in Lai et al.'s study [12], the acetabulum presented cavities and segmental or confluent bone defects. Among the 14 patients with acetabular bone defects, 11 were treated with morselized cancellous bone grafts, and only three were treated with structural bone grafts. When the host acetabulum cannot provide sufficient initial stability for a cementless cup, most surgeons at our institute prefer to use trabecular metal augments rather than structural bone grafts because the absorption of the bone graft over time may compromise the stability of the acetabular cup (Fig. 18.4a–d).
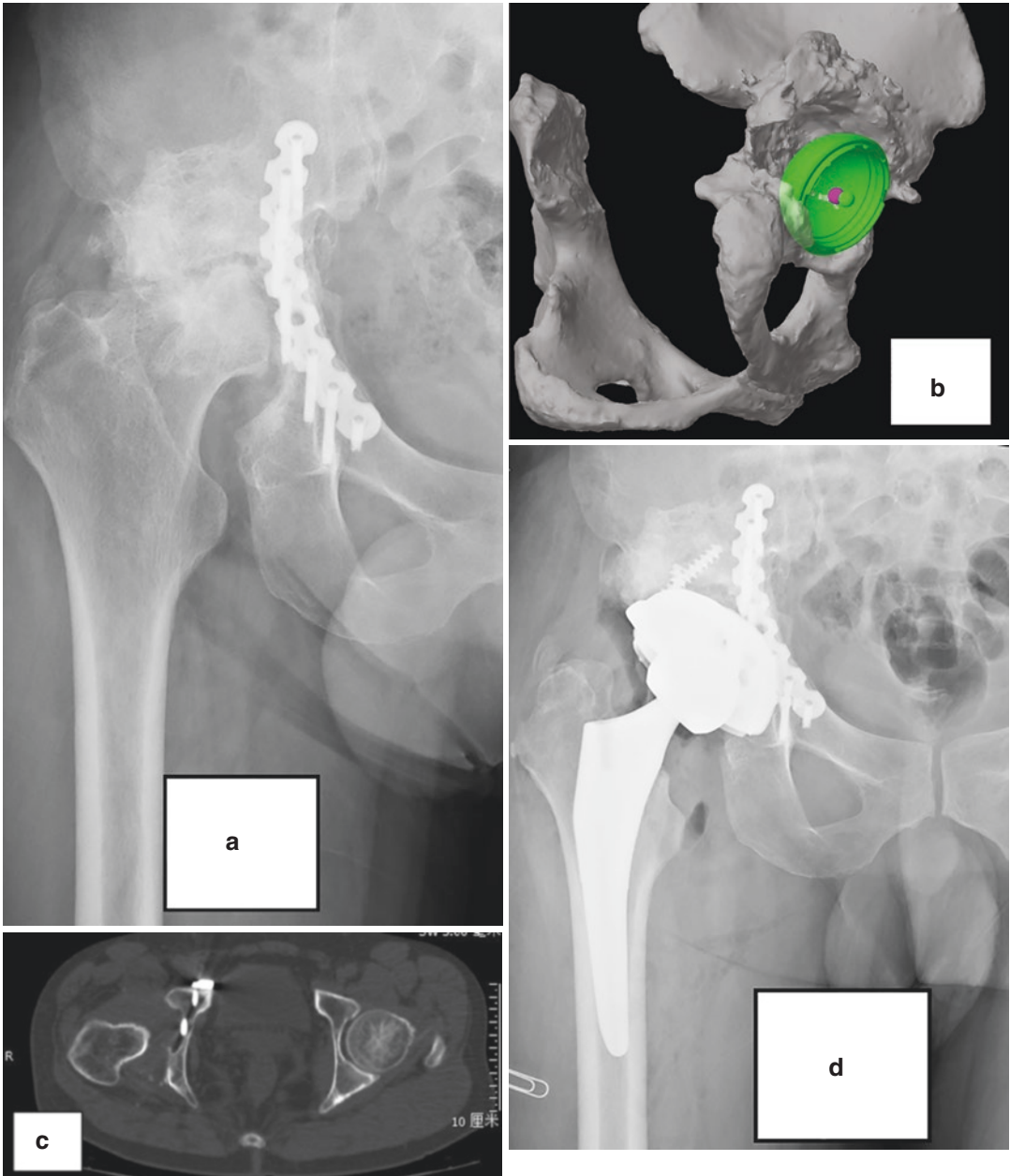
Fig. 18.4 (**a**) A 40-year-old man was diagnosed with posttraumatic arthritis of the right hip after ORIF of the acetabular fracture 5 years ago. (**b**) 3D CT showed significant bone defects of the posterior wall of the acetabulum. (**c**) According to the transverse section of the CT, the tips of the screws were detected in the acetabulum, which may interfere with the implantation of the acetabular compo-nent. (**d**) The acetabulum was reconstructed with a cementless cup with a highly porous coating surfacing, and the bone defects of the posterior wall were treated with a trabecular metal augment. The plate and screws in the anterior wall of the acetabulum were retained and the tips of the screws in the acetabulum were cut with a tung-sten bur

18.3.4 Reconstruction of Femoral Side

Reconstruction of the femoral side is not very difficult in most patients with a prior femoral neck fracture because the anatomy of the proximal femur is normal. Even in patients with poor bone quality, a single wedge cementless stem can be implanted with sufficient axial and rotational stability. However, intraoperative fractures should be avoided at all costs. When the femoral canal broaches, it is recommended to lateralize each broach to decrease the stress on the femoral calcar. Lateral sclerosis around cannulated screws that were implanted during previous surgery may result in malalignment or undersizing of the stem. Implanting a stem in varus increases the risk of a calcar split and aseptic loosening of the stem. Sclerotic tissue should be removed with a curette or curved osteotome before femoral broaching. Intraoperative radiographs are helpful when the size of the final broach is much smaller than that anticipated during the templating (Fig. 18.5a, b).

Reconstruction of the femoral side in patients with prior intertrochanteric fractures will encounter some difficulties because of the abnormal anatomy and poor bone quality of the femur. Standard primary cementless stems can be considered if there is limited anatomic change, but cementless revision stems are more suitable when the proximal femur cannot support primary stems because of fracture malunion or nonunion. As mentioned above, we use modular distally fixed cementless femoral stems in complex cases. The distal femoral canal is reamed with progressively larger reamers until diaphyseal cortical reaming is felt before we insert a fluted tapered stem as a modular component with appropriate length and size to bypass the deformed proximal femur and restore the leg length. The proximal femoral reconstruction is then performed according to the individual situation. We usually achieve

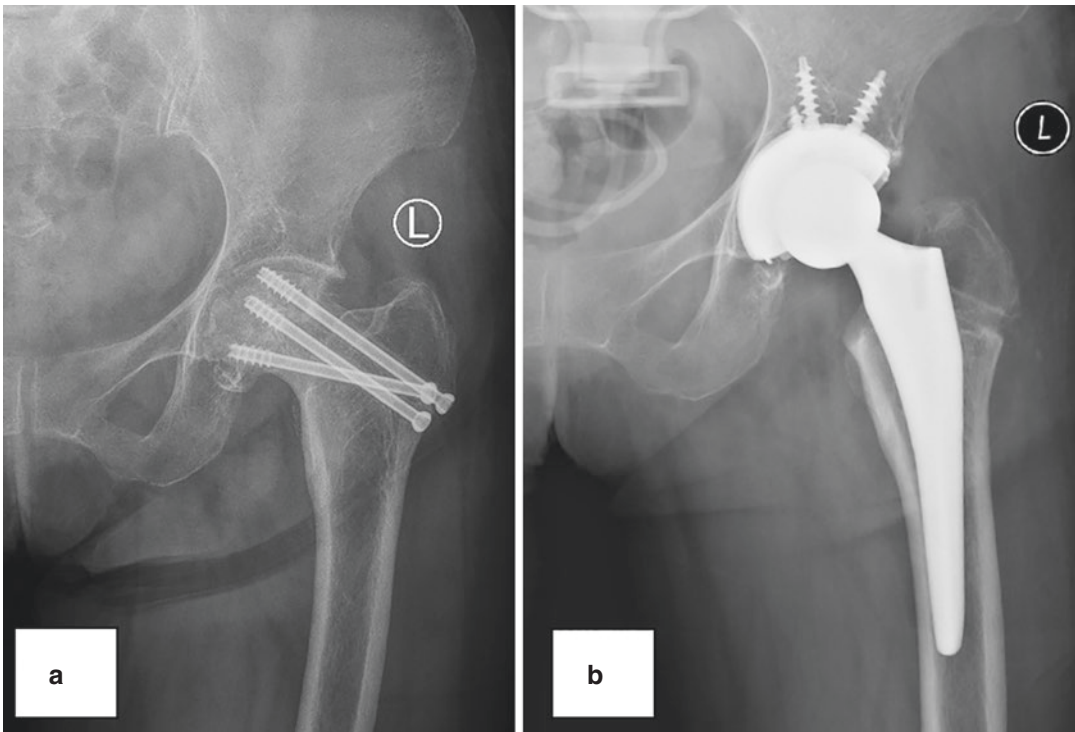**Fig. 18.5** (**a**) Anteroposterior radiograph of a 58-year-old woman with an osteonecrosis of femoral head 2 years after fixation with cannulated screws for femoral neck fracture. (**b**) The postoperative film showed an undersized stem was implanted because of sclerosis around the screws

contact of the proximal body of the modular component with the host bone by increasing the size of the body. If that is impossible because of severe proximal femoral deformity after the malunion of an intertrochanteric fracture, an extended trochanteric osteotomy may be necessary. A greater trochanteric osteotomy or extended trochanteric osteotomy should be performed first when femoral reaming is hindered by a proximal femoral deformity. In cases of nonunion of intertrochanteric fractures, the fragments should be reduced and fixed with wires, cables, or a cable plate system. It is very important to fix the fragment of the greater trochanter that is attached to the gluteus medius. A cortical strut allograft can be used when this fragment cannot be directly fixed to the distal femur.

18.4 Postoperative Rehabilitation

The postoperative rehabilitation is similar to that after standard primary THA. Partial or touchdown weight-bearing for 6–12 weeks may be necessary for patients with significant bone defects. Active abduction should be avoided if an extended trochanteric osteotomy or internal fixation of the proximal femur was performed. Decubitus precautions are critical in older patients.

18.5 Complications

Complications are more common in posttraumatic THA than in conventional THA. Hip fractures often require surgical interventions for fracture fixation. THA in patients who had previously undergone open reduction and internal fixation for a hip fracture might be associated with a high rate of subsequent periprosthetic joint infection (PJI). In a study reported by Aali et al. [13], 72 THA patients with prior acetabular fractures were matched 1:3 to primary THA patients without previous hip surgery. After a 3-year follow-up, the incidence of PJI was 6.9% in the acetabular fracture group and 0.5% in the control group ($P < 0.001$). In a recent meta-analysis [9], 10.3% of patients who underwent THA for posttraumatic osteoarthritis following acetabular fractures suffered from PJI. However, some other studies [14–16] and a study from our institute [17], found a lower incidence (0–4%) of PJI in patients who underwent THA after failed treatment of acetabular or intertrochanteric fractures.

Heterotopic ossification (HO) is one of the most common complications associated with THA after a prior hip fracture. In the meta-analysis mentioned above [9], the mean incidence of HO after THA for posttraumatic osteoarthritis was 38.2% (81/212, ranging from 28% to 63%) in five studies. However, most patients with heterotopic ossification were classified as Brooker class I or II. Morison et al. [18] reported that 32 of 74 patients who underwent THA for prior acetabular fractures developed HO. Of these, 30 patients were classified as Brooker Class II or less, and only 2 were classified as Class IV. Furthermore, indomethacin may play an important role in reducing HO occurrence following THA. Bellabarba et al. [19] established that only 20% (2/8) of patients who received HO prophylaxis developed this complication, compared to 50% (11/22) who did not receive prophylactic treatment.

Dislocation after salvage THA in patients with prior hip fractures is another intractable problem. The reasons for the higher risk of dislocation may include damage to the articular capsule or an abduction mechanism during the initial fracture, abnormal anatomy after malunion, over-release of soft tissue during surgery, and imbalance of soft tissue tension after surgery. Zhang et al. [20] reported that 15.8% of patients suffered from postoperative dislocation after hip arthroplasty for failed internal fixation of intertrochanteric fractures. Moon et al. [21] found that the overall dislocation rate was 7.3% after hip arthroplasty following failed internal fixation for femoral neck or intertrochanteric fractures. A systematic review [22] noted that the dislocation rate after THA following acetabular fractures was 4.4%.

18.6   Outcomes

Although THA is a well-established treatment option after failed hip fracture treatment, it presents inferior clinical results and more complications than in patients with nontraumatic arthritis.

Busch et al. [23] followed 48 patients who underwent THA after acetabular fractures and reported an average HHS of 75.7 after an average of 54 months, with 98% of the cups firmly fixed without periacetabular radiolucencies. The 8-year survival rate was 87% in the Kaplan-Meier analysis. Another study [18] on the clinical and radiographic results of 37 patients undergoing THA after surgery for acetabular fractures demonstrated an improvement of the mean HHS from 42.9 preoperatively to 83.5 and a survivorship rate of 83.4% after an average follow-up of 6.6 years. Morison et al. [18] compared the clinical results of 74 conversion THAs to 74 THAs for nontraumatic arthritis. Patients with a prior acetabular fracture had significantly inferior 10-year survivorship and more frequently experienced serious complications. Smith et al. [24], in their study of 369 THAs after previous intertrochanteric fractures and 56,522 primary THAs established that the mean length of stay was 1.5 days longer in the fracture group ($P < 0.0001$) than that in the primary THA group. The incidence of complications was significantly higher in the fracture group than in the primary THA group (infections 6.2% vs 2.6%, dislocations 8.1% vs 4.5%, and revisions 8.4% vs 4.3%). Mabry et al. [25] reported that the 10-year and 20-year survivorship rates of patients undergoing THA for femoral neck fracture nonunion were 93% and 76%, respectively, which were poorer than those reported in most other studies of patients undergoing THA for nontraumatic reasons.

Finally, some surgeons found that THA after intertrochanteric fractures was a more technically demanding procedure and presented a higher risk of complications when compared to THA after femoral neck fractures. Mortazavi et al. [26] compared THA after intertrochanteric fractures with THA after femoral neck fractures and found that they required a longer operative time (124 min vs. 94 min) and resulted in higher intraoperative blood loss (659 mL vs 335 mL). Dehaan et al. [27] concluded that THAs after failed femoral neck fracture treatment required fewer modular implants and a shorter operative time and led to lower blood loss and a shorter hospital stay when compared to THAs after failed intertrochanteric fracture treatment.

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Total Hip Arthroplasty in Adult Patients with Sequelae After Childhood Hip Infection

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Key Points

1. The sequelae of childhood hip infection manifest with multiplanar acetabular and femoral deformities and soft tissue problems in adult patients.
2. The focus of preoperative assessment before total hip arthroplasty is screening for a deep active infection of the concerned hip joint.
3. It is suggested that it is safest to perform total hip arthroplasty, not before 10 years after the initial infection.

19.1 Introduction

Adult patients with end-stage osteoarthritis (OA) after septic hip arthritis in their childhood frequently show multiplanar deformities on acetabular and femoral sides, as well as the contractures of the surrounding soft tissues [1–4]. Consequently, technical challenges can be anticipated during the reconstruction and perioperative management of total hip arthroplasty (THA) [3, 5–16]. In addition to young age of these patients and the presence of bone defects and soft tissue contractures, THA is often complicated by surgical procedures performed during childhood [3, 4, 17].

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19.2 Anatomical Abnormalities

The anatomical abnormalities may include a small and shallow acetabulum with insufficient bone stock in its superolateral area, a displaced center of rotation, a high-riding greater trochanter with abnormal abductor muscle length and direction, an undersized and narrow femoral canal, excessive anteversion of the proximal femur, abnormal course of the neurovascular structures secondary to long-standing soft-tissue contractures, and a leg-length discrepancy (LLD). The degree of the bone structure alterations and soft tissue contractures predominantly depends on age of the patient at the onset of original hip infection, the duration of that infection, and any previous surgeries.

19.3 Radiographic Assessment

In their study published in 2003, Kim et al. [5] proposed a radiographic classification system of OA after septic arthritis. The type-1 deformity refers to complete resorption of femoral head and neck with a high-riding greater trochanter, a dysplastic acetabulum, and a narrow femoral canal. In type 2, the deformities of the acetabular and proximal femoral are similar to those in type 1, but the size of the femoral canal is relatively normal. Type 3 describes complete destruction of the hip joint, but the anatomy and size of acetabulum

and femoral canal are relatively normal. In our opinion, the affected hips with a Perthes-like appearance on radiographs are another manifestation of concern. A Perthes-like hip presents with flattening and irregularity of the femoral head and widening and shortening, or even absence, of the femoral neck, with or without subluxation of the femoral head. Moreover, these hips are inevitably combined with secondary acetabular dysplasia and overriding of the greater trochanter because of premature closure of capital femoral epiphysis. There is a resultant limp and considerable LLD.

19.4 Bacteriological Evaluations

The focus of the preoperative assessment for THA is the screening for a deep active infection of the concerned hip. The screening process should include a comprehensive review of the patient's medical records, careful physical examination, laboratory tests, and radiographic examinations. The type of infectious microorganisms in the initial sepsis should be established. In our clinical practice, we routinely determine the erythrocyte sedimentation rate and C-reactive protein levels in all patients prior to THA. If an active hip infection is suspected before THA, a combination of imaging examinations, including a technetium-99 bone scan and magnetic resonance imaging of the hip, is performed. The criteria for preoperative joint fluid aspirations include clinical and/or radiological suspicion of active infection and elevated erythrocyte sedimentation rate and/or C-reactive protein levels [17]. During the operation, aspirates and excised specimens are cultured for the growth of aerobic, anaerobic, and tubercle bacilli. In the case of suspicious synovial fluid or tissues, frozen section biopsies are performed. More than five polymorphonuclear leukocytes per high-power field are considered indicative of an active infection.

19.5 Implant Selection and Technical Details

In the past two decades, most of the published papers have focused on cementless reconstruction either on the acetabular or femoral sides. Despite this, some papers reported high percentages of aseptic loosening and/or osteolysis, and the authors acknowledged that the observed polyethylene wear and osteolysis were attributable to suboptimal prosthetic designs and materials used at the time of their studies [3, 7, 10]. Ceramic-on-ceramic bearing surfaces are the first choice for this relatively young and active patient population. Similar to the course of disease in developmental dysplasia of the hip, the long-standing under-development and growth adaptation create a shallow, vertical acetabulum with insufficient coverage of femoral head, especially in Crowe III and IV. The surgical methods designed to address these issues include the selection of a small acetabular cup [18], medial placement of the cup through fracturing of medial acetabular wall [19], a structural femoral head autograft [8, 20], and circumferential osteotomy of medial acetabular wall [7, 21]. The introduction of a trabecular metal modular cup provided surgeons with a reliable treatment option. This porous material is made from tantalum and has inherent advantages of initial stability and accelerated bone ingrowth and soft tissue revascularization. Some clinical studies of trabecular metal cups in primary THAs have consistently reported satisfactory early and midterm results [22–24].

As mentioned, the undersized and narrow femoral canal, potentially obliterated by sequestra, and excessive anteversion of the proximal femur should be taken into consideration. Even with a high-speed burr, it is often difficult to ream a canal sufficiently wide to insert a stem of the desired size. As a result, there is a high possibility of undersizing and malpositioning of the femoral component with insufficient bone contact, all of which can lead to considerable subsidence and

early loosening. The described risk factors make the implantation of a standard monoblock stem almost impossible. The S-ROM® Modular Hip System (DePuy Synthes, Raynham, MA, US) stem may offer a solution for fitting and filling the femoral canal and stabilizing the diaphyseal and metaphyseal fragments under such conditions [6, 10–15]. The proximal sleeve offers maximal contact with host bone thereby providing a reliable porous coating for bone ingrowth and rotational stability. Meanwhile, the sleeve-bone interface seals medullary cavity against wear debris and reduces the degree of the stress-shielding effect on the proximal femur. A straight stem with a fluted distal design might offer additional rotational stability, which is essential for the combination with subtrochanteric shortening osteotomy (SSO). The possible disadvantages of modular femoral component include corrosion problems due to excessive stress in the modular junction, an increased risk of fractures, and femoral osteolysis associated with fretting debris from the sleeve-stem junction.

The indications for SSO in patients after childhood hip infection have been previously described [25, 26]. It was suggested that high cup positioning leads to increased rates of implant loosening and poor abductor function, and observations indicate that the acetabular component should be placed in true acetabulum. However, the implantation of a cup in true acetabulum generally requires a smaller implant with a thin liner. Thus, SSO is a reliable option for safe reduction of the acetabular cup while avoiding nerve injuries. Furthermore, SSO can effectively reduce the rate of postoperative LLD.

A series of osteotomy techniques have been reported, such as oblique, transverse, step-cut, V-shaped, Z-shaped, and double-chevron techniques [27]. The most significant complications of SSO are increased blood loss and delayed union or malunion of the osteotomy fragment [27–30]. Therefore, care should be taken to prepare for higher blood loss when performing THA with SSO. Transverse osteotomy has been reported to have lower rotational stability than the oblique, double-chevron, and Z-shaped techniques [28, 31, 32]. The site of the SSO should be augmented by morselized cancellous bone autografts from resected femoral head. Some authors further recommend routinely fixating the SSO using a plate and screw or strut grafts with cerclage wiring [13, 14].

19.6 Infection Reactivation

Infection reactivation is the most characteristic complication of THA in patients after childhood hip infection. Many authors have suggested that it would be safer if THA was performed no earlier than 10 years after the infection [5, 15, 16]. They emphasize the need for a comprehensive screening system, including clinical, laboratory, and radiological examinations and histological and bacteriological sampling to maximize the chances of identifying residual microorganisms.

19.7 Summary

Cementless THA reconstruction in adult patients with childhood hip infections presents substantial technical challenges and has a relatively high complication rate. Attention should be paid to meticulous preoperative planning and anticipation of the main technical difficulties. With adequate management, THA can achieve high implant survivorship and high levels of patient satisfaction.

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Total Hip Arthroplasty in the Treatment of Inflammatory Arthritis

20

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Key Points

1. Inflammatory arthritis (IA) is an autoimmune, chronic, and destructive joint disease. Rheumatoid arthritis (RA) and ankylosing spondylitis (AS) are the most prevalent types of IA.
2. In view of the complexities of RA and AS, perioperative management and surgery must be coordinated and monitored by a multidisciplinary team (MDT) mode.
3. The major purpose of the preoperative withdrawal of csDMARDs, bDMARDs, tsD-MARDs (JAK inhibitors), and GCs is to balance the risk of infection and compromised wound healing against the risk of a disease flare.

20.1 Introduction

Inflammatory arthritis (IA) is an autoimmune, chronic, and destructive joint disease. AS the most prevalent types of IA, rheumatoid arthritis (RA) and ankylosing spondylitis (AS) affect 0.5–1% [1] and 0.1–0.9% [2–4] of the general population, respectively.

In AS, the hip is the most affected joint outside the axial skeleton, with a reported prevalence

of clinical hip involvement of 24–36% and radiographic hip arthritis of 9–22% [5–7]. Hip AS is usually associated with severe pain, limited range of motion (ROM), functional impairment, compromised quality of life, work disability, and psychological disorders. Although the continuous use of nonsteroidal anti-inflammatory drugs (NSAIDs) has been shown to reverse the radiographic progression of AS in the axial skeleton [8], similar effects on peripheral joints have not been demonstrated to date. Meanwhile, several mid- and short-term studies have demonstrated reparative radiological changes in the hip joints after the use of tumor necrosis factor-alpha (TNF-α) inhibitors [9–12]. A study from 534 AS patients in the *Norwegian Arthroplasty Register* compared the numbers of procedures performed annually from 1988–2002 with those from 2003–2010. There was a trend, although not statistically significant ($p = 0.087$), toward less interventions during the second period. The mean age of these patients undergoing surgery increased significantly from 49.9 to 56.4 years ($p < 0.001$) when comparing the first with the second period. Given that TNF-α inhibitors were introduced into treatment for AS in Norway between 2000 and 2003, these results suggest that they may alter the prognosis of the disease by inhibiting or slowing arthritis of the large joints, and consequently reducing the need for total hip arthroplasty (THA) [13].

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Unfortunately, the progression of hip AS may at times be rapid, particularly in patients with juvenile-onset AS, bilateral hip involvement, radiographic sacroiliitis, longer diagnosis delay, and axial spine impairment [7, 14, 15]. Once hip AS reaches the end stage with irreversible pain and ROM limitation combined with severe gait and posture deviations, THA becomes inevitable.

In patients with RA, the metatarsophalangeal joints are the most frequently affected joints in the lower extremities, followed by the knees. Hip involvement in RA is relatively uncommon. However, its incidence may increase as a consequence of glucocorticoid (GC)-induced avascular necrosis of femoral head. The traditional combination of NSAIDs and GCs have been utilized as an initial treatment for RA, even though it only controls clinical symptoms and fails to prevent disease progression and structural damage. In reality, a high percentage of patients with RA undergo THA based on data collected in the last century. Wolfe and Zwillich [16] found that 33.8% of patients with RA enrolled in a 23-year prospective study in the 1970s and 1990s received some kind of joint surgery, of which 25% underwent joint replacement surgery. A study reviewed a cohort of 13,961 English RA patients for up to 15 years and found that the lifetime risk of THA was approximately 17%, approximately double that of the general population [17]. Fortunately, the introduction of conventional synthetic disease-modifying antirheumatic drugs (csDMARDs), especially methotrexate (MTX), has been highly efficacious in reducing signs and symptoms of RA and delaying or preventing structural joint damages. Furthermore, the development and clinical use of biological DMARDs (bDMARDs) and, more recently, targeted synthetic DMARDs (tsDMARDs), mostly tofacitinib, have dramatically altered the prognosis of patients with RA. These drugs are better tolerated, more effective, and offer substantial benefits compared to traditional treatments, particularly when combined with early diagnosis, prompt treatment, and a treat-to-target regimen. Over the last two decades, a series of researches from Western countries and Japan suggested that the rates of THA have been stable or decreased in patients with RA [18–21].

Nevertheless, many patients with end-stage hip involvement still have to undergo THA despite long-term combination therapy.

In this chapter, we will focus on treatment of THA in patients with RA and AS, including the clinical assessment and perioperative management (incl. anesthesia), implant selection and surgical techniques, and complications. In view of the complexities of AS and RA, perioperative management and surgery must be coordinated and monitored by a multidisciplinary team (MDT) mode. At our institution, the MDT for IA includes joint surgeons, spine surgeons, rheumatologists, anesthesiologists, rehabilitation physicians, psychologists, and where needed, cardiologists and endocrinologists, united by their common aim of minimizing perioperative complications in patients with AS and RA. Our team developed a flow chart for perioperative assessment and management of patients with AS and RA that we describe in detail below.

20.2 Psychiatric Status Assessment

Evidence suggests that psychiatric comorbidities are associated with a higher rate of complications following orthopedic surgery [22–24]. Patients with AS and RA are vulnerable to mental illness or psychological problems, including depression, anxiety, fatigue, stress disorders related to surgery, and sleep disturbances. Preliminary studies have shown that mental disorders adversely affect the preoperative functional status, length of hospital stay, medical costs, and postoperative outcomes. Hence, we emphasize the necessity of integrating perioperative psychiatric assessment and, if needed, intervention into the perioperative plan. In clinical practice, a psychiatric assessment is initiated by a request for consultation from the primary care team. As a team member, the psychiatrist will review the chart, interview this patient and his family, obtain further information from outpatient service providers as needed, and provide a written consultation report to inform the discussion with the primary medical and surgical teams.

20.3   Comorbidity Evaluation

Comorbidity refers to the coexistence of other chronic diseases in patients with an index disease [25]. The high prevalence of comorbidities in IA can be explained by the following factors: a high inflammatory burden, an overlap in the pathophysiology with other rheumatic diseases, a high detection rate as a result of the frequent monitoring and screening of IA patients, and improved survival. Both IA itself and the medications used to treat it can affect multiple organ systems. Before elective surgery, these patients must be carefully assessed for these comorbidities through history taking, physical examination, and laboratory and radiographic investigations (Table 20.1).

In clinical practice, comorbidities can be assessed via two approaches: recording each comorbidity separately or using comorbidity indices. The advantages of the latter include summarizing all coexistent illnesses and the severity of those in a single numeric score, monitoring the patient's status, and comparing comorbidities between patients. The most widely used comorbidity indices for the evaluation of IA conditions include non-rheumatological specific indices, such as the Charlson Comorbidity Index [27], Elixhauser Comorbidity Measure [28], and Functional Comorbidity Index [29]; rheumatology-specific indices, such as the Rheumatic Disease Comorbidity Index (RDCI) [30] and Multimorbidity Index [31]; disease-specific indices, such as the Rheumatoid Arthritis Comorbidity Index [32]. For example, the RDCI is the first comorbidity index that specifically addresses diseases commonly associated with rheumatic diseases, including RA, osteoarthritis, systemic lupus erythematosus, and fibromyalgia. It encompasses only 11 of the most representative comorbid illnesses (Table 20.1) with a total score range of 0–10. In our clinical practice, RDCI applies equally to patients with AS (Table 20.2).

Table 20.2   Rheumatic Disease Comorbidity Index

Comorbidity	Points (max.)
Lung disease	2
Heart attack, other cardiovascular events, or stroke	2
Hypertension	1
Fracture	1
Depression	1
Diabetes	1
Cancer	1
Ulcer or stomach problem	1

Rheumatic Disease Comorbidity Index calculation: add all items to arrive at the total score (range 0–10).
Max. maximum

Table 20.1   Systematic preoperative assessment of patients with ankylosing spondylitis and rheumatoid arthritis [26]

History	Physical examination	Laboratory test	Imaging or function test
Disease onset	General health	Full blood count	Chest radiograph or/and lung computed tomography
Diagnostic delay	Dental inspection	Electrolytes	Full spine radiography
Pattern and sequence	Joint tenderness	Urinedipsticks+/− Urine cultures	Electrocardiogram
Presence and persistent joint swelling	Joint deformity and range of motion	Biochemical tests	Pulmonary function tests
Pain (site, severity, duration)	Soft tissue integrity	Coagulation function	Abdominal ultrasonography
Morning stiffness	Spine deformity and range of motion		Echocardiogram
Functional limitations	Extra-articular features		Full-length lower limb radiographs
Psychological features	Grip strength		
Systemic features	Neurological assessment		
History of anesthesia and surgery			
Drugs and allergies			

Table 20.3 Disease activity measurements used in rheumatoid arthritis

Scoring system	Formula	Disease activity status			
		Remission	Low disease activity	Moderate disease activity	High disease activity
SDAI	SJC28 + TJC28 + PGA + EGA + CRP	≤ 3.3	>3.3–11	>11–26	>26
CDAI	SJC28 + TJC28 + PGA + EGA	≤ 2.8	>2.8–10	>10–22	>22
DAS28	Complex formula including the TJC28, SJC28, ESR (or CRP), and GH	≤ 2.6	>2.6–3.2	>3.2–5.1	>5.1

RA rheumatoid arthritis, *SDAI* Simplified Disease Activity Index, *CDAI* Clinical Disease Activity Index, *DAS28* Disease Activity Score using 28-joint count), *SJC* swollen joint count (number indicates the number of joints taken into account), *TJC* tender joint count (the number indicates the number of joints taken into account), *PGA* patient global assessment (on a 0–10 cm scale), *CRP* C-reactive protein (in SDAI in mg/dL), *EGA* Evaluator Global Assessment (on a 0–10 cm scale), *ESR* erythrocyte sedimentation rate, *GH* global health (that is, patient global assessment)

20.4 Disease Activity Assessment

The critical parameter during the preoperative assessment is disease activity since it is indicative of the degree of systemic inflammation, which in turn is closely correlated with the rate of perioperative complications, implant survivorship, and functional status after THA [33–36]. The disease activity in AS is quantified using two scoring systems. A long-established system is the Bath Ankylosing Spondylitis Disease Activity Index (BASDAI), which consists of six subjective clinical elements: fatigue, axial and peripheral joints, entheses, and morning stiffness duration and intensity. The score ranges from 0 (no activity) to 10 (highly active). A cut-off of 4 is indicative of active disease [37].

A newer method is the Ankylosing Spondylitis Disease Activity Score (ASDAS), which contains both subjective clinical elements and objective laboratory results, including C-reactive protein (CRP) levels and the erythrocyte sedimentation rate (ESR) [38]. The cut-off values for the different disease activity levels are as follows: a score below 1.3 is considered low disease activity, a score between 1.3 and 2.1 indicates moderate disease activity, a score between 2.1 and 3.5 means high disease activity, and above 3.5 is considered very high disease activity [39]. The Bath Ankylosing Spondylitis Functional Index (BASFI) is the most commonly used general functional measure in AS [40].

RA disease activity is assessed mainly with the 28-joint Disease Activity Score (DAS28)

[41], the simplified disease activity index (SDAI) [42], and the clinical disease activity index [43]. The calculation and cut-off values for the different disease activity levels are shown in Table 20.3.

20.5 Medication Management

Patients with RA may be on long-term pharmacological management to alleviate their pain, improve their function, and prevent deformity and structural damage. The four main categories of drugs are NSAIDs, csDMARDS, bDMARDS, or tsDMARDs (e.g., Janus kinase (JAK) inhibitors) and GCs, which must be seriously taken into consideration in perioperative medication management of patients.

NSAIDs are regarded as a cornerstone of AS treatment and are also frequently used by RA patients. However, they are ineffective in preventing hip deformity or local syndesmophyte formation and are consequently mostly used in combination with other pharmacological agents. The main adverse reactions after long-term use are gastrointestinal and cardiovascular events, which may be life-threatening [44, 45]. Patients with AS and RA are at an increased risk of cardio- and cerebrovascular morbidity and mortality. If the risk of gastrointestinal events exceeds that of cardiovascular events, we refer to a cyclo-oxygenase-2 (COX-2)-selective inhibitor. If the risk of cardiovascular events is higher, a combination of nonselective NSAIDs with proton pump inhibitors should be considered. However, since the preoperative use of NSAIDs may impair

wound healing, we recommend continuing COX-2 selective inhibitors during the perioperative period but stopping nonselective NSAIDs for a period of about five half-lives before surgery.

As mentioned above, csDMARDs, especially MTX, have revolutionized the treatment of RA since they modify the course of disease both clinically and radiographically. Consequently, their use among RA patients is very high, and 75–84% of patients undergoing arthroplasty are on csDMARDs or bDMARDs [46]. In contrast, there is insufficient evidence to support the use of csDMARDs in AS patients, where sulfasalazine only may have limited effects in the treatment of peripheral joint symptoms [47].

Previous studies have supported the view that continuing with csDMARDs during the perioperative period is safe for RA patients [48–50]. A major advance in this field has been the introduction of guidelines from the *American College of Rheumatology (ACR)* in collaboration with the *American Association of Hip and Knee Surgeons (AAHKS)* in 2017 for perioperative management of medications in patients with rheumatic disease undergoing elective hip or knee arthroplasty [51]. These guidelines recommend continuing csDMARDs, including MTX, leflunomide, sulfasalazine, and hydroxychloroquine, throughout the perioperative period without interruption.

The use of bDMARDs or tsDMARDs has become a hot topic in academia in recent years. The management of biological agents in perioperative period is a clinical dilemma because of the need to balance infectious risk and compromised wound healing against the potential of disease flares. The *2017 ACR/AAHKS Guidelines* recommend that patients with AS and RA should stop all biological agents prior to elective THAs, and surgery should be performed at the end of the dosing cycle. The recommendation not to resume these medications until 14 days after THAs is based on the normal wound healing time, but in the clinic, this decision should be made on an individual basis, considering potential complications in wound healing and ruling out surgical site or systemic infections [52]. For example, tofacitinib, a new synthetic targeted medication,

should be withheld for 1 week prior to THA. After THA, to optimize wound healing, we extend the timing of stitch removal (usually 3–4 weeks), which is synchronized with the reuse of tofacitinib.

The long-term use of GCs in high doses is quite common in RA patients but rare in patients with AS at the time of THA. GCs have been correlated with a substantial increase in perioperative complications, including deep infections, delayed wound healing, periprosthetic fractures, and readmissions [52–55]. These risks are dose-dependent, but it is unclear whether there is a "safe" GC dose. The *2017 ACR/AAHKS Guidelines* recommend against routine administration of a preoperative stress dose. The patient should continue their usual daily dose of GCs, which should be gradually tapered to a daily dose of prednisone or an equivalent of less than 20 mg before surgery. In our opinion, patients with a history of long-term GCs use should receive a therapeutic schedule for GCs tapering or even completely stop using them before surgery. Our medication regimen consists of a combination of NSAIDs, MTX, and a TNF-α inhibitor or JAK inhibitor (tofacitinib), and the daily dose of prednisone or an equivalent should be less than 5 mg. At the same time, we anticipate better control of disease activity when GCs are completely stopped.

20.6 Considerations for Anesthesia

AS has always presented a significant challenge to anesthetists because of the potentially difficult airway, cardiovascular and respiratory complications, and the medications used to control pain and disease activity [56]. The limited mobility of the neck and temporomandibular joints makes intubation difficult to perform. On the other hand, ligament ossification, bony bridges, and severe deformity of the lumbar spine lead to a very low success rate of epidural and spinal anesthesia in AS patients with end-stage spinal involvement [57]. At our institution, anesthetists have alternative options in this situation. Awake fiberoptic

intubation is a safe solution, especially when visualization of the larynx is impossible. It also allows for constant neurological monitoring during tracheal tube placement. The other option is using a laryngeal mask, especially for patients who refuse awake fiberoptic intubation or patients with restricted mouth opening [58]. A further option is a combined ultrasound-guided peripheral nerve block (usually lumbar plexus, sacral plexus, and paravertebral nerves). Although this is a time-consuming task and may evoke patient discomfort, the advantages are obvious and include avoiding stressful awake intubation and multiple lumbar puncture attempts, improving hemodynamic stability, reducing opioid requirements, and earlier ambulation and participation in rehabilitation programs [59]. The most significant limitation of this method is its lack of muscle-relaxing effects. Consequently, it is not suitable for technically difficult cases, such as a hip with bony ankylosis. Finally, the paramedian approach or Taylor approach as a modification of the paramedian approach may be used for spinal anesthesia.

In RA patients, our anesthetists prefer epidural and spinal anesthesia to general anesthesia with the following rationale. Cervical spine is the second most common site of destruction in RA after the metacarpophalangeal joint. As a result, the percentage of cervical instability, especially anterior atlantoaxial subluxation, is very high in patients with RA [60]. A necessary part of the preoperative assessment of RA patients is taking lateral cervical spine radiographs during flexion and extension. In this situation, it is essential that efforts are made to prevent hyperextension of the neck, a common occurrence in airway maneuvers. In addition, ankylosis of the temporomandibular joint and involvement of the cricoarytenoid joints resulting from chronic synovitis may increase the difficulty of airway management further [61, 62].

20.7   Implant Selection

In view of the need to preserve bone stock for future revision in young patients with AS and bony union of the spine, most published studies have focused on cementless fixation of the acetabular cup. Acetabular reconstruction by cemented or cementless fixation can consistently achieve satisfactory clinical outcomes and implant survivorship [63–76]. However, the implant selection on the femoral side, remains a controversial subject, although cementless reconstruction has been the leading mode of fixation. Some authors [64, 73, 77] found that the Dorr type C is the dominant morphology of proximal femur in AS patients, which is closely associated with trabecular bone loss. Consequently, they suggested that cemented stems should be prioritized in this specific patient population.

Similar satisfactory clinical outcomes and implant survivorship were seen in cemented and cementless cups and stems in RA patients [78–81] over the last decade. Despite the altered biomechanical properties of the rheumatic bone bed, the initial implant stability and osseous integration are sufficient. Higher rates of aseptic loosening have been reported in patients with RA in studies published in the last century. This was largely attributed to bone stock loss and consequent stress shielding, as well as high disease activity in RA patients.

20.8   Surgical Techniques

The posterior lateral approach has been the gold standard for THA because it makes the exposure of the acetabulum and femoral neck osteotomy very easy. However, in bony hip ankylosis in AS and RA patients, the surgeon will inevitably encounter a dilemma between locating the true acetabulum and dislocating the femoral head. Fixed external rotation can exaggerate these difficulties. There is a subsequent risk of damage to greater trochanter, posterior acetabular wall, and sciatic nerve during femoral neck osteotomy. Our solutions include a lateral approach combined with osteotomy of the greater trochanter [82], a two-step femoral neck cutting technique [83], or a direct anterior approach. The latter is a minimally invasive and truly interneuromuscular approach with the inherent advantages of protecting the posterior rotator muscles, vessels, and nerves [84]. Especially for patients with bony hip

ankylosis, the direct anterior approach can release contracted anterior soft tissue under direct vision and avoid damaging them [85].

Acetabular protrusion is a characteristic radiological feature in approximately 5% of patients with RA. It progresses at a rate of 2–3 mm per year. The poor bone stock in RA leads to superomedial migration of the femoral head, in line with the joint forces. In the classification system of acetabular protrusion by Sotelo-Garza and Charnley [86], the ilioischial line on the anteroposterior radiograph of the pelvis is the reference from which to measure the location of the acetabulum. A distance of 1–5 mm is regarded as mild, a distance of 6–15 mm as moderate, and a distance of >15 mm as severe protrusion. The key in acetabular reconstruction is to restore the anatomical hip center of rotation (COR) [87]. The deficient bottom of the acetabulum should be routinely strengthened by morselized bone grafting. This autografting consolidation creates a medial buttress for the cup that may resist the superomedially directed reactive joint force. A metal-backed porous-coated component is preferable in such conditions, and we tend to select a tantalum trabecular metal cup in combination with multiple dome screw fixations. If structural bone defects are evident in the acetabular wall, or the graft supports more than 50% of the host bone-cup contact area, structural autografting from the resected femoral head or iliac bone should be considered. Alternative options include metal augmentation, antiprotrusio cages, and rings.

We developed a multivariate regression model to assess the clinical and radiographic outcomes of THA performed in 167 hips of 100 patients in a retrospective study at our institution [70]. Before surgery, flexion contracture was found in 101 hips and averaged 25.6 ± 14.6° (range, 5–70°). Ankylosis was observed in 95 hips. After THA, 106 hips had no flexion contracture, whereas 61 hips had an average flexion contracture of 12.6 ± 5.8° (range, 5–35°). Before THA, the passive flexion arc of the hip averaged only 0° (0–40.0°), compared with 100.0° (85.0–110.0°) at the last follow-up examination. After surgery,

patients with 44 hips (26.3%) were unable to put on their shoes, and patients with 57 hips (34.1%) were unable to do so with ease. These data suggest that flexion contracture of the hip is very common in AS. The soft tissue release of the anterior joint capsule, iliopsoas, and iliotibial band should be performed meticulously to correct deformity and restore sagittal balance. The vertical tension of the soft tissue should not be too high. Extension contracture of the hips in AS is relatively uncommon. Gautam et al. [63] from India described a modified Z-plasty technique for iliotibial band to correct this deformity, and the clinical outcomes were encouraging.

20.9 Surgical Complications

20.9.1 Disease Flares

The major purpose of the preoperative withdrawal of csDMARDs, bDMARDs, tsDMARDs (JAK inhibitors), and GCs is to balance the risk of infection and compromised wound healing against the risk of a disease flare [88]. Consequently, flares are frequent in patients with IA during perioperative period. Goodman et al. [89] reported that the percentage of flares during the first 6 weeks after THA or total knee arthroplasty (TKA) was as high as 63%. Patients who experienced flares after surgery had significantly higher disease activity, ESR, CRP levels, and more pain at baseline. In another study by them [90], the flare rate was 58.1% within 6 weeks of surgery. In multivariable models, baseline DAS28 was the strongest predictor of pain and function after 1 year, but postoperative flares did not increase the risk of worse outcomes after 1 year. They concluded that decisions on perioperative medication management may be made without concern for the impact on long-term arthroplasty outcomes as these are not linked to flares. If a flare is combined with unacceptable clinical symptoms, the short-term use of GCs, either orally or by intramuscular injection, should be considered [90].

20.9.2 Allogeneic Blood Transfusion

Three papers from China reported a high rate of allogeneic blood transfusion during and after THA in AS patients, ranging from 73–80% [91–94]. They reported several risk factors predisposing patients to blood loss and a need for blood transfusion that included high disease activity and a low body mass index (BMI). There is little data on allogeneic blood transfusions in RA patients. Ogbemudia et al. [94] retrospectively reviewed 349 patients with RA who had undergone either THA or TKA, and 21% ($n = 72$) of them required allogeneic blood transfusion. For each 1 g/L increase in the preoperative hemoglobin (Hb) level, there was an 8.3% decrease in the probability of transfusion. The only statistically significant predictive factors for the need for postoperative blood transfusions included a low preoperative Hb level, THA, and a history of myocardial infarction and blood transfusion. In a similar study by Morse et al. [95], the allogeneic blood transfusion rate was 11.2%, and nearly half (46.2%) of patients with an Hb of less than 8 mg/dL required blood transfusion. In the multivariate analysis, a decreased baseline Hb level, long operation duration, and high CDAI were associated with an increased risk of transfusion. However, the use of tranexamic acid (TXA) was not associated with a decreased risk of postoperative transfusion.

AS the most common extra-articular manifestation of RA, anemia is frequently multifactorial. While 25% of RA patients are diagnosed with anemia of chronic disease, other contributing factors, such as iron deficiency, may be present. These results highlight the importance of optimal perioperative management, including preoperative anemia correction and nutritional support, disease activity control, intraoperative hemostasis maintenance, use of autologous blood salvage, intravenous and intra-articular TXA, and wound compression. In a systematic review, Wilson et al. [96] reported significantly lower transfusion requirements in anemic RA patients who underwent major arthroplasty after receiving erythropoietin (EPO) treatment and iron supplementation.

20.9.3 Heterotopic Ossification

Heterotopic ossification (HO) is a well-known complication after THA and is characterized histologically by the abnormal formation of mature lamellar bone. AS has been identified as a risk factor for HO in patients who received THA [97–100], and the incidence of HO after cement or cementless THA in the literature has ranged from 3 to 90% over the last two decades [63–66, 69, 70, 72–75]. The most commonly used radiographic HO classification system is Brooker classification based on the anteroposterior radiograph. Postoperative HO can be visible radiologically 4–6 weeks after THA. Generally, most cases of HO are asymptomatic, and only a minority of cases with Brooker grade III and IV may evoke symptoms of pain and limited ROM of the operated joint. As described in the next section, our multivariate regression model demonstrated that one of the risk factors predisposing to poor hip flexion after THA in AS patients was postoperative HO formation.

Various methods exist to prevent postoperative HO, including drug prophylaxis and radiotherapy. Although low-dose radiotherapy has been proven effective for preventing HO in AS patients after THA, controversy over its use remains owing to the potential complications, including impaired bone ingrowth, malignancy, wound healing problems, and deep infection. The most commonly chosen drugs for HO prophylaxis are NSAIDs and diphosphonates. It should be noted that nonselective NSAIDs and COX-2 selective inhibitors are equally effective in HO prophylaxis.

Surgical resection is the standard treatment for symptomatic HO grade III and IV. Considering the potential for excessive intraoperative blood loss and postoperative recurrence, the timing of the operation must consider the maturation period of HO.

20.9.4 Limited Range of Motion

Joint stiffness after THA is a major concern in the postoperative management of AS. The average

total hip ROM across several studies was only 167° [72, 73, 101–106]. We compared the pre- and postoperative flexion and total ROM after THA in AS patients [70]. The passive ROM averaged only 0° (0–60°) before surgery, compared with 205° (185–220°) at the last follow-up. The hip passive flexion arc averaged only 0° (0–40°) before surgery, compared with 100° (85–110°) at the last follow-up examination ($p < 0.001$). Before surgery, 154 hips (92.2%) could not be flexed more than 90° passively. After THA, 99 hips (59.3%) had a passive hip flexion of >90°, but 75 patients with 103 hips (60.4%) were still unable to put on their shoes or had difficulty doing so. Moreover, the main cause of patient dissatisfaction was limited flexion and/or rotation (53 hips, 31.7%). Multivariate regression demonstrated that the significant variables for postoperative hip flexion were the degree of preoperative flexion contracture, preoperative CRP levels, a 32 mm femoral head used during THA, and postoperative HO. Implant survivorship and hip ROM are important in the relatively young and active group of patients with AS, in whom decreased motion of the spine may result in increased loading and functional demands on the hip joints [70]. Consequently, a comprehensive regimen for achieving optimal joint mobility is of critical clinical significance, and we want to stress the following points. First, all possible risk factors should be identified, including previous hip surgery, high disease activity, and severe anatomical deformity (i.e., fibrous or bony ankylosis and flexion contracture). During the preoperative conversations, the surgeon must inform patients that there is a possibility of decreased ROM or even re-ankylosis after surgery. Second, the surgeon should attend to any technical details intraoperatively that may have a negative impact on ROM after THA. The tightness and compliance of the soft tissue surrounding the hip should be thoroughly examined, and excessive tightness should be avoided as much as possible. The use of a larger head size is recommended since it can improve the ROM and joint stability by improving the jump distance. Third, maximizing hip ROM should be the prime target of the postoperative rehabilitation program. We emphasize that an efficient, multimodal rehabilitation program is of utmost importance and should include peripheral nerve blocks for pain control, active and passive ROM exercises, muscle strength training (especially for the abductor mechanism), proprioception, and gait.

20.9.5 Dislocation

Theoretically, THA in a hip with AS is susceptible to dislocation. Abnormal spinopelvic parameters, manifested clinically by excessive thoracic kyphosis and loss of lumbar lordosis, result in a stooped, downward-looking posture of patients, which is characteristic of advanced AS. Patient has to sort to flex their ankles and knees, retrovert their pelvis and extend the hips, and tilt the entire rigid segment of the spine backward in an attempt to compensate for this posture. The posterior inclination of the pelvis can be observed on lateral radiographs of the pelvis, where the sacral slope may reach a horizontal orientation [106]. Tang and Chiu [76] defined this phenomenon as "pelvic hyperextension." They found that the longitudinal diameter of the obturator foramen appears longer than the transverse diameter on plain standing radiographs of the pelvis, indicating that the pelvis is rotated in the sagittal plane. They postulated that the anatomic abnormality might lead to anteverted and vertical implantation of the acetabular cup, which may predispose the prosthesis to anterior dislocation. A parametric experimental model to evaluate posterior inclination of the pelvis and THA instability found that 20° of posterior pelvic tilt failed to achieve a safe ROM when the cup was positioned within Lewinnek's safe zone. Reduced anteversion in the range of 0–10° appeared to be acceptable to compensate for pelvic tilt [107]. In contrast, Bhan et al. [72] provided another explanation for exaggerated femoral anteversion, especially in combination with an external rotation deformity. However, our study among our AS patients prior to THA using CT scans showed no tendency of increased femoral proximal anteversion angle [107]. We conclude that a successful THA in patients with AS has to strike the right

balance between mobility and stability. During the operation, joint stability should be carefully checked in every direction to prevent dislocation and impingement. Larger head size is recommended. The surgeon must be aware of the possibility of cup malposition, and intraoperative radiography of both hips can be helpful.

Several researches have suggested an increased risk of dislocation in RA patients, too [108–110]. Several factors may contribute to this. Patients with RA have a higher risk of developing secondary sarcopenia and osteoporosis due to chronic inflammation, decreased physical activity caused by pain and deformity of the joints, and medical treatment, such as the use of GCs [111–115]. Acetabular protrusion secondary to osteoporosis may increase the risk of impingement and create a short lever arm, increasing the risk of dislocation. On the other hand, a lower BMI is common in patients with RA, which may result in surgeons using a small head during THA thus increasing the risk of dislocation. In addition, impaired abductor strength and function secondary to sarcopenia also affect hip stability. Therefore, acetabular reconstruction in RA patients should focus on reconstructing hip center of rotation and abductor mechanism.

20.9.6 Venous Thromboembolism

Theoretically, the risk of venous thromboembolism (VTE) is higher in patients with IA than in the general population as a consequence of the chronic systemic inflammation, which induces endothelial activation, increases tissue factor expression, and inhibits endogenous anticoagulants and fibrinolysis. Interestingly, the results on the incidence of VTE in RA and AS patients after THA are controversial [116–119]. In clinical practice, the surgeon team must keep in mind that VTE risk stratification in patients with IA is based on balancing the risk of thromboembolism against that of bleeding [120]. A high risk of VTE results from a preoperative hypercoagulability status, including antiphospholipid syndrome (APS), intraoperative activation of the coagula-

tion system, and postoperative immobilization. In contrast, the bleeding risk increases with previous hemorrhagic events, thrombocytopenia, use of NSAIDs, and congenital or acquired hemorrhagic syndromes. Hence, the administration of subcutaneous low-molecular-weight heparin (LMWH) must be performed cautiously to prevent adverse bleeding events. Other practical management strategies for VTE and bleeding include avoiding dehydration, mobilizing patients as early and as much as tolerated, and using antithrombotic stockings and/or intermittent pneumatic compression devices (IPCD).

Aspirin is an irreversible inhibitor of the constitutive isoform of platelet COX, meaning the return of platelet aggregation function is unrelated to its half-life. Consequently, aspirin should be withheld for 5–7 days before surgery to allow for the formation of sufficient new platelets. Usually, the use of aspirin may safely resume 24–48 h postoperatively.

20.9.7 Surgical Site Infections

Surgical site infections or periprosthetic infections are the most common complications of THA in IA patients. The overall incidence of infection is higher in patients with IA, especially in RA, than that in non-rheumatic patients [108, 121–124]. The increased risk of infection has been predominantly attributed to high disease activity and therapy with immunosuppressive medications, including GCs, csDMARDs, and biologics. Careful perioperative medication management is the best intervention to minimize the infection risk since THA itself presents an increased infection risk, and its details are discussed above.

Patients with RA have a high wound healing complication rate. Special attention should be paid to achieving intraoperative hemostasis, and surgeons should have a low threshold for utilizing drains to avoid hematoma formation. Meticulous wound closure is paramount. Current guidelines suggest the use of cefazolin, vancomycin, or clindamycin in cases of beta-lactam allergy for total joint replacement [125]. The

optimal timing and duration of prophylactic antibiotics in patients with IA after THA remains controversial. We recommend that the first dose of intravenous prophylactic antibiotics should start within 30 min before tourniquet inflation and stop within 48 h after THA.

Acute prosthetic infections within 1 month after surgery are attributed to contamination of surgical site, but late infections within 1 year after surgery are seen after episodes of sepsis or bacteremia, and oral flora may play a role [126]. While *Staphylococcus aureus* is not typically a constituent of the oral microbiome, RA patients may harbor *S. aureus* in their oral cavity [127].

20.10 Summary

In view of the potential impact of disease activity, medications, and comorbidities on the outcomes of THA in IA patients, perioperative management necessarily is a multidisciplinary and complex task. The concept of an MDT has been developed for many years and has received broad recognition in clinical practice [128, 129]. The MDT unites orthopedic surgeons, rheumatologists, anesthesiologists, rehabilitation specialists, and specialist nurses in close collaboration. We recommend a "one-stop shop" MDT management program [129, 130]. After a preliminary screening ordered by the specialist nurse, IA patients scheduled for THA receive an appointment with our MDT staff in an outpatient setting. In our experience, this model is both efficient and effective with a low complication rate and a high patient satisfaction rate.

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Total Hip Arthroplasty for Avascular Necrosis (AVN) of the Femoral Head

21

Wang Deng and Dejin Yang

Key Points

1. Avascular necrosis (AVN) of the femoral head is an important etiology of joint damage requiring total hip arthroplasty (THA), especially in Eastern countries.
2. THA for AVN has higher revision rates and worse outcomes than THA performed for osteoarthritis.
3. THA after hip-preserving procedures for AVN presents specific technical challenges and results in more perioperative complications than primary THA without such prior surgery.

Avascular necrosis (AVN) of the femoral head is a progressive disease initially characterized by local ischemia and osteocyte necrosis, which causes high intraosseous pressure that further aggravates the ischemia [1]. Although the exact pathogenesis of AVN remains unclear, impaired blood supply is the most widely accepted underlying mechanism [2]. Corticosteroid use and alcohol abuse are well-known etiologies, but 20–40% of AVN are idiopathic [2, 3]. If left untreated, the head will eventually collapse in 80% of hips with AVN, and they will progress to secondary osteoarthritis [4].

After the head collapse, total hip arthroplasty (THA) is often inevitable [5]. Statistics in the United States during 1992–2008 showed an increasing rate of THA and a decreasing rate of joint-preserving procedures in the management of AVN [6]. Given that most patients are diagnosed with AVN at relatively young ages of their lives [3], the disease brings a tremendous socioeconomic burden to the patients' families and society overall. Hence, performing a well-functioning THA with excellent long-term survival is of great importance.

In this chapter, we focus on the epidemiology of AVN and the indications, implant selection, and survivorship of THA as the initial treatment for AVN and after failed joint-preserving procedures.

21.1 Epidemiology of AVN and THA for AVN

Estimates are that over 20 million patients worldwide live with AVN [5–7]. However, the prevalence varies among different nations and regions. Among Asian countries, the prevalence of AVN is reported to be 28.9/100,000 in Korea with an average number of new cases of approximately 14,000 annually [8]. The annual incidence of AVN is estimated to be 1.91/100,000 in Japan, resulting in over 14,000 new cases diagnosed each year [9]. A recent representative national

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survey in China found that the overall prevalence of AVN is as high as 0.725%, with an estimated 8.12 million AVN cases among the population [10]. In Western countries, the prevalence is lower than that in Asia. About 10,000–20,000 new AVN cases are diagnosed annually in the United States [6, 7]. The different frequencies with which AVN occurs in the East and the West result in substantially different proportions of AVN patients among all THAs. Only about 3–12% of THAs are performed for AVN in Western countries [5, 11, 12], whereas, in China, AVN patients account for as many as 30.5% of all THA patients [7].

21.2 Indication for THA

In the clinical decision-making on the optimal treatment for patients diagnosed with AVN, assessing the extent of the necrosis is critical because it directly affects the treatment options. Magnetic resonance imaging and computed tomography scans are necessary for the pre-collapse and early subchondral fracture stages. Different staging systems (Ficat and Arlet, Steinberg, Association Research Circulation Osseous, and the Japanese Investigation Committee) have been proposed to guide decisions [13]. Asymptomatic osteonecrosis of the hip should not be treated with any surgical procedure but by observation or conservative management.

Joint-preserving techniques, especially core decompression (CD) with different supporting structures and adjuvants (e.g., autologous mesenchymal stem cells, platelet-rich plasma), have been recommended for early symptomatic pre-collapse stages with small-to-medial-size lesions [14]. Positive results of these interventions have been demonstrated in that they slow down disease progression [15].

Commonly, a femoral head depression of >2 mm or acetabular changes are considered radiographic indications for THA [2]. Although THA shows good results for pain relief and functional restoration in AVN, it should be performed with great prudence in young and active patients. Complications after THA may result in the need for revision and devastating outcomes later in life [4]. Some underlying conditions, such as alcohol abuse and corticosteroid treatment, increase the risk of infection and decrease bone density.

21.3 Implant Selection

The main concerns in implant selection for THA in AVN are patients' young age and active lifestyle. Because metal-on-metal bearing surfaces show a high rate of wear with early periprosthetic osteolysis and loosening, they are not recommended for patients with AVN [16]. Regarding the choice of polyethylene, conventional polyethylene should be replaced with highly cross-linked polyethylene (HXLPE) to minimize wear and avoid debris-induced osteolysis and implant loosening. Min et al. [17] reported excellent survivorship (100% during a minimum 10-year follow-up) for HXLPE with a metal femoral head and a mean liner wear of 0.037 mm per year in THA for AVN. Hart et al. [18] found no case of polyethylene wear of >1 mm among 461 hips with an HXLPE liner for AVN after a median follow-up of 10 years. Based on these studies, we conclude that HXLPE-bearing surfaces are safe and have acceptable long-term survival.

Ceramic surface represents another material option with good long-term outcome in young patients with AVN [19]. Baek and Kim [20] reported an implant survival rate of 100% and no osteolysis at an average of 7.1 years after 71 THA cases when ceramic-bearing surfaces were used in patients with AVN younger than 50 years. However, the component noise occurred in nearly 20% of patients and two intraoperative liner fractures happened. Some intrinsic shortcomings of ceramic surfaces, including fractures and squeaking hips, should be explained to patients and weighed against the advantage of resistance to wear. In our center, ceramic-on-ceramic or ceramic-on-HXLPE represent the most common two choices.

21.4   Survivorship

Generally, THA for AVN has a higher revision rate and worse outcomes than THA performed for primary hip osteoarthritis because of the younger age and higher activity level of the patients [21]. Mont et al. [2] performed a review of 23 studies published after 2006, with the mean follow-up ranging from 1.7–18 years. Among these publications, eight studies reached the mean follow-up, and six of them had over 90% survivorship. Hart et al. [18] reported a 93.4% survivorship after 15 years in one of the largest cohorts investigated so far (461 hips in 413 patients with AVN). The 2017 Annual Report of the *Australian Orthopaedic Association National Joint Replacement Registry* defined a 15-year cumulative revision risk of 10.8% (9.5–12.2%) for patients with AVN [12]. THA for AVN has a higher risk for postoperative infection and may lead to devastating outcomes. Managing the infection risk, such as reducing corticosteroid dosage when possible or improving general conditions, should get particular attention in THA for AVN.

21.5   THA After Hip-Preserving Strategy

Hip-preserving surgeries, which aim to delay THA, have drawn great attention from surgeons and young patients with early-stage AVN. These interventions include CD and femoral osteotomy. However, a large proportion of patients undergoing hip-preserving surgery progress to the post-collapse stage regardless. Performing THA in these patients requires careful planning, skill, and experience on the part of the surgeon, since it may entail substantial technical challenges and lead to more perioperative complications than those seen with primary THA in AVN, further impairing long-term outcomes in these patients.

21.5.1   THA After Core Decompression (CD)

After the treatment of CD for AVN, collapse of the femoral head will still occur in 10–70% patients and lead to THA within 2 years (Fig. 21.1) [22]. Although CD is considered a minimally invasive procedure, the possibility of negative effects on the outcomes of conversion THA after failed CD is reasonable, including intraoperative fractures and postoperative metal wear debris, radiolucent lines, function, and survivorship.

A recent meta-analysis of five high-quality retrospective cohort studies concluded that prior CD did not impair early survivorship or the post-operative Harris Hip Score (HHS) [23]. Among the included 110 patients who had undergone THA after CD, two cases had to be revised, one for periacetabular osteolytic lesions and the other for acetabular loosening. The mean postoperative HHS ranged from 85 to 97, with a proportion of patients achieving the maximum score of 100.

The channel drilled during CD inevitably interferes with the proximal femur, which is also the bone bed of the femoral component in THA. In fact, in cases after CD with tantalum

Fig. 21.1 Radiograph of a patient with AVN of the right femoral head. The femoral head collapsed after core decompression with artificial bone

rods, the bone of the greater trochanter, even the entire proximal femur, may be destroyed when removing the rods. Intraoperative fractures during THA are more likely to occur around the CD channel and the greater trochanter, especially during broaching to remove a tantalum rod, the femoral canal preparation, and stem insertion. Ryan et al. [24] reported that conversion THA from failed free vascularized fibular grafting also resulted in more intraoperative fractures than primary THA for AVN. Surgeons need to be extremely cautious when preparing the femoral stem bed in the proximal femur with CD channel. Cerclage cables should be available to fix femoral fractures.

Given the presence of tantalum debris in patients with prior CD and tantalum rod insertion, concerns regarding osteolysis and radiolucent lines have lingered. The mechanism of metal debris for osteolysis or radiolucent lines may rely on the inflammatory reaction and disruption of the process of bone ingrowth in cementless THA. Both antegrade (removal of the tantalum rod from the tip to the butt at the lateral femoral cortex) and retrograde approaches (removal of the tantalum rod from the butt at the lateral femoral cortex to the proximal tip) have been attempted [23]. Zhao et al. [25] compared the two approaches and found that the antegrade procedure resulted not only in shorter operation times and less blood loss but also in less tantalum debris and radiolucency postoperatively.

New generation support structures, i.e., cages (Fig. 21.2), used in CD showed encouraging early clinical follow-up results with osteosclerosis around the cages. These 3D-printed hollow structures provide more space for pressure relief and have higher permeability for pasty artificial bone grafts. Moreover, these cages, which are shorter than conventional tantalum robs, allow surgeons to avoid having to cut through them during the femoral osteotomy in THA. This type of design will simplify the preparation of the proximal femur during THA and address the concern of metal debris.

Fig. 21.2 Postoperative radiograph after core decompression using short hollow 3D-printed titanium cages in a patient with bilateral AVN of the femoral head. Osteosclerosis around the cages is visible after a follow-up of 6 months. The patient experienced complete pain relief

21.5.2 THA After Failed Femoral Osteotomy

Osteotomy represents another hip-preserving concept and surgical treatment option that includes curved intertrochanteric varus osteotomy and transtrochanteric rotational osteotomy. Osteotomies are intended to create a distance between the necrotic bone and the weight-bearing region to delay the collapse of the femoral head and relieve patients' symptoms. While survivorship of more than 80% has been reported for short- and mid-term follow-ups, these osteotomies are less frequently performed because their indications are limited to small lesions and a detrimental influence on subsequent THA may occur [2]. When these interventions fail, extensive procedures are often required during conversion THA because of the deformed proximal femur. A recent meta-analysis found significantly longer operative time and significantly more blood loss in THA after transtrochanteric rotational osteotomy than in THA without previous osteotomy [26]. Moreover, it increased the rate of stem malalignment. This demonstrates that failed osteotomy increases the technical demands during subsequent THA. Employing intraoperative navigation and

robotics and choosing a modular stem may help to obtain an accurate stem position.

21.6   Summary

THA is the definitive surgical treatment in the post-collapse stage of AVN. However, the comparatively young age and high activity levels of patients place exceptional demands on the skills and techniques of surgeons. Optimal timing of the operation, adequate implant choice, and careful intraoperative management allow achieving satisfactory outcomes of THA with long survivorship in this population.

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Part IV

How to Avoid the Pitfalls in the Primary Total Hip Arthroplasty

How to Achieve a Stable Hip Arthroplasty

22

Qing Liu

Key Points

1. Most unstable prosthetic hips occur soon after surgery. Dislocation after total hip arthroplasty is caused by various complex factors.
2. The dislocation rate after total hip arthroplasty is higher when using a posterolateral approach than anterolateral or direct lateral approach.
3. A large femoral head of the prosthesis can decrease the dislocation rate compared to a smaller head.
4. Closed reduction may sufficiently treat some early dislocations.
5. An inappropriate prothesis location and impingement require revision surgery whereas unbalanced soft tissue can be corrected during open reduction.

22.1 Background

With improvements in surgical techniques and prosthesis design, the rate of dislocations after total hip arthroplasty (THA) has decreased to 0–1.5% in recent reports [1, 2] compared to 0.05–3.9% [3–5]. Nevertheless, postoperative dislocation remains the most common early com-

plication and one of the most common causes of early revision after primary THA.

Consequently, surgeons must identify patients who are likely to dislocate postoperatively before surgery. Awareness of the factors that predict dislocation can help surgeons identify high-risk patients and plan appropriate intervention strategies [6]. In that regard, two basic recommendations exist to reduce the dislocation rate: ensuring an accurate implant position and choosing a large-diameter femoral head [7]. However, the problem of instability after THA remains unsolved.

22.2 Underlying Mechanisms of Dislocation

Most prosthetic hips are unstable in one of two movement patterns. Hip flexion, adduction, and internal rotation may cause a posterior dislocation, typically in patients who sit in low chairs and then rise. Extension, adduction, and external rotation result in the less common anterior dislocations.

Another mechanism of dislocation occurs most frequently after an anterior surgical approach and with excessive anteversion of one or both components. Surgeons try to prevent dislocation after THA by implanting the prosthesis as accurately as possible and using a larger head. Nevertheless, modern surgical techniques and hip

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prostheses have not been able to eliminate dislocation after THA to date. Hence, studies have focused mainly on soft tissue laxity and imbalance, which can increase the dislocation rate either individually or in combination [8–10].

22.3 Time to Dislocation

Most dislocations occur soon after surgery. Woo and Morrey [11] found that 59% of dislocations occurred within 3 months and 77% within 1 year postoperatively. They also found that 6% of dislocations occurred 5 years after surgery. Dislocations that occur for the first time 5 years or more after the operation are defined as late dislocations [12]. Late dislocations are associated with a higher risk of recurrent dislocation than early dislocations. Coventry [13] reviewed late dislocations in 32 patients whose first dislocation occurred between 5 and 10 years postoperatively and suggested that these patients had a greater range of motion than the overall THA population.

22.4 Risk Factors for Unstable Hip Arthroplasty

Numerous studies have explored the causes of postoperative hip joint dislocations [10]. These relate to the characteristics of patients, such as elder age, underlying comorbidities, gender, and the diagnosis leading to THA. The factors shown or suspected to be associated with an unstable THA are distinguished into preoperative, perioperative, and postoperative variables (Table 22.1).

Surgeons should assess the dislocation risk of patients in detail, including the preoperative dis-

Table 22.1 Risk factors for dislocation after total hip arthroplasty

Preoperative	Perioperative	Postoperative
Sex	Approach	Rehabilitation
Age	Cup inclination	Range of
Diagnosis	Cup version	motion
	Component head size	Subluxation
	Leg length discrepancy	
	Trochanter problem	

ease features, patient characteristics, perioperative technique/design considerations, and postsurgical variables.

22.5 Patient Characteristics

Many studies have explored patient-inherent factors, including the etiology of hip disease factors, older age, female gender, BMI > 30, an American Society of Anesthesiologists score > 3, surgical volume, and neuromuscular disorders. Female gender has been consistently proven to be an important risk factor for dislocations that occur twice as frequently in females than in males [14]. The risk increases with age, and one series reported that the rate of instability in those older than 80 years was 4% [15].

22.6 Disease Features

Generally speaking, most THAs are performed for one of five diagnoses: degenerative arthritis, rheumatoid arthritis, avascular necrosis, congenital hip dislocation, or trauma. The frequency of these diagnoses in a controlled series was compared with that in patient populations with these unstable hips [16]. Among them, THA after femoral neck fractures showed a dislocation rate of 7.6%.

22.7 Psychological Factors

There is clear evidence of a markedly increased incidence of postoperative hip dislocation with excessive alcohol consumption. However, emotional problems were not found to be contributing factors to instability [17]. Cerebral dysfunction associated with increased age has also been shown to be a significant risk factor [18].

22.8 Prior Surgery

Prior hip surgery has been recognized to play a significant role in subsequent hip instability. Williams et al. [19] noted a 0.6% incidence of

dislocations after primary procedures and a 20% incidence after THA revisions. Combining the data of several large series, they revealed that among 4753 patients who had undergone primary procedures, dislocations occurred in 2%. This contrasted with 82 dislocations (6.3%) after 1290 revision operations. In the Mayo Clinic experience with 10,500 THAs, instability developed in 2.4% of the 7241 THA patients who did not have previous surgery and in 4.8% of the 3259 procedures in patients who had some type of previous hip surgery ($P < 0.001$) [20].

22.9 Surgeon's Experience

One study examining the relationship between surgical experience and postoperative instability after THA revealed a direct correlation, with the patients of less experienced surgeons having a higher dislocation rate. However, no difference was observed among surgeons who had performed more than 30 procedures [21].

22.10 Surgical Approach

The posterior surgical approach to the hip has been associated with an up to threefold increase in hip instability (4%) compared with the anterior approach (1.3%) [22]. Mallory et al. [9] performed an extensive review of the literature and documented a 4% instability rate after 11,000 procedures described by 11 authors who used a posterior approach. The anterior approach in 6677 procedures performed by 10 authors had a rate of 2.1% dislocation. The authors described an anterior split technique that resulted in a 0.8% dislocation rate after 1518 operations.

22.11 Component Size

The rationale behind using a large head is that substantial displacement must occur before the hip can dislocate, which exerts significant tension on the soft tissues. However, previous experience did not confirm the translation of this logic into
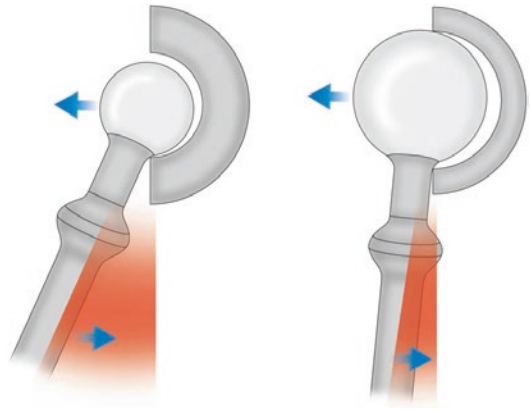

Fig. 22.1 The femoro-acetabular component-on-component impingement results in levering out the femoral head. On the right, larger heads with a higher head-to-neck ratio may improve the range of motion before impingement occurs

clinical practice. Woo and Morrey [4] reviewed the Mayo Clinic's experience with over 10,000 procedures. Among the 331 dislocations, they observed an incidence of 2.9% and 3.3% instability in the 22 mm implants and 32 mm implants, respectively. This difference was not statistically significant. More recent clinical data clearly demonstrate a correlation between smaller head size and hip instability [23]. The jump distance and range of motion without impingement are both greater in the larger femoral head than in the smaller femoral head. Kelley et al. [24] made an interesting observation concerning the relationship between the head/cup ratio and instability: With a 22 mm femoral head, the incidence of dislocation was 14% in cups greater than 62 mm in diameter, and 4% in 60 mm or smaller acetabular implants (Fig. 22.1).

22.12 Impingement

Impingement describes the contact of two extra-articular structures during the full range of motion in the hip joint thereby creating torque that can lead to dislocation of the femoral head. Impingement may occur between the prosthetic femoral neck and the liner or other fixed objects, such as cement, osteophytes, or soft tissue.

22.13 Skirted Neck Design

Elongated modular head/neck implants frequently have a "skirt." A review of Lawton R L, Morrey [25] revealed a sixfold higher instability rate compared with a non-skirted device, but both groups had a selection bias inherent in the clinical selection of the long-necked, skirted device.

22.14 Acetabular Liner Lips

This acetabular design may place the hip at risk of dislocation by promoting impingement [26]. Modular components provide surgeons with more flexibility in positioning the implant. Although the theoretical advantage of acetabular lip liners appears obvious, there are some potential disadvantages of increasing the extent of one portion of the socket and limiting the range of motion. Krushell et al. [27] demonstrated that the range of motion with this design was not significantly altered but simply reoriented. The increased surface area in contact with the femoral head may result in increased wear debris and osteolysis and eventually render the hip more unstable. In fact, case reports of femoral loosening have also been associated with impingement on an extended posterior wall acetabular component [5].

22.15 Offset

A statistically significant correlation was found between hips with decreased offset and instability [8]. This is logical because the decreased offset decreases the range of motion before impingement occurs, and the myofascial tension of the gluteus musculature is increased by the increased offset. Fortunately, the amount of offset can be controlled with modular head and neck implants and eccentric cup liners, and this should be carefully assessed. Abductor weakness was described as a constant feature in several instability studies [6].

22.16 Limb Length Inequality

Some surgeons try to achieve a stable hip by slightly increasing the leg length in the belief that lengthening the leg will increase hip stability. LLD results in "soft tissue imbalance" around the hip joint, which is different from soft tissue laxity (Dorr dislocation Type II). Leg length shortening is a common factor in hip instability. However, relative leg length as a measure of myofascial tension has not been shown to be associated with instability. Fackler and Poss [28] reported that the unstable hip was about 1.5 mm longer than the non-operated leg. Coventry [11] found that the leg length was equal to the preoperative leg length in 75% of 32 late hip dislocations and shorter in only 25%.

22.17 Component Orientation

Component orientation has been recognized as a critical factor in the stability of artificial joints. Optimal acetabular orientation is difficult to achieve consistently. Variations in positioning the patient on the operating table lead to inaccurate estimates of cup orientation during surgery. An unnoticed forward rotation of the pelvis in the lateral decubitus position causes inadvertent retroverted positioning of the cup. This topic is discussed in more detail in the following chapters.

Regardless, acetabular orientation is probably the most sensitive variable in the predisposition to hip dislocation after THA. Cup inclination has been studied by several investigators, and most studies have not found a close correlation unless the cup is placed in an extreme position. The study by Lewinnek et al. [29] demonstrated a "safe" cup position range for an anteversion of $15 \pm 10°$ and abduction of $40 \pm 10°$. In their experience, instability was 1.5% within this range of cup orientation and 6% outside this range. This difference in stability was statistically significant ($P < 0.05$). Although dislocations within the "safe range" were less frequent, the "safe range" is relatively wide and, consequently, will not completely avoid dislocations.

Relatively little attention has been paid to the anteversion of the femoral component other than recommendations that this should be 15°. The rotation of the femoral component is difficult, if not impossible, to accurately measure using radiography. Fackler and Poss [28] showed that 44% of their 34 dislocation patients had a malposition of one or both components, compared with only 6% in patients without dislocation. Importantly, they demonstrated that the most common orientation error was excessive anteversion of the femoral component, and this was independent of whether trochanteric osteotomy was performed as the surgical approach.

22.18 Postoperative Variables

One interesting study found no difference in the rate of instability whether patients were rehabilitated in an acute care facility or in a formal rehabilitation unit [30]. None of the included studies showed any benefit of hip precautions in preventing dislocation.

22.19 Range of Motion

The relationship between laxity of the soft tissue and stability has not been well addressed in the literature. Coventry [11] noted that patients with hip instability who experienced early dislocation showed a slight increase in internal and external rotation, whereas those with late dislocation showed a greater range of motion for flexion. The greatest overall range of motion for the five functions of flexion, abduction, adduction, and internal and external rotation has been found in individuals with late dislocations. This important observation is presumably related to the stretching of the pseudocapsule.
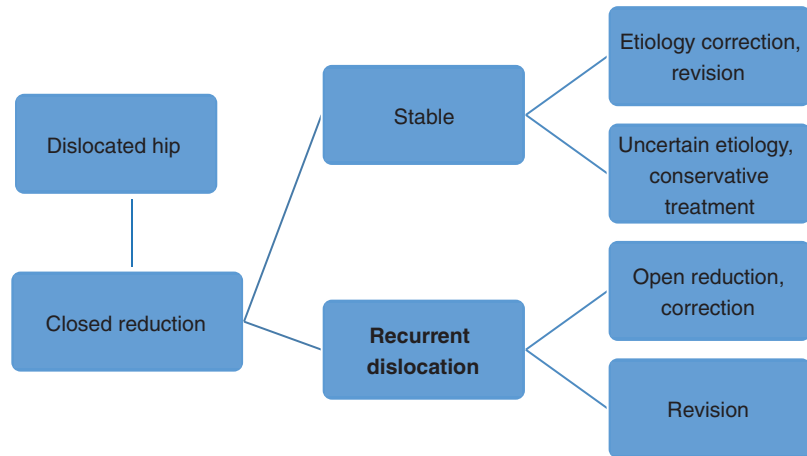
22.20 Treatment

Dislocations continue to occur after THA, and many arise in the early postoperative period. However, it is important to remember that dislocations can occur for a long time after THA. An accurate assessment of the causes of recurrence after an initial dislocation is probably not possible because numerous variables may be involved. However, a very important question for the clinician is: If my patient sustains a dislocation after THA, what are the chances of it being treated in such a way that it will not recur? The time at which dislocations occur postoperatively may be an important prognostic factor. Long-term follow-up is essential for identifying and treating these complications.

Dislocated hip prostheses should be treated with closed reduction under spinal or general anesthesia as soon as possible, regardless of whether they present as early, late, first, or recurrent dislocations. Vigorous reduction attempts under intravenous sedation should be avoided in favor of the gentler reduction that can be achieved under general anesthesia. This reduces soft tissue trauma and minimizes negative patient experiences.

After reduction, patients should be instructed about hip precautions to avoid early recurrence. Hip immobilization with a specific orthosis has not been shown to reduce the incidence of recurrent dislocation. Therefore, it is not part of our standard protocol. If the hip is unstable after reduction, and the cause of dislocation is known, etiology correction revision should be performed. Our strategy is shown in Fig. 22.2.

Fig. 22.2 Strategy for the treatment of dislocated hips after arthroplasty

22.21 Nonoperative Treatment

Nonoperative treatment in a patient with a dislocated or unstable primary THA may be effective, particularly if the initial event occurred within 3 months of the procedure. A review of the available literature on this topic is best summarized as a two-in-three chance to eliminate or prevent future recurrence by immobilizing the hip for 6–12 weeks [8]. This study also recommended closed reduction as the first-line therapy in late dislocations after THA.

22.22 Revision Surgery for Dislocation After THA

When a dislocation occurs, radiographs should be thoroughly assessed for any signs of component failure (polyethylene wear, implant loosening, and migration).

If closed reduction fails, open reduction is warranted, where the hip is reduced and soft tissue reinforcement is performed. Revision surgery should only be performed if the etiology of the dislocation can be identified.

Recurrent and late dislocations generally require surgical intervention. Component malpositioning and abductor insufficiency are the two main reasons for these dislocations. If there is a dislocation of any of the modular components (femoral head and/or acetabular liner), an open reduction should be performed to reassemble the THA.

22.23 Soft Tissue Repair/ Reinforcement

Soft tissue reinforcement and advancement of the greater trochanter may be considered in patients with avulsion or nonunion of the greater trochanter. Trochanteric advancement to address recurrent dislocations has shown highly variable outcomes. Although the indications for soft tissue reinforcement are not firmly established, it is mostly performed when the complex of the posterior hip capsule and the short external rotator is severely deficient or absent in THAs that are optimally fixed and positioned.

22.24 Component Revision

There are many options for component revision, depending on the type of instability. These include revision of the acetabular and/or femoral components, exchange of modular components (acetabular liner and/or femoral head), conversion to tripolar arthroplasty, sue of larger femoral or acetabular components, and/or stem revision. Component malpositioning is one of the main causes of recurrent dislocations that can be successfully treated by component revision [8]. The decision on which component to revise relies on a thorough preoperative assessment using radiography and computed tomography and should be confirmed by the intraoperative inspection of the components during revision surgery. The femoral stem is revised when it is retroverted, when there

is insufficient offset, or if there is excessive ante-version. The use of a larger femoral head is recommended whenever possible as it increases the head-neck ratio, resulting in a higher jump distance and less impingement than those observed in small heads. These considerations reflect the complex interplay of many factors involved in dislocation after THA. What can be said is that adequate acetabular anteversion may be more critical with a posterior approach.

22.25 Tripolar Arthroplasty

This prosthesis consists of a small femoral head inside a polyethylene shell that is enclosed in a larger femoral head to reduce the likelihood of dislocation. Thus, tripolar arthroplasty involves two planes of motion: the one between the small femoral head and the polyethylene shell and the one between the polyethylene shell and the femoral head in the acetabulum. However, this arthroplasty can be associated with groin pain and medial or superior migration of the prosthesis into the pelvis over time. Hence, its indication is mainly limited to elderly and debilitated patients with insufficient acetabular bone stock that precludes the use of constrained liners. Grigoris et al. [31] were the first to treat recurrent dislocations with tripolar arthroplasty and reported a favorable outcome.

22.26 Constrained Acetabular Liners

Constrained liners significantly decrease the hip range of motion. They are often used in patients with medical conditions such as those with neuromuscular dysfunction, Parkinson's disease, dementia, or alcohol abuse who may not adhere to hip precautions, and in patients with insufficient soft tissue tension due to deficient abductor repair. These patients may benefit from open reduction and insertion of a constrained liner.

However, constrained liner increases the joint contact forces that are transferred to the femoral and acetabular bone interfaces. This force transfer enhances micromotion, which may lead to early loosening and require salvage treatment.

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How to Control Leg Length during Total Hip Arthroplasty

23

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Key Points

1. Careful preoperative design, templating, and accurate realization of the key points of the preoperative design intraoperatively help avoid leg length discrepancies after total hip arthroplasty.
2. The length of the legs should be compared by various methods during the operation to identify errors and correct them to prevent postoperative leg length discrepancy.
3. Postoperative leg length discrepancies can be conservatively treated in the vast majority of cases.

A leg length discrepancy (LLD) after total hip arthroplasty (THA) is one of the most common complications, regardless of whether the legs were equal in length before surgery [1]. Consequently, it is an important aspect of THA to accurately maintain or restore the length of the concerned leg, even though this remains difficult to achieve. Although LLD is clinically acceptable in most patients, some have discomfort or symptoms that may include limping, low back pain, and instability of the hip [2–4].

Avoiding LLD during THA and the best postoperative treatment are hot topics. In this chapter, we discuss the types of patients and conditions that frequently lead to LLD, what kind of methods are used to assess leg length, and how to accurately reconstruct the length of the concerned leg.

23.1 Preoperative Evaluation

Careful clinical and imaging evaluations are very important before THA. The physical examination of patients may establish a functional LLD, such as seen in lumbar scoliosis, pelvic tilt, and other conditions [5]. This assessment is helpful in judging whether the functional LLD is easy to correct, for example, whether it can be corrected passively. If the deformity cannot be corrected, such as in patients with fixed scoliosis, the position of the prosthesis will have to be adjusted according to the actual situation [6].

Some patients, for example, those with dysplasia of the hip, coxa vara, pelvic tilt, scoliosis, or an absolute LLD before THA, have a particularly high risk of postoperative LLD [7–9]. The deformity of the pelvis and spine should be fully evaluated before surgery, and the gait and standing posture of patients should be monitored. In fixed and uncorrectable pelvic and spinal deformities, LLD should be carefully assessed and properly treated.

The length of both legs is generally measured from the anterior superior iliac spine or greater trochanter to the medial malleolus. In patients

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with knee deformities, the length from the trochanter to the lateral knee gap and the length from the lateral knee gap to the lateral ankle can be measured separately and compared between the legs.

The preoperative imaging evaluation includes radiographs of the hip joints on both sides in the anteroposterior and lateral views, an anteroposterior pelvic radiograph, and a lower extremity full-length film. If combined with spinal deformities, radiographs of the full length of the spine in the anteroposterior and lateral views are required. If necessary, computed tomography scanning and 3D reconstruction can provide a more intuitive view of the deformity in individual patients.

The preoperative radiological assessment is performed by measuring the length of both legs on the full-length film to determine the objective LLD. The ischial tubercles or the lower edge of the teardrops on both sides are connected. By measuring the distance from this line to the center of the femoral head or the apex of the greater trochanter, we can determine the LLD. The measurement using a full-length film of both legs is highly recommended in patients with hip infections during childhood, unilateral dysplasia, or a high dislocation of the hip joint(). A full-length film of the legs should be taken before surgery to understand the absolute LLD and considered carefully during surgery.

Templating is very helpful prior to THA (Fig. 23.1). In patients with a unilateral hip problem, the normal side is considered the standard, and the position of the acetabulum and the femoral reconstruction and osteotomy should be based on that side. Templating determines the size and location of the acetabular and femoral prostheses and the length of the femoral calcar retention preliminarily before surgery. These reference indices should be reproduced during the operation but need to be confirmed by intraoperative radiographs. Templating is helpful to assess whether the acetabulum shifting upward, whether the femoral calcar retention length is appropriate, and other aspects thereby assisting in the avoidance of LLD.
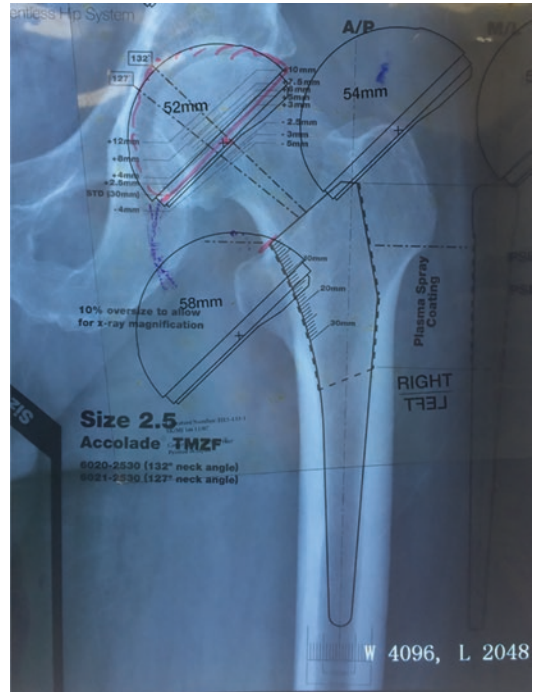

Fig. 23.1 Accurate templating + accurate intraoperative reconstruction = accurate leg length reconstruction. Accurate template measurements should be made before total hip arthroplasty, and the ideal prosthesis angle, size, position, and length should be determined. Good surgical technique reproduces the basic parameters of the preoperative design, such as prosthesis size, position, and angle. Only in this way can we achieve a perfect joint reconstruction and good results. The factors that affect the length of the leg include: the center of hip rotation has been moved too far cranially, calcar retention that is too long or too short, excessive relaxation caused by excessive soft tissue release, and excessive tension caused by insufficient soft tissue release

23.2 Evaluation of Intraoperative Leg Length

The length of both legs should be evaluated again during the operation because we should accurately reproduce the preoperative design during the operation to maintain the length of both legs as far as possible. For example, the position of the acetabulum after reconstruction and the length of the femoral calcar should be consistent with the preoperative design.

It is easiest to compare the leg length in the supine position [10]. In the lateral position, the adduction of the operated leg and the changes in posture during the operation frequently result in errors when comparing the leg length (Figs. 23.2 and 23.3). When comparing the leg length in patients with pelvic tilt and scoliosis, the influence of these deformities on the leg length has to be carefully considered.
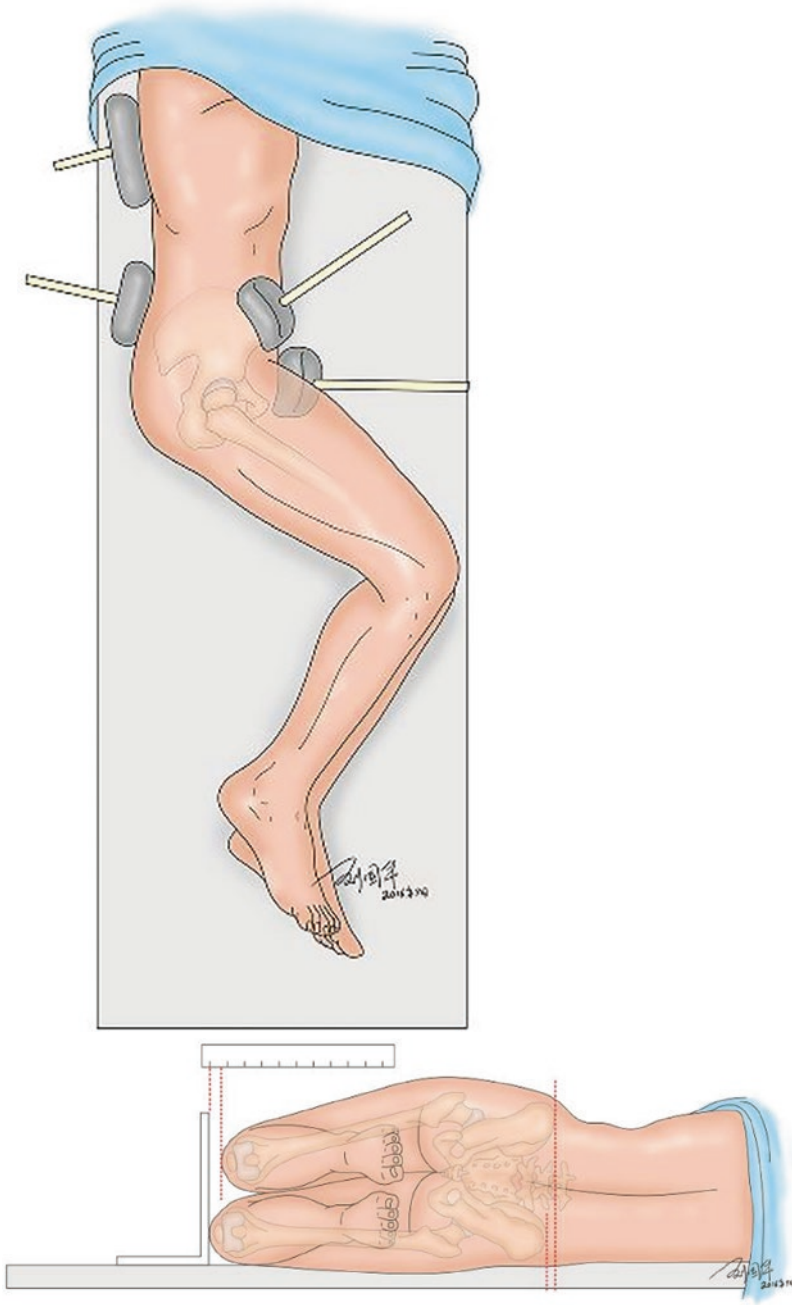
Figs. 23.2 and 23.3 The reconstruction of leg length can also be evaluated by bringing the two patellae and heels to touch during operation. But in the lateral position, the patella and heel are not at the same level due to the adduction of the operated leg
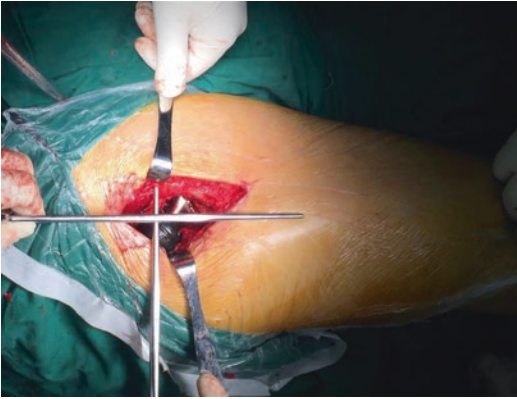
Fig. 23.4 Another method of leg length comparison is to compare the height of the greater trochanter with the position of the center of the femoral head. Intraoperatively, the reconstructed position of the femoral head can be compared

After placing the trial prosthesis during the operation, we can evaluate whether the relative height of the femoral head is appropriate and adjust the length of the femoral head and calcar and how far the prosthesis is inserted into the femoral canal according to the preoperative design to ensure an equal length of the legs (Fig. 23.4).

The tension of the periarticular soft tissue has a significant influence on the length of the leg. If too much soft tissue is released, it will generally lead to a lengthening of the operated leg. On the other hand, if the soft tissue is not released sufficiently and is too tight, this will lead to joint tension and leg shortening.

Intraoperative radiographs are also helpful in evaluating leg length (Fig. 23.5). In the lateral position, the operated leg is relatively adducted, and the hip joint is slightly flexed, which makes the assessment of intraoperative radiographs challenging. However, we can still determine whether there is an acetabular prosthesis shift upward, whether the femoral calcar retention length is consistent with the preoperative design, and assess the position of the lesser trochanter relative to the ischial tubercle, which is helpful in determining the length of the leg. Still, we should not rely on intraoperative radiography only for evaluating leg length.

Fig. 23.5 Leg length comparison on the intraoperative radiograph to ensure the correct length of the leg

This description demonstrates that each of the current methods has its own advantages and disadvantages. Only the consideration of various methods in comparison can provide the surgeon with sufficient references intraoperatively and helps to prevent being misled by the measurement errors inherent in the individual methods and achieve a length of the operated that is as equally as possible to that of the other leg.

Consequently, we advocate the simultaneous use of multiple methods to be able to refer between them. Before the operation, templating allows to measure and design the acetabular rotation center and the length of the femoral calcar retention. The position of the hip rotation center and the length of the femoral calcar should be kept consistent with the preoperative design, which can be confirmed by intraoperative radiography. During the operation, we assess the central position of the femoral head, compare the position of the greater trochanters between both sides, and test joint tightness. The

lengths of the legs are compared using body surface markers by bringing the two patellae and heels to touch the knee and heel. Through the combination of a variety of methods, LLD can usually be avoided.

23.3 Postoperative Assessment and Treatment

The postoperative evaluation of LLD should first determine whether it is a functional or true LLD. Functional LLD will mostly have existed or been predicted during the preoperative evaluation, as it is a frequent finding in fixed pelvic tilt, scoliosis, and ipsilateral or contralateral knee varus deformity. True LLD is often directly associated with THA and can be easily established on the conventional hip or full-length leg radiographs.

However, the most common reasons for LLD after THA are functional. Most patients experience LLD after THA because of preexisting deformities of the spine, pelvis, or knee joint. Some patients may perceive an LLD because of improper postoperative rehabilitation, insufficient muscle strength, or an abnormal posture [11]. Functional LLD may lead to discomfort and symptoms, such as limping, buttock soreness, and discomfort.

The general method to treat a perceived LLD is to use an insole of adequate thickness to provide the patient with the feeling that the legs are of equal length. This will improve or address limping simultaneously. With time, patients gradually adjust their body posture and adapt. In the process, the thickness of the insole is gradually reduced, until it can be removed entirely. Thus, the symptoms of functional LLD will gradually disappear within 3–6 months after THA.

Patients without clinical symptoms frequently tolerate an objective LLD after THA, and there is no need to draw a patient's attention to the fact since this may result in overfocusing.

Obvious LLD of more than 1.5 cm in length is less common, but it will lead to limping after THA and affect the lifespan of the prosthesis. Therefore, it needs to be addressed accordingly.

There is no uniform standard defining an LLD that is considered unacceptable and needs to be treated. In general, an LLD of more than 1.5 cm in length will lead to obvious clinical symptoms. An LLD of less than 1.0 cm is likely to be compensated by a tilt of the lumbar spine and pelvis without causing symptoms. However, we recommend that these patients use an insole to establish a normal mechanical environment after THA to prevent low back pain that may be caused by pelvic and spinal tilt compensation in the long term.

Most symptomatic LLDs can be treated by nonsurgical methods, such as insoles, muscle strength exercises, and adjusting the walking posture. If all conservative methods fail and the patient is obviously dissatisfied with the LLD, surgery may be the last resort. We would like to caution that correcting an LLD is often difficult. we support revision THA only in the case of obvious prosthesis malposition, where adjusting the position of the prosthesis may solve the LLD problem.

In conclusion, careful preoperative design and surgical reconstruction help prevent postoperative LLD. Although LLD is common after THA, the majority of patients have no clinical symptoms and are easy to treat and correct. Most symptomatic LLDs can be treated conservatively using appropriate means. The proportion of LLDs requiring reoperation is very low. Surgical treatment requires detailed preoperative planning, and a modular or restrictive prosthesis may be needed to restore the correct leg length as far as possible without risking postoperative dislocation.

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Periprosthetic Fractures After Total Hip Arthroplasty

24

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Key Points

1. Periprosthetic fractures are common complications of THA with high mortality and morbidity.
2. The Vancouver-UCS can inform the treatment strategy in periprosthetic femoral fractures (PFFs). Stem stability and bone stock should always be considered in the treatment of type B fractures that comprise the majority of PFFs.
3. Periprosthetic acetabular fractures (PAFs) are rare. In the absence of an established algorithm, treatment of PAFs depends on the etiology, component stability, and bone stock in the individual case.

Periprosthetic fractures belong to the most severe complications after total hip arthroplasty (THA). With more and more THAs performed and the increasing life expectancy of patients, the number of periprosthetic fractures is skyrocketing. Today, periprosthetic fractures are one of the most common reasons for revision THA. Treatment for periprosthetic fractures is usually difficult and has high complication and mortality rates.

Most periprosthetic fractures occur at the femoral site (periprosthetic femoral fractures, PFFs),

and this chapter will focus on them. Periprosthetic acetabular fractures (PAFs) are rarely reported and will be briefly discussed in the last section of this chapter.

24.1 Epidemiology

It is difficult to estimate the real prevalence of PFFs after THA, even for official registry centers, because patients who undergo reoperation do not always choose the institution of their primary THA, and many PFF patients do not undergo revision THA as their reoperation. One of the most convincing statistics by Meek et al. [1] reported that the 10-year PFF rate was 1.7% for primary THAs and 6.2% for revision THAs. According to the Swedish registry, PFFs occurred on average 7.4 years after primary THA and 3.9 years after revision THA [2]. Although many PFFs did not need revision, they remained one of the most common indications for revision THA. In the Swedish registry, PFFs represented the third most frequent reason for revision THA, accounting for 5.6% of all revision surgeries, whereas the French registry found that a PFF was the second most frequent indication for revision THAs [3].

PFF patients often have many systemic comorbidities, resulting in high general mortality and reoperation rates and worse clinical outcomes than those after revision THAs for other

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reasons. According to Phillips et al.'s [4] report on 79 PFF patients with a mean age of 86 years, the 2-year mortality rate was 49%, but most of the causes of death were not directly associated with the operation. Another report on 121 patients with a mean age of 75.5 years established that the 1-year mortality rate was 13.2% and the 1-year revision rate 16.5% [5]. In the Swedish registry, the reoperation rate was as high as 23.4%, with the most common reasons for reoperation being aseptic loosening, refracture, nonunion, and infection, usually occurring within 2 years after surgery [2].

24.2 Risk Factors and Protective Factors

According to the literature, female sex, old age, obesity, metabolic bone disease, and revision THA are the most commonly reported risk factors for PFFs [6]. An underlying diagnosis of inflammatory arthritis for primary THA is also a risk factor for PFFs because rheumatic diseases are often associated with osteoporosis. An initial femoral neck fracture is another risk factor because the patients concerned are usually osteoporotic and fall easily. Moreover, patients with peptic ulcers before THA are also a high-risk population, probably because proton pump inhibitors may reduce intestinal calcium absorption and negatively affect bone density. In contrast, an underlying diagnosis of osteoarthritis is considered a protective factor against PFFs.

The implant type also plays a role in PFFs. Generally, the incidence of PFFs is higher in cementless stems than in cemented stems. Among cemented stems, highly polished double-tapered stems, such as the CPT® (Zimmer Biomet, Warsaw, IN, USA) and Exeter® (Stryker Corp., Kalamazoo, MI, USA) stems, are associated with a higher risk of PFFs [7]. Among cementless THAs, the ProxiLock® (Zimmer Biomet, Warsaw, IN, USA) stem has been reported to have a significantly higher incidence of PFFs than other stems. Anatomic designs have also

been reported to have a higher PFF risk [8], whereas a collared design of the femoral stem is a protective factor.

More recent studies have focused on the relationship between femoral morphology and PFFs. Bigart et al. [9] found that patients who sustained a PFF following cementless THA had statistically significantly different Canal Flare Indices, Canal Calcar Ratios, and Canal Bone Ratios compared to patients without PFFs, indicating that patients who suffer a PFF have thinner distal cortices and a decreased meta-diaphyseal taper.

24.3 Diagnosis and Classification

The diagnosis of a PFF requires a complete history and radiography of the hip. Most patients have a distinct history of injury, either involving a low-energy (falling at home or while walking, etc.) or high-energy (e.g., traffic accidents) trauma. A few patients may not have such history but recall pain after twisting their leg or standing up from a chair. It is important to ask whether the patient had pain in the concerned hip before injury, as this may indicate loosening of the component, which influences the surgical options for treating the PFF. All patients with a PFF must undergo blood tests (and joint fluid aspiration, if indicated) to exclude a periprosthetic infection, as these two conditions may coexist. The anteroposterior radiograph of the pelvis is an important examination since it identifies the fracture and its location and shows the bone quality around the femoral and acetabular components, stem stability, and fracture classification. In PFFs around uncemented stems, radiolucent lines, calcar widening, new bone-implant interface gaps, and stem subsidence usually denote a loosened stem. However, the false-negative rate for diagnosing stem loosening on plain films might be as high as 20–47%. Computed tomography and digital tomosynthesis with metal artifact reduction may also help surgeons to assess implant stability. However, the gold standard for assessing stem stability remains the intraoperative evaluation.

Although there are many PFF classifications, the Vancouver-Unified Classification System (UCS) [10] is the most commonly used as it can both define the fracture type and inform the surgical strategy. According to the UCS, type A is defined as fractures in the trochanter areas and subclassified as A1 fractures (around the greater trochanter) and A2 fractures (around the lesser trochanter). UCS type B is defined as fractures occurring around the stem or at the tip of the stem. As the most common type of PFF, it accounts for more than 80% of all PFFs. Based on the stem stability and bone quality, type B is further classified into B1 (well-fixed stem), B2 (loosened stem with acceptable bone quality), and B3 (loosened with poor bone quality). UCS type C fractures occur in the distal femur, and UCS type D describes femoral shaft fractures between a hip and knee implant after arthroplasty of both joints. Typical radiographs of these types are shown in the respective sections below.

Although the Vancouver-UCS has been adopted by most authors, it has obvious limitations. First, stem stability cannot always be diagnosed on plain films, and many B2 fractures are consequently diagnosed and treated as B1 fractures. Second, the UCS does not consider fracture morphology. For instance, the treatment strategies for short transverse fractures of the distal femur are different from those for comminuted fractures of the proximal femur. Third, the UCS does not consider the stem type, even though the PFF patterns and treatment options differ between cemented and cementless stems.

Recently, Karam et al. [11] compared fracture patterns in cemented and uncemented stems. The authors classified B2 fractures into four patterns: burst fractures, clamshell fractures, reverse clamshell fractures, and spiral fractures. These patterns occurred with statistically significantly different frequencies in cemented and uncemented stems. Clamshell fractures mostly occurred around uncemented stems, while almost all burst fractures occurred around cemented implants. Spiral fractures were more common in cemented THAs.

Although the authors proposed a new subclassification system, they did not elaborate on the treatment options for the four fracture patterns. Interestingly, while the authors did not intend to propose a modification of the Vancouver-UCS, they provided further support for this classification. Regardless, this new description of PFF fracture patterns is valuable and worth further investigation.

24.4 Treatment Strategies

24.4.1 Type A1

Periprosthetic fractures in the trochanter areas might be associated with osteolysis but can also occur in patients with good bone quality. The treatment of fractures around the greater trochanter (A1) depends on whether the fracture is displaced. Fractures with less than 2 cm of displacement can be treated by immobilization and abduction braces. Most A1 fractures achieve good clinical outcomes after nonoperative treatment [6].

Surgical treatment options for A1 fractures include cerclage wiring, screws, and trochanter claw plates (Fig. 24.1). Compared to wiring, cable-plate systems show more reliable fixation, with lower nonunion and trochanter displacement rates. However, some patients with trochanter claw plates may complain of painful hips because of aseptic bursitis around the trochanter area. The general prognosis of A1 fractures is better than that of other PFF types.
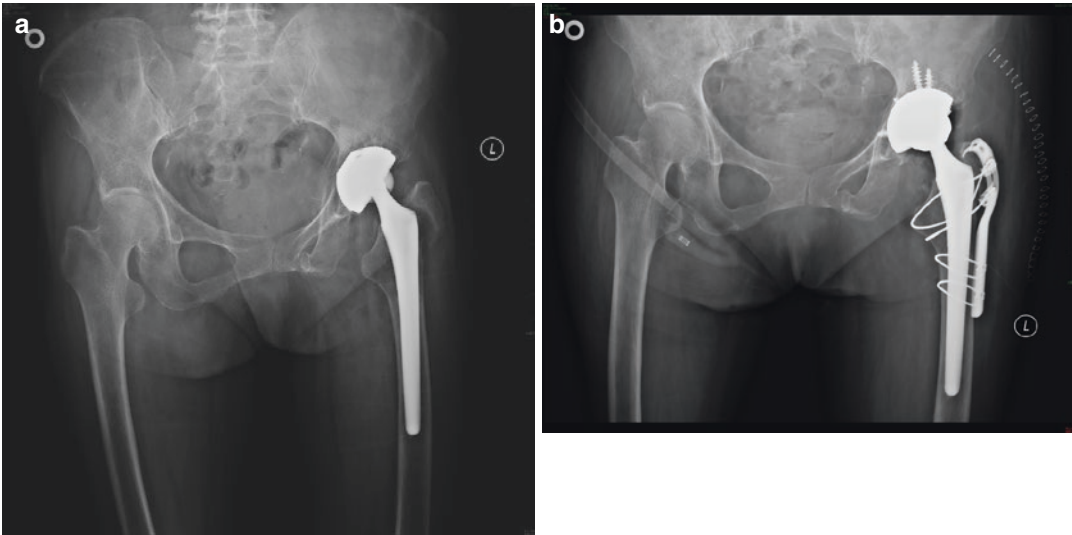
Fig. 24.1 Radiograph of a periprosthetic femoral fracture type A1. (**a**) Preoperative image. (**b**) Postoperative image after treatment with a trochanter claw plate

24.4.2 Type A2

True A2 fractures occur around the lesser trochanter, and most of them are avulsion fractures. A2 fractures should be evaluated with caution because many of them involve the femoral calcar and may be associated with stem loosening. In fact, most periprosthetic fractures of the lesser trochanter involve the stem, and consequently, should be classified as type B. Conservative treatment or simple wiring would lead to potential instability of the stem. A2 fractures with a loosened stem should be treated by revision surgery (Fig. 24.2).

24.4.3 Type B

As the most common PFF type, type B fractures are difficult to treat, and the optimal treatment remains controversial. Conservative treatment could be an option for patients with severe comorbidities or minimally displaced fractures, while most authors recommend surgical treatment [6]. Zheng et al. [12] analyzed 11 conservatively treated type B PFFs. Four of their patients

died within 1 year. The nonoperative treatment was effective in five of the remaining seven patients. In another study of 19 PFF patients who underwent conservative treatment, fractures healed in all B1 cases and 75% of B2 cases [13]. Surgical treatment of type B fractures usually depends on stem stability, bone quality, and sometimes the fracture pattern.

24.4.3.1 Type B1

B1 fractures are fractures around a stable femoral stem or slightly distal to its tip. Open reduction and internal fixation (ORIF) are recommended. Currently, there are many ORIF options, including cerclage wiring, traditional plates, cable-plate systems, and locking compression plates. Simple wiring has shown high complication and poor union rates and is no longer used with the advancement of cable-plate systems, such as the Odgen and Dall-Miles plates. Such plates are designed with proximal cables that do not interfere with the stem and cement and are fixated with screws distally. However, these plates frequently have complications, including nonunion, varus malunion, and plate breakages. Recently, locking compression plates have become popular
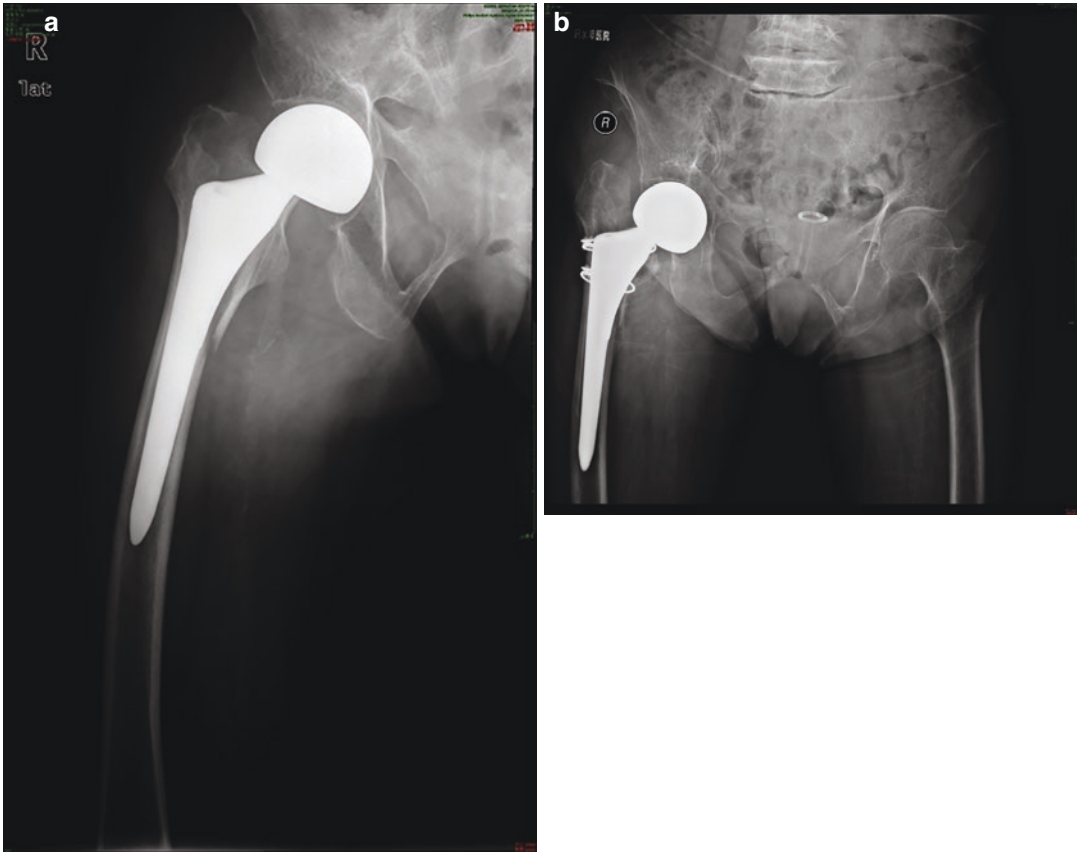
Fig. 24.2 Radiograph of a periprosthetic femoral fracture type A2. (**a**) Preoperative image before revision (**b**) Postoperative image after cerclage wiring

for B1 fractures. The locking design provides more rotational stability, and the plate is not in direct contact with the cortical bone, providing protection to the periosteum (Fig. 24.3).

Most authors agree that in type B1 fractures, the plate should extend at least two femoral diameters distal to the fracture site since otherwise, it would cause stress concentration and refracture [6, 14]. At the same time, extensive stripping of the soft tissue has a negative effect on the blood supply to the femur and results in a higher risk of nonunion. If the surgeon chooses screws for fixation, at least eight cortical screws should be fixed distally and four cortical screws proximally to the fracture. Bicortical screws might provide better axial stability but would have disastrous consequences if they fail. Surgeons may leave three to

four empty screw holes around the fracture site to increase the working length of the plate.

There are still controversies regarding whether B1 fractures require bone grafting. Although many biomechanical tests have shown the advantage of cortical allografts combined with plates for B1 fracture fixation, the increased risk of infection remains a valid concern. Hernández and Holck [15] summarized indications of bone grafting in PFFs, including short transverse B2 and B3 fractures in young patients, and previously failed PFF treatment with comminuted medial cortices or fracture reabsorption.

The high failure rate of surgical treatment for B1 fractures is mostly due to the use of simple fixation modes and misdiagnosis of B2 fractures as B1 fractures. Lindahl et al. [2] found that about
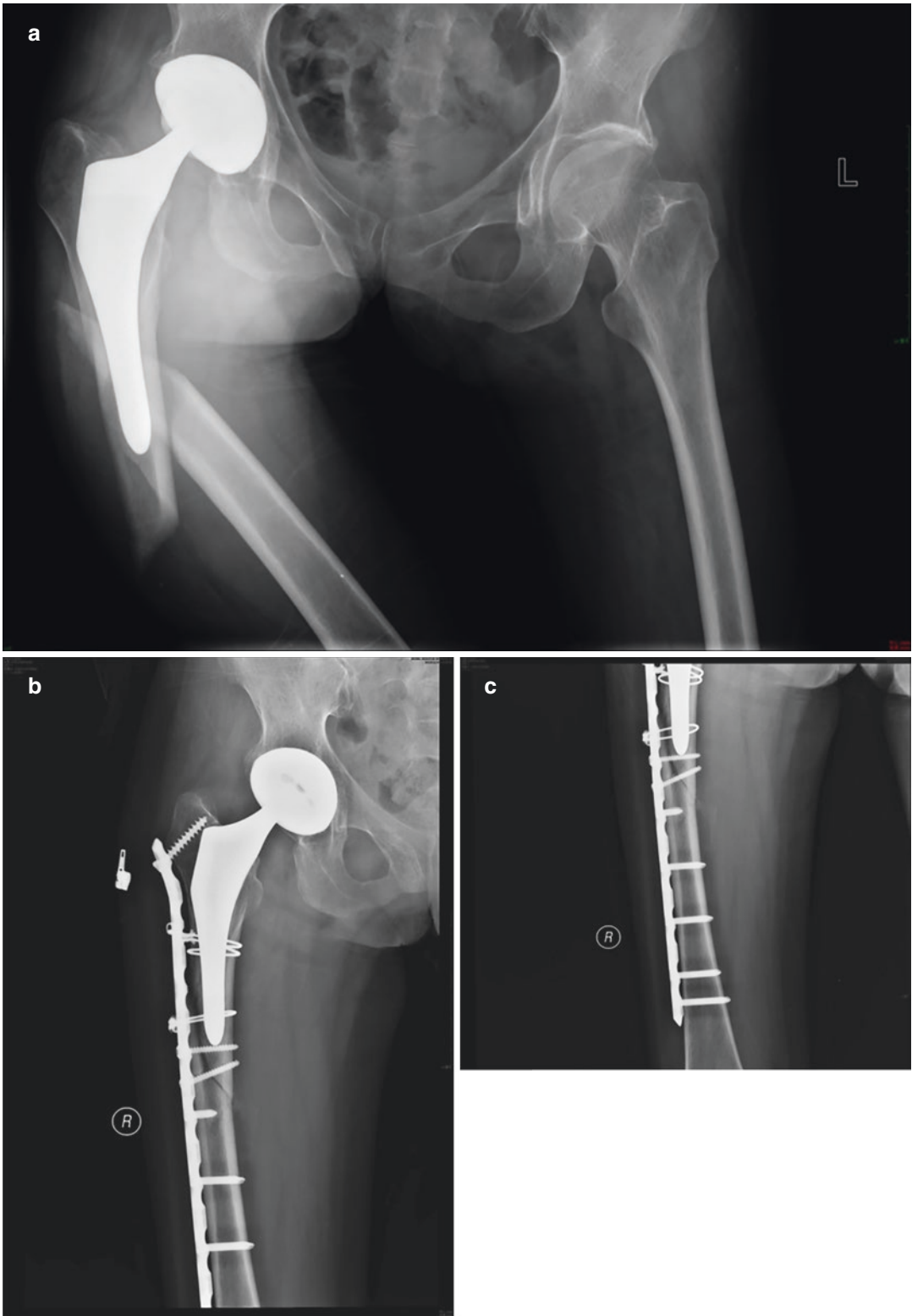
Fig. 24.3 Radiograph of a periprosthetic femoral fracture type B1. (**a**) Preoperative image showing the fracture just distal of the stem tip. (**b**, **c**) Postoperative image after treatment with a locking compression plate
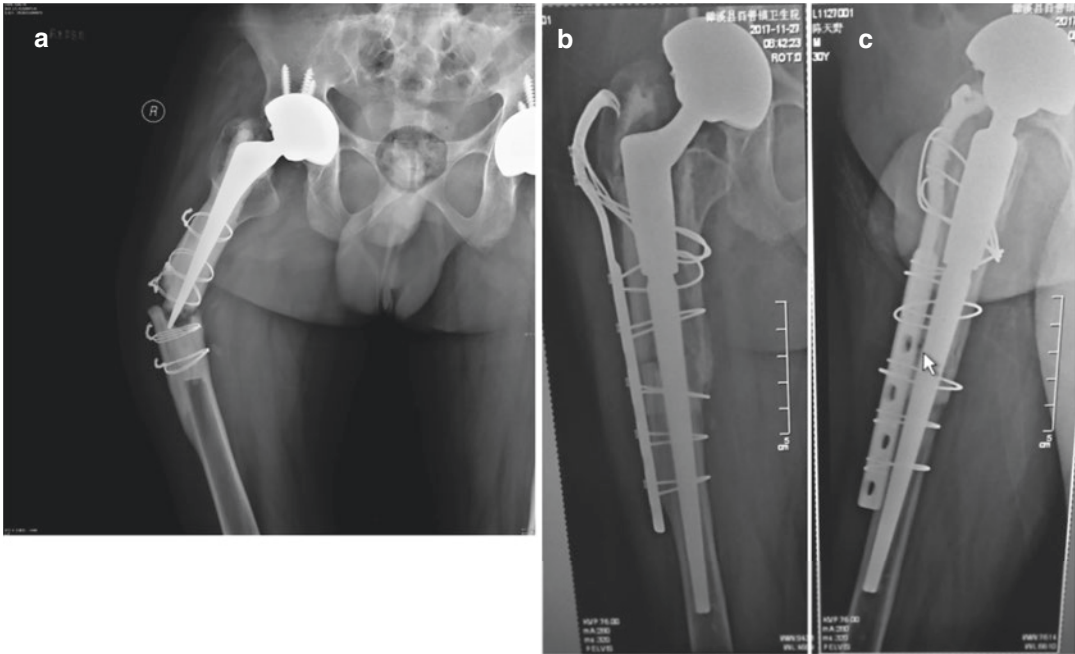
Fig. 24.4 Radiographs of short and transverse periprosthetic femoral fracture type B1. (**a**) Preoperative image. (**b**) Postoperative image after treatment with revision arthroplasty. (**c**) Two years after surgery, the patient was painless and could walk without aid

20% of patients who were diagnosed with a B1 fracture had stem loosening intraoperatively, and the diagnosis of a B1 fracture was a significant risk factor in predicting treatment failure. The authors suggested that the femoral stems in all type B fractures should be assumed to be loose unless careful intraoperative evaluation proves implant stability.

Some authors believe that revision surgery can be used in B1 fractures [16]. In the case of short transverse fractures, internal fixation might not provide enough biomechanical stability compared to intramedullary fixations, as the stress is concentrated in a small area (Fig. 24.4). This is similar to the use of either intramedullary nails or plates in the treatment of femoral shaft fractures. Buttaro et al. [14] treated 14 Vancouver B1 fractures with lateral locking compression plates (LCP), and 6 resulted in a postoperative plate breakage, all of them short transverse fractures. Naturally, most surgeons might be reluctant to remove a well-fixed femoral component and implant a longer stem only to acquire better fixation stability. However, revision THA might still be a better option for such B1 fractures. If a decision is made to perform ORIF, the patient has to be informed of the greater risk of refractures.

24.4.3.2 Types B2 and B3

B2 and B3 fractures are associated with a loosened stem and usually require revision THA with a long stem. The acetabular component should also be evaluated and revised, if necessary (Fig. 24.5).

Over the past decade, evidence has accumulated that some B2 fractures may be treated with ORIF alone without revisions. For patients with severe comorbidities who cannot tolerate revision surgery, ORIF might be a feasible alternative. Smitham et al. [17] performed ORIF in 52 Vancouver B2 PFFs around cemented polished double-tapered stems. All fractures healed, and only five patients required reoperation, suggesting that Vancouver type B2 fractures around cemented polished double-tapered stems might be treated by ORIF alone without revision, provided that the cement-bone interface is intact. Still, there have been numerous reports on poor
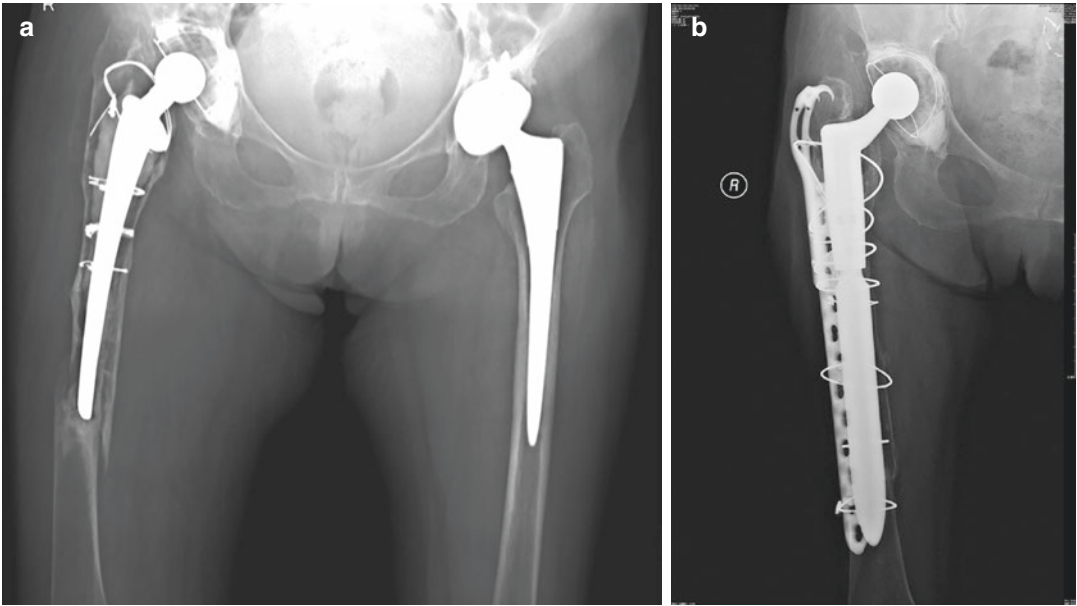
Fig. 24.5 Radiograph of a periprosthetic femoral fracture type B3. (**a**) Preoperative image. (**b**) Postoperative image after revision arthroplasty and cable-plate fixation

clinical outcomes in treating B2 fractures with fixation alone [2, 18]. Revision THA is still the first choice for most Vancouver B2 and B3 fractures [18].

Most authors recommend uncemented stems for revision THA [6, 19]. Cemented stems are only appropriate for patients in poor overall condition with a short life expectancy. The presence of bone cement may negatively influence fracture healing. In cementless stems, fully coated cylindrical stems gain primary stability by "scratch fit" and might be used in fractures with an intact isthmus. Titanium modular tapered stems (such as the Wagner SL Revision® stem, Zimmer Biomet, Warsaw, IN, USA) might provide better rotational stability but also have a greater risk of stem subsidence. Over the last decade, tapered modular fluted titanium (TMFT) stems have become popular in the treatment of PFFs, especially in fractures with substantial bone loss. Surgeons may choose from different sizes of distal components to obtain reliable primary stability and match the stem with an appropriate proximal component for bone restoration and leg-length adjustment. TMFT stems have shortened the duration of surgery and substantially simplified the treatment of PFF [19]. The distal part of femoral component could be used as a

scaffold to assemble the bone fragments and fix them with cables or plates.

Extended trochanteric osteotomy (ETO) is an effective way to retrieve the femoral stem in revision THAs and can also be applied in treating PFFs. Although ETO adds a further injury to the fractured femur, it might shorten the duration of operation and limit the damage. Moreover, the osteotomy can be performed as an extension of the fracture line. After ETO, fracture fixation is achieved by cerclage wiring, cable-plate systems, and greater trochanter plates, allowing most fractures to heal [6].

There is still controversy regarding B3 fractures. The UCS does not quantify the amount of bone loss in B3 fractures. Originally, B3 fractures required bone stock restoration with impaction bone grafting frequently applied in the past. Cortical bone allografts can achieve better support during revision THA but may increase the risk of infection. With the advancement of TMFT stems, many PFFs with bone defects no longer require bone grafting. However, in PFFs with severe bone loss, an allograft-prosthesis composite might present an alternative [6]. Proximal femoral replacement is a salvage procedure reserved for patients with severe bone loss and low functional expectations (Fig. 24.6).

Fig. 24.6 Radiographs of a comminuted periprosthetic femoral fracture type B3. (**a**) Preoperative image showing severe osteolysis. (**b**) Postoperative image after revision arthroplasty, cable-plate fixation, and acetabular reconstruction
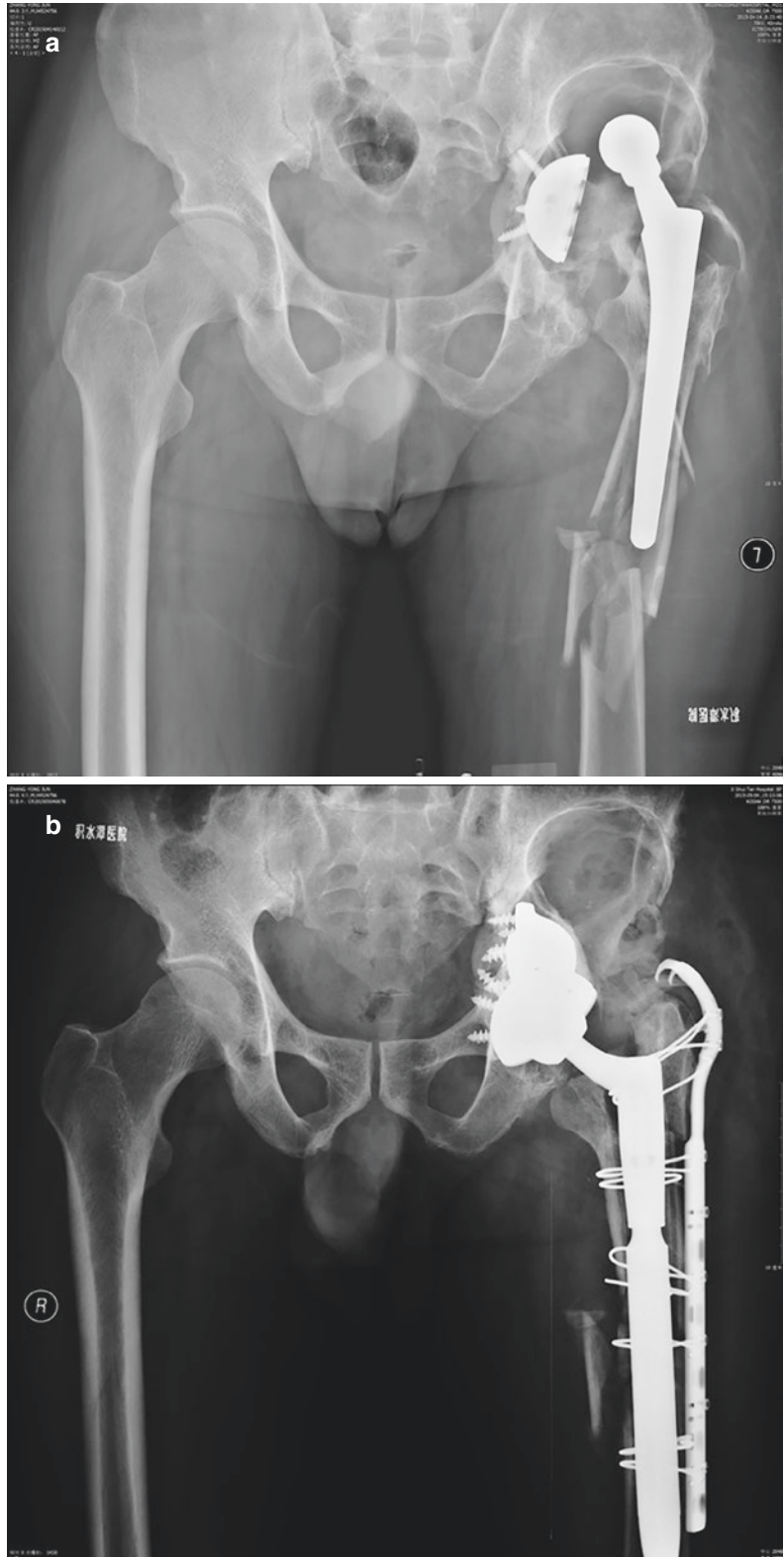
24.4.4 Type C

Fractures distal of the stem tip account for approximately 10% of all PFFs. Usually, this type of fracture has a stable stem and can be treated similarly to distal femoral fractures. The preferred treatment for type C fractures is ORIF with cables, screws, and plates. The proximal part of the plate should extend beyond the stem tip to avoid stress concentration and refracture. Long plates are recommended, and at least four bicortical screws should be inserted distal to the fracture. Proximally, surgeons may choose monocortical or bicortical screws or cables. The most common failure mode after type C fracture treatment is refracture. The principles of the treatment and rehabilitation of type C PFFs are similar but not exactly the same as those of distal femoral fractures (Fig. 24.7).

24.4.5 Type D

With the continuous developments in total knee arthroplasty and THA, increasing numbers of PFFs between the hip and the knee implant, classified as type D fractures, have been reported over recent years. According to the American Academy of Orthopedic Surgeons statistics, there are approximately 19,200 patients who live with ipsilateral total knee arthroplasty and THA, and 240 interprosthetic fractures occur per year in the USA [20]. These fractures are difficult to treat, especially those with extension rods of the knee implant distally or with a loosened femoral stem proximally.

Fractures between a stable hip stem and a stable knee component can usually be treated similarly to type B1 and type C fractures. Long locking compression plates are used in these
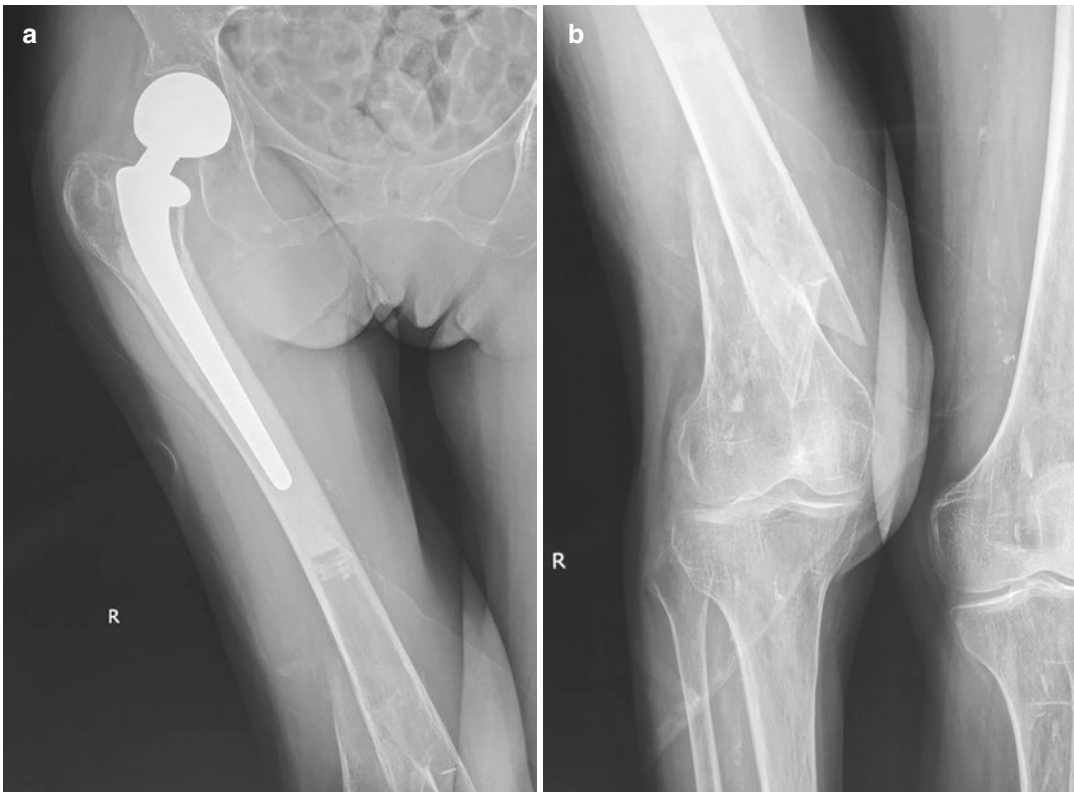

Fig. 24.7 Radiograph of a periprosthetic femoral fracture type C after revision total hip arthroplasty. (**a**) Radiograph on the proximal site. (**b**) Radiograph on the distal site
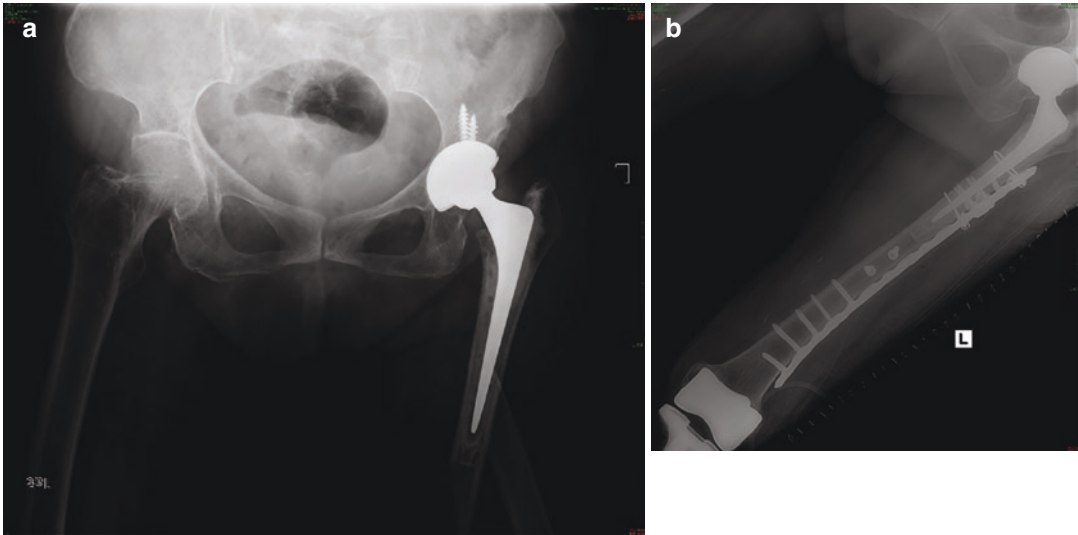
Fig. 24.8 Radiograph of a periprosthetic femoral fracture type D between the proximal and distal components after total hip and knee arthroplasty. (**a**) Preoperative image. (**b**) This patient was treated by open reduction and internal fixation

fractures, and if a single plate fails, fixation with two plates might be attempted. Treating fractures with a loosened hip component together with an extended knee component is challenging since neither revision THA nor ORIF provides sufficient stability. Total femur replacement might be an option but sacrifices the biomechanics of the limb. In these complicated cases, custom-made implants, where available, might be an alternative [21] (Fig. 24.8).

24.5   Periprosthetic Acetabular Fractures

PAFs are a rare complication that might occur intraoperatively, especially during biological cup impaction, reaming, and revision THA. The reasons for postoperative PAFs include trauma and pelvic discontinuity caused by periacetabular osteolysis.

The successful treatment of PAFs requires achieving a stable acetabular component and fracture fixation [22]. Similar to PFFs, PAFs should also be evaluated for stability to determine whether they might be treated by immobilization, internal fixation, or revision THA. The

most widely applied classification of PAFs is the one by Paprosky, which divides PAFs into five types, each of them with subclassifications [23]:

1. Intraoperative during component insertion.
2. Intraoperative during removal.
3. Traumatic.
4. Spontaneous.
5. Pelvic discontinuity.

If recognized intraoperatively, non-displaced PAFs should be treated conservatively, whereas displaced ones require further fixation. In the case of PAFs that were not recognized during surgery, close follow-up is necessary to determine further treatment.

Non-displaced traumatic PAFs might occasionally be treated by immobilization, yet most cases require surgical intervention to achieve pelvic and implant stability and ensure adequate bone stock. Plate fixation and revision surgery are options, but there is no defined algorithm.

The treatment of pelvic discontinuity is difficult. Acute cases might be treated similarly to unstable traumatic PAFs, but chronic cases require complicated revision techniques, which are beyond the scope of this book.

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Part V

AI Assisted Primary Total Hip Arthroplasty

Determining the Goals of Component Orientation in Total Hip Arthroplasty

25

Hao Tang

Key Points

1. The target angle of the acetabular cup should be determined both functionally and individually.
2. Movements of the spine and pelvis has a significant effect on the direction of the cup.
3. A patient's individual safe zone based on their pelvic position in different postures, combined with robot-assisted surgery for the precise execution, provides an effective solution for personalized total hip replacement.

If there has been any revolutionary progress in hip replacement in the past 10 years, functional X-ray imaging and robotics definitely qualify as two breakthroughs. The former gives us the ability to set individualized goals, and the latter gives us the ability to execute the procedure to achieve these goals accurately. The robot is a precise surgical tool, and the implantation of the prosthesis can be as accurate as 1°. However, as an analogy, we know that the more precise the weapon system, the more precise the target guidance needs to be in order to achieve the maximum effect. Hence, we need to define accurate targets in the preoperative planning of robot-assisted surgery.

In this chapter, we will first explain why we need an individual target for component position-ing in each patient; second, what methods are currently available for such personalized target setting; and third, how to precisely quantify the cup orientation target for robotic surgeries.

25.1 Rationale

25.1.1 Death of the Lewinnek Safe Zone

The robot's preoperative plan in total hip arthroplasty includes several goals. The literature shows that the robot is very accurate in controlling the size of the prosthesis, the offset, the length of the leg, and the center of rotation. Our aim in total hip arthroplasty is to restore these parameters based on the normal anatomical relations of the hip joint. However, the orientation of the acetabular prosthesis presents an entirely different challenge to the surgeon. The cup's anteversion and abduction angles can be adjusted freely. At the same time, we need to be aware that if we restore the physiological direction of the acetabulum, this may not necessarily meet the individual needs of the patient.

There are basically two options for determining the target angle of the acetabular cup. Traditionally, a standardized prosthesis safe zone has been used, but recently, personalized cup angle values have become increasingly popular.

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In 1978, Dr. Lewinnek studied 300 patients and proposed a "safe zone" of 40 ± 10° abduction and 15 ± 10° anteversion of the cup, within which dislocation would not occur. Since then, the *Lewinnek Safe Zone* has dominated the development of hip replacement. One might say that it has been regarded as sacrosanct doctrine by arthroplasty surgeons for over 40 years. However, in recent years, evidence has accumulated showing that cup angles within this zone do not prevent postoperative dislocation. In fact, Abdel et al. [1] found that in 50% of patients with dislocations after hip arthroplasty, the cup angles were within *Lewinnek's Safe Zone*.

In 2019, Dr. Lawrence Dorr et al. announced the "death" of the *Lewinnek Safe Zone* and proposed the concept of a functional safe zone [2, 3]. The major shortcoming of the *Lewinnek Safe Zone* is that it is static and that the effect of dynamic pelvis motion is not considered.

25.1.2 Shortcomings of the Transverse Acetabular Ligament Method

The transverse acetabular ligament (TAL) is a constant anatomical landmark that represents the patient's physiological anteversion angle [4–6]. However, Archbold et al. found that the orientation of the transverse acetabular ligament is highly variable both in its inclination (38.4–50.3°) and anteversion (5.3–36.1°). Moreover, some recent studies have shown that the anteversion angle of the TAL is not applicable in some cases. For example, in patients with kyphosis, the posterior tilt of the pelvis increases when they are standing, and the anteversion of the acetabular cup correspondingly increases, causing anterior edge loading. Abe et al. [7] reported that the TAL is highly variable and not suitable as an anatomical landmark in patients with hip dysplasia.

25.1.3 Influence of Sagittal Imbalance and Stiffness on Cup Orientation and Joint Stability

The pelvis is a central structure that connects the spine and hip joints. In functions such as standing, sitting, and squatting, the posture of the pelvis can change up to 70°, which considerably affects the actual functional position of the cup after implantation.

Figure 25.1 shows a full-body EOS (EOS Imaging, Paris, France) scans of different patients in a standing position. It can be seen that the severity of the kyphotic deformity of the spine increases from left to right.

In general, kyphosis will increase the risk of anterior dislocation of the hip. The reason is that when the physiological lumbar lordosis decreases, the pelvis will automatically tilt backward, moving the line of gravity posteriorly to restore balance and compensate for the spinal deformity. Essentially, hyperextension of the hip joint compensates for extra-articular deformities. Studies have shown that for every 10° of posterior pelvic tilt, the cup abduction angle will increase by 3° and the anteversion angle by 7° [8]. This is why patients with kyphosis are prone to posterior impingement while standing, which may cause anterior dislocation.

Figure 25.2 shows EOS scans of different patients in a sitting position demonstrating the effect of lumber spine stiffness on the pelvis. The loss of mobility in the lumbar spine leads to its inability to retrovert the pelvis in the sitting position.

In general, there is an increased risk of posterior dislocation after total hip arthroplasty in patients with previous spinal fusion. Studies have shown significant increases in the rate of dislocations and revisions after total hip arthroplasty in this patient population [9, 10]. There are two reasons for this phenomenon. On the one hand, the
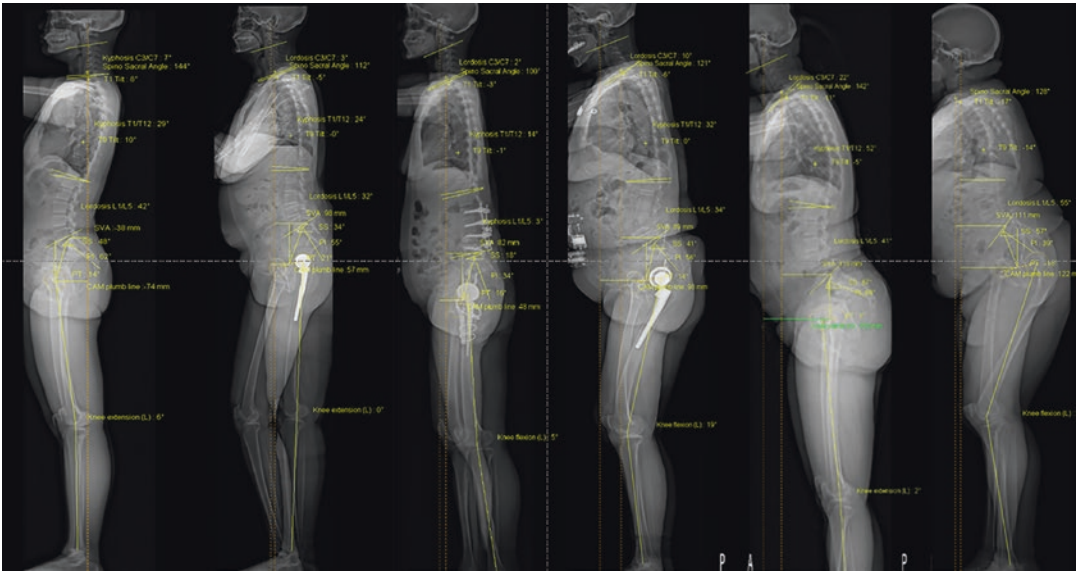
Fig. 25.1 The influence of kyphosis on sagittal balance during standing
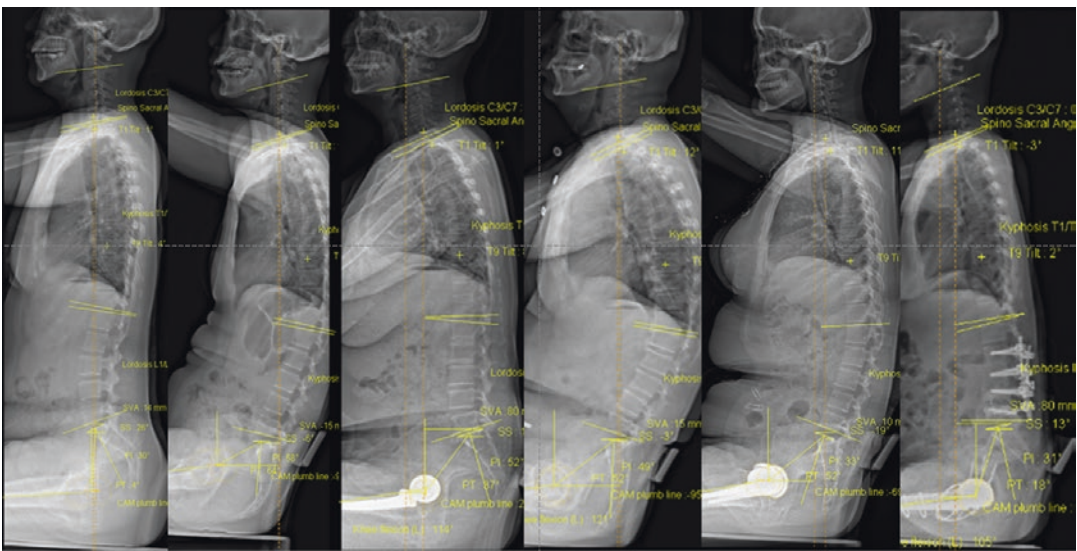

Fig. 25.2 EOS scans of different patients in sitting position. The patient on the far right has undergone internal fixation of the lumbar spine. The lost mobility of the lumbar spine results in an inability to retrovert the pelvis

reduced pelvic tilt reduces the front opening of the cup when sitting. On the other hand, patients will flex their hip more to compensate for the lumbar stiffness in a sitting position [11].

In a recent study published by our team's Dr. Gu [12], we found that when the spinal degeneration exceeds three lumbar levels, patients flex their hip more … to compensate for spinal stiff-

ness in the sitting position. Considering these two factors, it is not difficult to understand why patients with a stiff spine are prone to anterior impingement while sitting, which causes posterior dislocation.

The above explains why we cannot indiscriminately use the *Lewinnek Safe Zone* in every patient but need to consider the effect of different

postures on the pelvis in an individual patient to determine the acetabular target angles of robotic surgery.

25.2 Qualitative Solution: Pelvic Posture Analysis

A personalized cup goal requires the consideration of the effect of different postures on the pelvis. Currently, two methods are commonly used to achieve this.

One is to classify patients according to their sagittal plane balance when standing and the degree of lumbar spine movement in the sitting position and define the reconstruction goals accordingly [13]. Based on the data collected at Jishuitan Hospital, only 50% of the patients have a balanced and flexible spine and pelvis. In this population, the traditional safe zone of 15–25° anteversion of the cup can be used. However, the other 50% of the hospital's patients showed imbalances or stiffness.

In 2018, the research team led by Dr. Lawrence Dorr studied a group of patients with repeated dislocation and proposed another method, the functional safe zone in the sagittal plane [2]. The combined sagittal index integrates the movements of the spine, pelvis, and hip in the sagittal plane, opening up a new perspective for the evaluation of the ideal prosthesis position. The researchers proposed normal reference ranges for the sagittal angles of the acetabular cup and femur in both the standing and sitting positions. This method provides a functional safe zone within which the function of the prosthesis can be dynamically assessed.

These two methods consider the posture changes in the standing and sitting positions, and the combined sagittal index furthermore assesses femoral movement. However, they still have significant shortcomings. Most importantly, they cannot quantify a precise target angle that can be executed by the robot in an individual patient. The sagittal safe zone cannot be easily transformed into the anteversion and abduction angles of the cup. Furthermore, neither of these methods considers the squatting position, but squatting is very important in the Asian population.

25.3 Quantitative Solution: Patients' Individual Safe Zones

In order to identify a universal safe zone of the cup for THA, we deducted a mathematical algorithm to calculate the ante-inclination (AI) angle in the sagittal view based on the combined sagittal index method as proposed by Lawrrence Dorr et al. [2]. There were 100 patients who had robot-assisted THA enrolled for this study. Each patient had standing and sitting EOS scans both before the index surgery and at 1 year follow-up. Using the validated algorithm, we found that neither universal safe zone existed for all the 100 patients, nor any patient subgroups by stand-to-sit pelvic motion or pelvic incidence, to fulfill the criteria of AI angle (standing AI <45° and sitting AI >41°). Thus, we further conclude that the target cup orientation should be individualized [14].

To solve this problem, our team aims to establish a quantitative assessment that provides personalized goals for robotic total hip replacement through patient-specific safe zones to address these insufficiencies. We routinely conduct a comprehensive posture assessment that includes standing, sitting, and squatting positions in each patient before surgery. This enables us to define a patient-specific safe zone by considering several indicators such as edge loading, impingement, and the sagittal functional angle. We then use the geometric center of this safe zone as the execution goal for the robot in the individual patient (Fig. 25.3) [15].

We conducted a preliminary study of this method from June to December 2019, and the preliminary results showed significant differences in the standing and sitting cup angles between the postoperative MAKO+PSSZ experimental group had and the traditional control group. The sagittal angle of the acetabular cup was within the functional safety zone during both standing and sitting in 96.7% and 70.7% of patients in the experimental group and control group, respectively. This difference was statistically significant (Fig. 25.4).
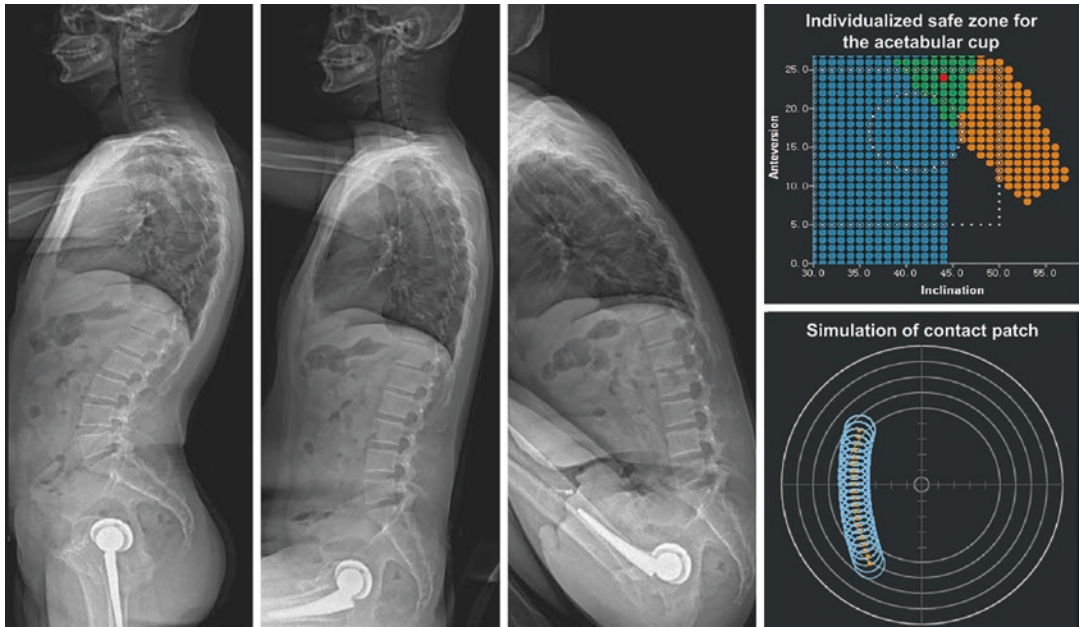
Fig. 25.3 The postoperative radiographic evaluation of standing, sitting, and squatting positions with the corresponding patient-specific safe zone and the pathway of head-cup contact Patch during flexion
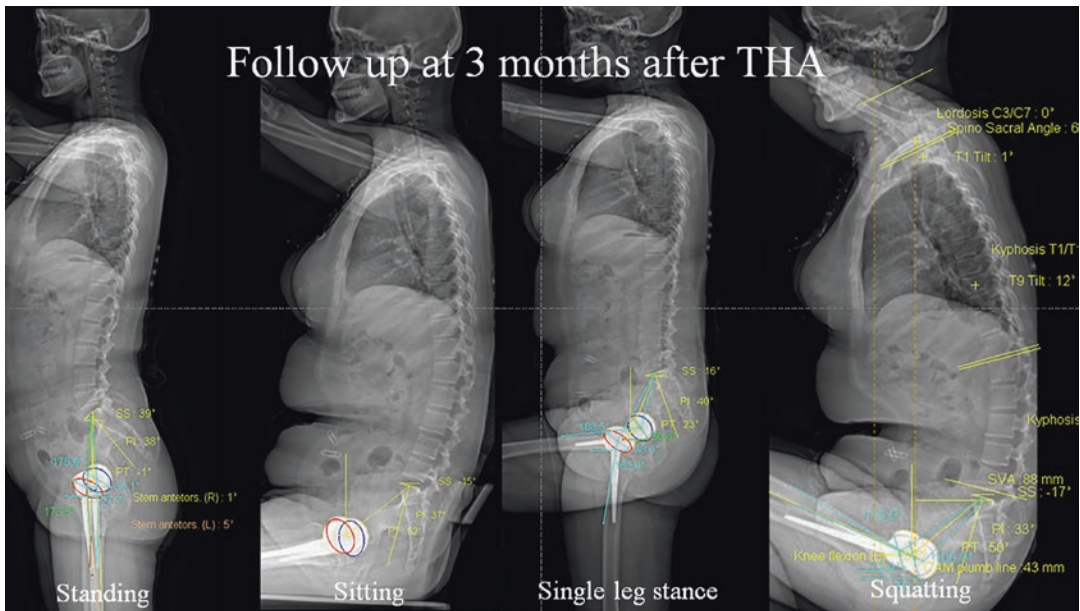

Fig. 25.4 EOS functional lateral radiographs in a patient 3 months after total hip arthroplasty. In all functional postures, the functional angle of the cup is maintained, and the patient can easily squat. As predicted by the patient-specific safe zone, no impingement occurred

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Robotic-Assisted Total Hip Arthroplasty

26

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Key Points

1. Introduction types and theory of the robotic-assisted total hip arthroplasty.
2. Introduction to some surgical techniques and tips for MAKO THA.

Total hip arthroplasty (THA) has been performed and has continuously been improved for more than half a century. However, complications such as dislocation, leg length discrepancy (LLD), bearing wear, and aseptic loosening related to prosthesis malposition remain a concern for joint surgeons [1–3]. Therefore, new technologies, such as patient-specific cutting guides, navigation, and robotics, were developed to improve the accuracy and reproducibility of the implant position [4]. Among them, robotics has become increasingly widely used in clinical practice over the past 20 years [5].

26.1 Technologic Types of Robotics

There are different types of robotic platforms used in THA that can be classified into active, semi-active, and passive. Active systems, such as the ROBODOC® Surgical System (THINK Surgical Inc., Fremont, CA, USA) can automatically perform bone cutting and milling when being well-positioned and adequately fixed to the patient without surgeons' involvement. In passive mode robots, surgeons take control of the robotic arm and perform the procedures without any automatic constraints by the robot. In comparison, a semi-active platform will give surgeons feedback and constrain their means of manipulation, which we call a "haptic system." The representative system is the Mako® robotic hip system (Stryker Inc., Kalamazoo, MI, USA).

Robotic systems can also be classified as either image-based or imageless systems. In image-based systems, preoperative imaging is necessary, usually computed tomography (CT) or magnetic resonance imaging. Surgeons can perform 3D templating to mimic the surgery preoperatively. During surgery, they perform registration to match preoperative imaging and implement cutting or reaming based on preoperative templating. For imageless systems, surgeons identify anatomic landmarks intraoperatively and perform registration without preoperative imaging and planning. The robotic system often cre-

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ates a virtual model, and surgeons determine the implant position and size intraoperatively.

26.2 Surgical Technique with Mako® Assistance

26.2.1 Preoperative Planning

The Mako® system is an image-based, haptic-assisted robotic system. Before surgery, we perform 3D templating similar to templating on preoperative radiographs (Chap. 7.4). However, with CT-based templating, we can obtain more information than when using radiography, such as the bony cover area of the acetabular roof, the required amount of bone reaming in the anterior and posterior columns, and accurate offset reconstruction. The cup position can be adjusted in the anteroposterior direction to ensure proper reaming of both the pubic and ischial sides. Furthermore, we can also visualize the different coronal planes to ensure sufficient roof coverage. The system supports accurate medialization and craniocaudal positioning of the acetabular component to obtain better bone contact in patients with developmental dysplasia of the hip (Fig. 26.1).

On the femoral side, the Mako® system functions more like image-based navigation. However, the preoperative CT measurements may slightly differ from the postoperative stem anteversion [6]. Still, preoperative templating can provide 3D information and provide valuable information on whether the femoral neck has abnormal torsion or whether the femoral canal can host the selected stem.

26.2.2 Intraoperative Surgical Techniques

When using robotic systems, surgical exposure is the same as for conventional techniques, regardless of whether the posterior approach or direct anterior approach is used, as discussed in previous chapters.

The most important step in robotic-assisted THA is intraoperative registration. Usually, we first fix the registration jig to the anterior superior iliac spine (ASIS) for the acetabular side and to the lesser trochanter for the femoral side. It is important to ensure that both of them are stable. We strongly recommend performing the enhancement process first and start with the femoral side
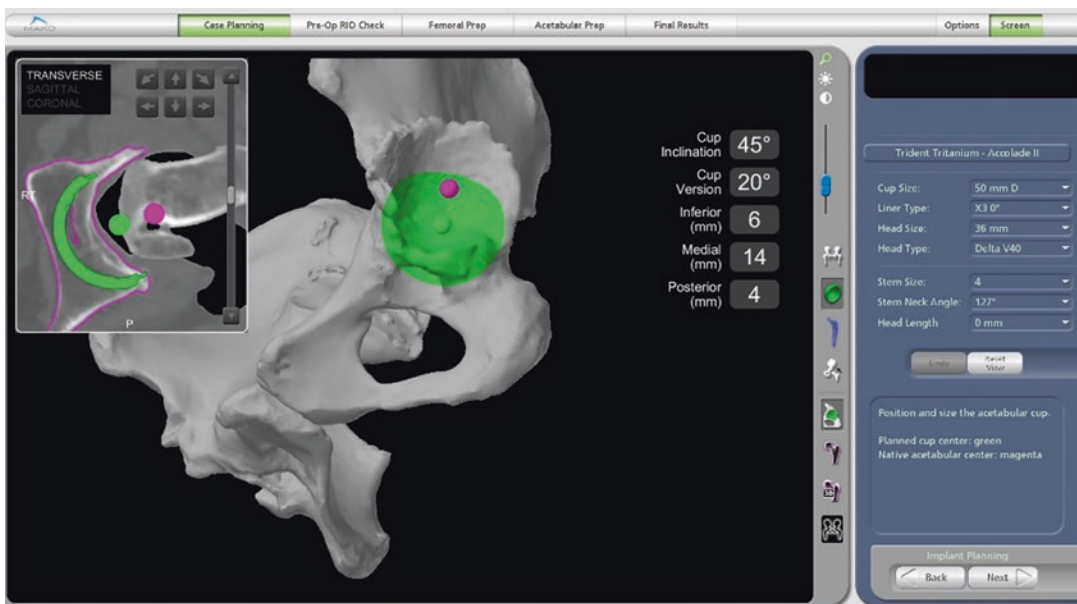

Fig. 26.1 Preoperative 3D planning and templating with Mako® robotic system

in order to determine the femoral anteversion in severe dysplasia, where the registration points can be widely scattered. This will make the registration process easier.

These are some surgical tips for using the Mako® system:

- If the robotic arm encounters difficulty in reaching the safe range during reaming of the acetabulum, the reaming anteversion can be adjusted to 10°, or even less, to position the arm more easily.
- Owing to the advantages of high precision and stability, we can use a single-sized reamer to prepare the acetabulum in its final shape. However, if the acetabulum is osteosclerotic, a smaller reamer can be used before the final reaming.
- When reaming gets close to the final position, attention should be paid not only to the screen of the robotic system but also to the acetabulum bed. This will help to recognize any reaming errors.
- Sometimes, it may initially be difficult to position the robotic arm with the acetabular components in the surgical site. In this situation, we may position the cup first, and then assemble the robotic arm onto the cup holder.

26.3 Advantages and Disadvantages of Robotic-Assisted THA

The robotic-assisted technique provides surgeons with a tool to implant the prosthesis precisely. Several publications have demonstrated the precision of the Mako® robotic system [7–9]. Initial concerns about the learning curve of robotic systems were alleviated by Redmond et al. [10], who reported that the learning curve is in fact short and can be easily overcome. Domb et al. [11] demonstrated that robotics could improve accuracy regardless of the type of approach used by surgeons. In another study in obese patients, the robotic technique allowed to implant cups reproducibly and more accurately [12]. Compared with these advantages, prolonged surgical time, increased blood loss, additional pin insertion, and increased costs are considered potential disadvantages [13].

One critical question is whether more accuracy will result in better clinical outcomes. To date, this question has not been answered. However, the importance of patient-specific zones was discussed in the previous chapter. With robotics, we can target the exact desired location. With continuous hardware and software innovation, robotic-assisted THA may eventually indeed provide better results, and future studies may alleviate these current concerns.

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