13 Periacetabular Reconstruction

Tao Ji and Wei Guo

Approximately 10–15% of primary malignant bone tumors involve the pelvic girdle. The most common primary sarcomas in this location are chondrosarcoma, osteosarcoma, and Ewing's sarcoma. More commonly, 80% of patients with carcinomas have osseous metastases. Pelvic bone tumors are often large at presentation and proximal to organs, nerves, and vessels, which makes limb salvage and reconstruction difficult and challenging. Before the 1980s, hemipelvectomy was the standard surgical treatment for primary pelvic sarcomas. Such a procedure, however, removes a viable extremity to achieve local control. Additionally, hemipelvectomy is disfiguring and disabling. With the improvement in preoperative imaging techniques, neoadjuvant treatments, and surgical techniques, limb-preserving procedures have become more common in the past several decades. Enneking and Dunham proposed a tumor classification typically associated with four types of pelvic resections and/or reconstructions: Type I, the ilium; Type II, the periacetabulum; Type III, the obturator; and Type IV, the sacrum. Isolated resections of the ilium or ischium and pubis may not require reconstructive procedures to achieve excellent postoperative function. Type II resections require reconstruction to restore force transmission and weight-bearing along anatomic axes. The ideal pelvic resection would achieve an adequate tumor resection followed by a reliable and functional reconstruction with minimal morbidity. Adequate excision of Type II tumors often requires complete excision of the skeletal hemipelvis and large parts of the soft tissue of the pelvis. Several different reconstruction options have been proposed after this type of resection, including ischiofemoral arthrodesis or pseudoarthrosis, iliofemoral arthrodesis or pseudoarthrosis, massive allograft, autoclaved autograft, allograft prosthetic composite, custom-made endoprosthesis combined with hip arthroplasty, or the modular saddle prosthesis and 3D printing endoprosthesis. There are various options for reconstruction, each having advantages and limitations. Implantation of a megaprosthesis in early years has resulted in a high complication rate and a poor functional result. Major complications of megaprosthetic reconstructions, such as infection, loosening, and dislocation, occur frequently (approximately 25–35%).

13.1 Arthrodesis and Pseudoarthrosis

Iliofemoral and ischiofemoral arthrodeses or pseudoarthroses have been employed successfully for many years. The basic concept is to obtain continuity of the hip with residual pelvis by either fusion way or coaptation, achieving stability and weight-bearing potential. The method is associated with limb shortening. Another advantage of arthrodesis or pseudoarthrosis is the fact that resection can be done without looking at reconstruction. Hip transposition was developed to improve the stability of flail hip in pseudoarthrosis. By shortening of the leg, adequate soft tissue coverage can be achieved. The ideal candidate for iliofemoral fusion is a patient requiring periacetabular resection with or without pubis and ischium resection. Availability of most of the ilium minimizes limb length discrepancy and allows wider bone contact, enhancing fusion and stability. In arthrodesis, rigid fixation is usually achieved with a plate, and cable wires are used for pseudoarthrosis. Iliofemoral fusion is preferable for young and active patients because it provides stable and durable construct capable to withstand high-demand functional requirement. Iliofemoral pseudoarthrosis is indicated for more sedentary and older patients. The ability to flex hip seems to be appreciated by older patients with lower daily activity level. When the proximal osteotomy is above the neck of ilium, the iliac becomes thin which makes it difficult to obtain solid fixation and fusion. Pseudoarthrosis may be an option.

Ischiofemoral arthrodesis results in less shortening of the limb than an iliofemoral arthrodesis, and it is often associated with motion of the symphysis pubis. Pain in symphysis

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remained the main concern, and difficulty in achieving a fusion at the small area of bone contact limited the application. Overall, the fusion rate for iliofemoral or ischiofemoral was reported to be about 50–80%. The iliofemoral fusion results in good function while the result of iliofemoral pseudoarthrosis is unpredictable.

13.2 Pelvic Allograft or Devitalized Autograft

Satisfactory functional results have been reported after internal hemipelvectomy, despite at least a 50% prevalence of instability or shortening of the limb and complications such as failure of the arthrodesis. Several techniques have been developed for reconstruction of the hip and hemipelvis so that the patient retains a functional and cosmetically acceptable limb without shortening. These techniques include biologic and/or prosthetic reconstructions. Mnaymeneh and Mankin both reported cases of implantation of an osteoarticular graft after wide resection of the hemipelvis. The two cases showed the reconstructions did not fail within 5 years after surgery. Biologic reconstructions with allograft or replantation of the resected hemipelvis after it has been autoclaved have a number of advantages, including a readily available source, the ability to be size matched, and biologic union with host bone.

Early reports showed the allograft reconstruction after hemipelvic resection was feasible; however, postoperative x-ray showed evidence of localized resorption of bone at the proximal graft-host junction and progression. A comparison of the results of the use of long-bone allografts with that of pelvic allografts revealed that fractures of the former occur much earlier than those of the latter. No matter which fixation devices were used, none of fixation devices provided effective permanent splintage of the thin innominate bone. Many serious complications were associated with allograft including infection, nonunion, dislocation, fracture, nerve palsy, and local relapse. There were relatively few mechanical complications once the bone union was achieved. Although the rate of union after allograft reconstruction is reasonably high, and fractures of the graft in the pelvis are not common and may heal spontaneously, the high risk of other complications might suggest that this techniques should be used with strict indications. Rosenberg and Mankin [1] reported high rates of infection and recurrence after pelvic reconstruction with allograft. They reported that five of nine reconstructions with an osteoarticular graft failed, as did all of four reconstructions with an intercalary graft or an allograft-implant composite. Ozaki [2] reported that the allograft was removed usually because of infection after seven of nine reconstructions with an allograft-implant composite. Infection is a high risk of such type of surgery and is further increased by implantation of avascular biologic material such as allograft.

Reconstructions with autograft include devitalized tumor bone, fibular, or ipsilateral femoral autograft. Puget and Utheza described an option of reconstruction involving transportation of proximal part of the ipsilateral femur into the defect and implantation of a conventional total hip replacement in the autograft. The technique was further reported by Biau et al. [3]. Mechanical failure was the main complication and might be attributed in part to technical flaws and the so-called learning curve, also the inadequate fixation. They suggested the autograft to be stabilized with a plate and screws, with four cortices fixed at each extremity in the host bone, and a reinforcement acetabular ring should always be used. Femoral head autograft plus total hip arthroplasty has been reported to be used in reconstruction for periacetabular defect after tumor resection. In a pilot study of 13 patients who received femoral head autograft, the complication rate was reported to be 4 out of 13 [4].

There are several methods for recycling of the resected tumor bone, including autoclaving, freezing, pasteurization, extracorporeal irradiation, and alcohol devitalization, although the mechanical properties and osteoinduction may vary. Pasteurization is a proven effective method for devitalizing bones with tumor, and the devitalized bone usually integrates well with the host bone. Hypertonic saline (10%) can be used for pasteurization which can make a better preservation of protein. Surgeons from Asian countries usually choose the reconstruction using recycled tumor bone [5]. Complete union of pasteurized bone to the host bone was usually achieved at 1 year after surgery.

13.3 Endoprosthetic Reconstruction

A number of techniques have been described for the reconstruction of a periacetabular defect. Although associated with a significant reduction in range of motion, some authors prefer to perform biologic reconstruction including arthrodesis or pseudoarthrosis. However, failure to obtain a solid fusion is a frequent occurrence and results in a painful reconstruction with poor function outcome. The high failure rate of allografts and autografts due to nonunion, fracture, and graft resorption generates thoughts being given to endoprosthetic reconstruction, and a number of different types of endoprosthesis have been reported. Generally, dislocation and aseptic loosening are the two most common failure reason with prevalence of 12–22% and 3–12% retrospectively [6]. It is well accepted that reconstructing a pelvic defect with an endoprosthesis has the greatest potential to achieve a well-functioning limb. However, long-term mechanical failures are the major concern regarding endoprosthetic reconstruction.

The first attempts of endoprostheses to reconstruct resected pelvic bone and to restore the pelvic ring can be found in the early 1970s [7]. Scales and Rodney implanted a temporary spacer of acrylic cement and designed a steel prosthesis in the shape of resected iliac bone. The prosthesis was removed due to infection. The first case reported in literature about endoprosthetic reconstruction after pelvic tumor resection was in 1974 for a patient with chondrosarcoma. In early days, the preoperative plan was determined on x-rays. Later, attempts have been made to improve the accuracy of pelvic prosthesis design and production. The first report on endoprosthetic pelvis reconstruction was by Gradinger in 1993 [8]. The prosthesis was custom-manufactured from plain x-rays with low accuracy for intraoperative orientation of acetabulum. The anchorage into the remaining sacral ala or iliac bone was mainly provided by screws with additional plates or flanges, also the rigid fixation to the contralateral pubis with high shear forces. Ozaki et al. [9] reported a series of 12 cases of pelvic prosthetic reconstruction following tumor resection based on computer-aided design according to preoperative CT scan. Deep infection occurred in 3 of 12 patients. The overall survival of endoprosthesis at 3 years after surgery was 42%. Windhager et al. [10] reported a series of 21 consecutive cases of different reconstruction approaches. Nine of the 21 patients received a custom-made prosthesis with best functional results compared to saddle prosthesis and allografts (Fig. 13.1).

The main trend of pelvic endoprosthesis is modularity and iliac- or iliosacral-based fixation. With the advent of megaprosthetic reconstruction in pelvis, the custom-made fashion was the main design in early days. However, with development of modularity in endoprosthesis for limb salvage procedure in extremity, the modularity concept was introduced into pelvic endoprosthetic reconstruction. The symbolic design was reported by Guo et al. [11] in 2007.

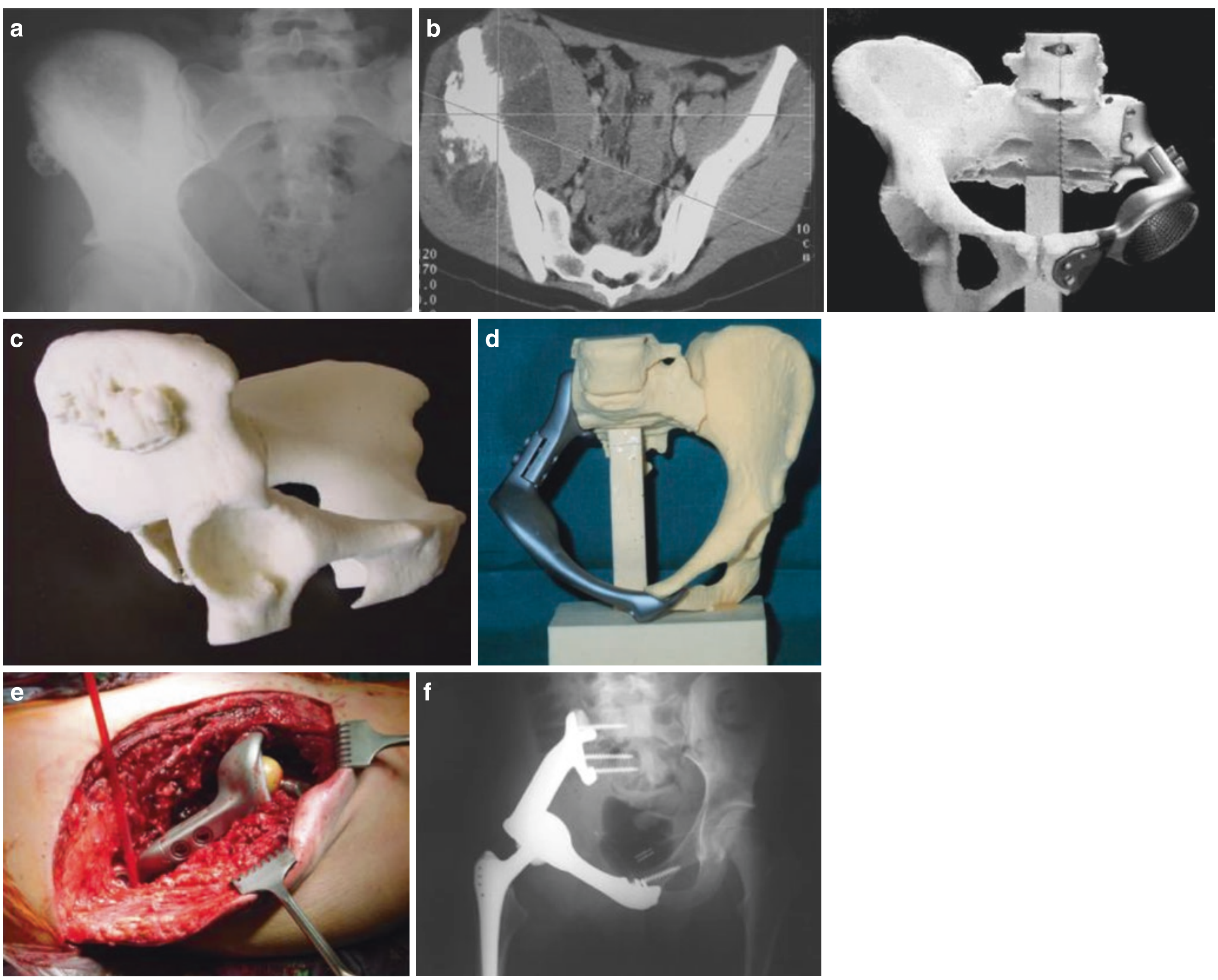

Fig. 13.1 The custom-made pelvic endoprosthesis by CAD approach. The planned resection area and custom-made endoprosthesis was fixed on the pelvic saw bone. The intraoeprative photo and postoperative x-ray was shown. (Copyright © Wolters Kluwer Health | Lippincott Williams & Wilkins)

There were three parts in the design: iliac fixation part that served as main fixation structure between prosthesis and residual bone, acetabular part which connected to iliac fixation part by Morse taper which is commonly used in modular limb reconstruction system, and pubic connection plate which was an optional part in reconstruction. The pubic connection part was rigidly connected to the contralateral pubis without any dynamic motion resulting in high breakage rate. The same results were found in custom-made endoprosthesis, and the high complication rate was approved by biomechanics study [12, 13]. In their midterm follow-up study, the pubic connection plate was seldom used; however, no higher fixation failure was observed [14]. Pedestal cup and ice-cream endoprostheses are both iliac-based fixation without structure to restore anterior pelvic ring. The advantage of modular pelvic endoprosthesis is the smaller size, which facilitates soft tissue coverage and may reduce infection rate. As for the fixation strategy, multiaxial fixation by screws is used in Guo's modular pelvic endoprosthesis which has a low breakage rate and loosening rate. Pedestal endoprosthesis has a cemented or press fit fixation technique, which is similar to megaprosthesis used for extremity. However, the lack of channel structure and cortical bone in ilium and iliosacral area brings difficulty in such fixation concept. It seems that it is well accepted that anterior pelvic ring should be left open in prosthetic reconstruction due to the rigidity at pubic connection area. Both intramedullary fixation (pedestal endoprosthesis) and extramedullary fixation (iliac flange fixation) exclude anterior ring restoration part (Figs. 13.2 and 13.3).

Both pedestal and Guo's hemipelvic endoprosthesis need at least a remaining part of the ilium and cannot be used for ilium removal. However, large pelvic tumor often involves both periacetabular and iliac part even with partial ipsilateral sacrum. Initially, Guo [15] attempted to reconstruct such defect by femoral head structural autograft to the sacrum and then the standard modular hemipelvic endoprosthesis. However, the early stability after surgery was inadequate for ambulation. Then pedicle screw system was used as adjuvant fixation to enhance the strength of the whole system (Figs. 13.4, 13.5 and 13.6).

The method achieved acceptable complication rates and favorable functional outcomes at a minimum follow-up of 15 months [16]. However, further follow-up of the patients identified a number of major complications, including rod breakage, prosthetic dislocation, and pedicle screw loosening, leading to substantial deterioration of lower limb function. As a result, a modified new generation of modular pedicle-hemipelvic endoprostheses with the aim of decreasing the complication rate and increasing the durability of the prosthesis was developed. The newer design is characterized by its enhanced fixation to the remaining sacrum aside from the simple connection to the lumbar spine. The newly designed prostheses achieve both fixation to the residual sacrum and connection to the lumbar spine. Additionally, the porous structure was three-dimensional (3D) printed on the medial surface to facilitate osseointegration and long-term stabilization. A double-axle component by sawteeth was also introduced to facilitate intraoperative adjustment of acetabular angle and acetabular anteversion angle. A series of 20 cases was reported recently. With the newly designed endoprosthesis, a favorable functional outcome (MSTS score 65%) was achieved with short follow-up. This appears to be better in comparison to the previous generation of pedicle-hemipelvic endoprostheses, which yielded an MSTS score of 58%. The new prosthesis offers enhanced modularity and more precise positioning of the acetabular cup compared with the previous design. The complication occurred in 3 out of 20 patients with one deep infection and two dislocations.

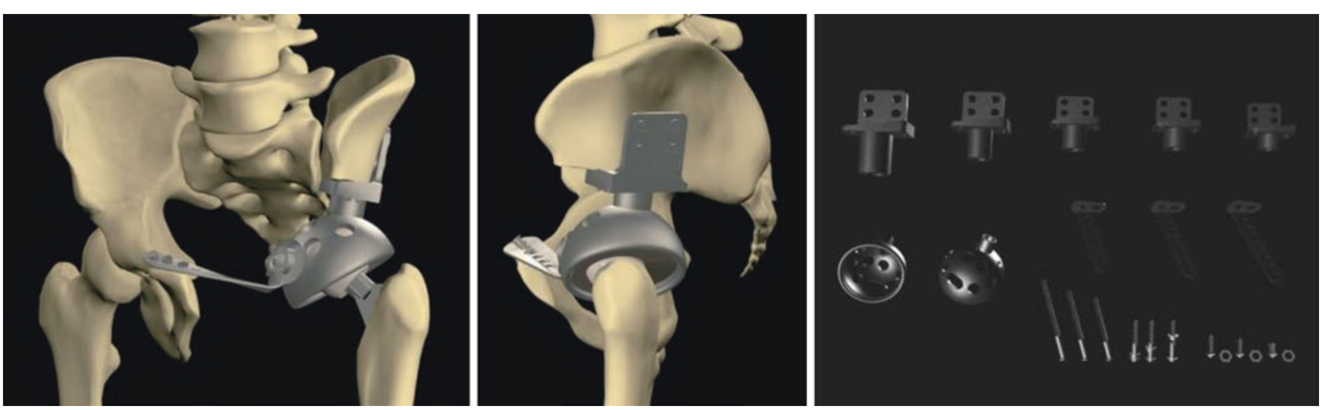

Fig. 13.2 The first-generation modular hemipelvic endoprosthesis which contains three parts: iliac fixation part, acetabulum part, and pubic connection plate

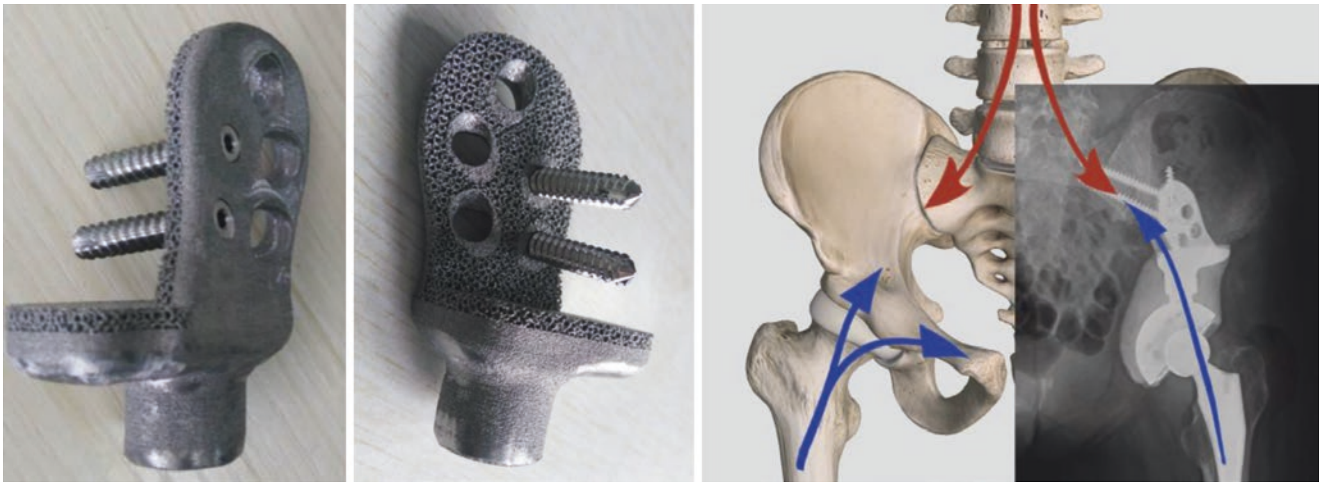

Fig. 13.3 The second-generation 3D printing-based modular hemipelvic endoprosthesis. The fixation location has been shifted from iliac osteotomy surface (first generation 2003–2015) to the iliosacral part with screws passing through iliosacral joint (second generation since 2016)

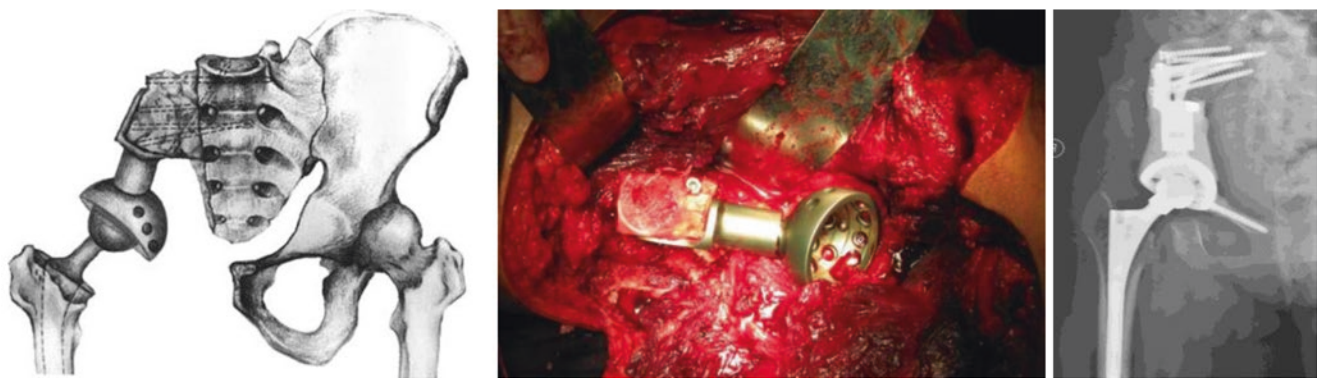

Fig. 13.4 Reconstruction with femoral head autograft and standard hemipelvic endoprosthesis after total internal hemipelvectomy

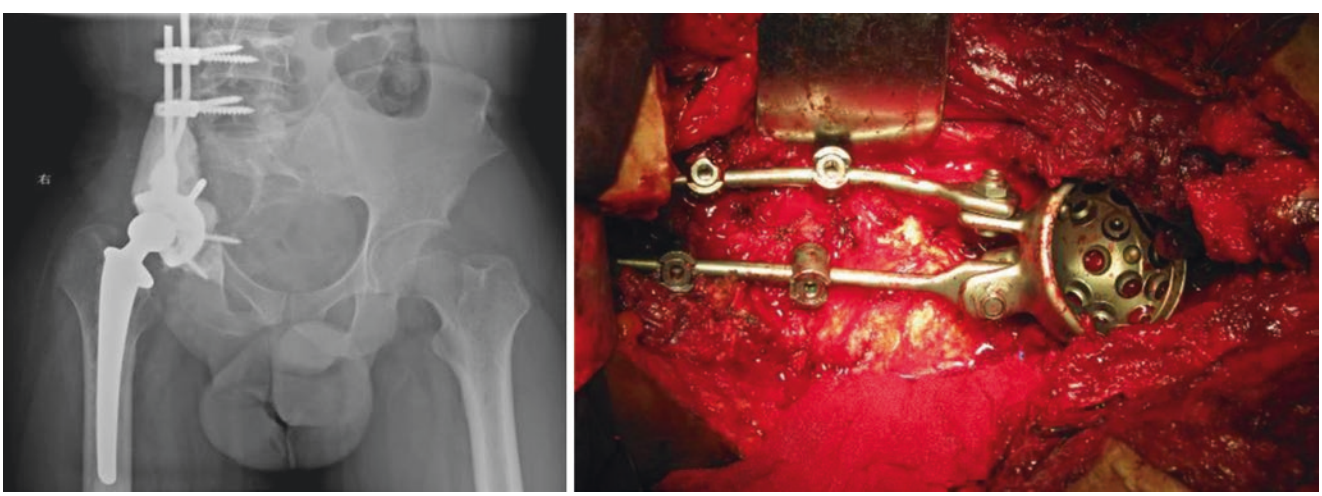

Fig. 13.5 Universal spine system was used to connect to the acetabulum to improve the stability of the reconstruction after ilium was removed

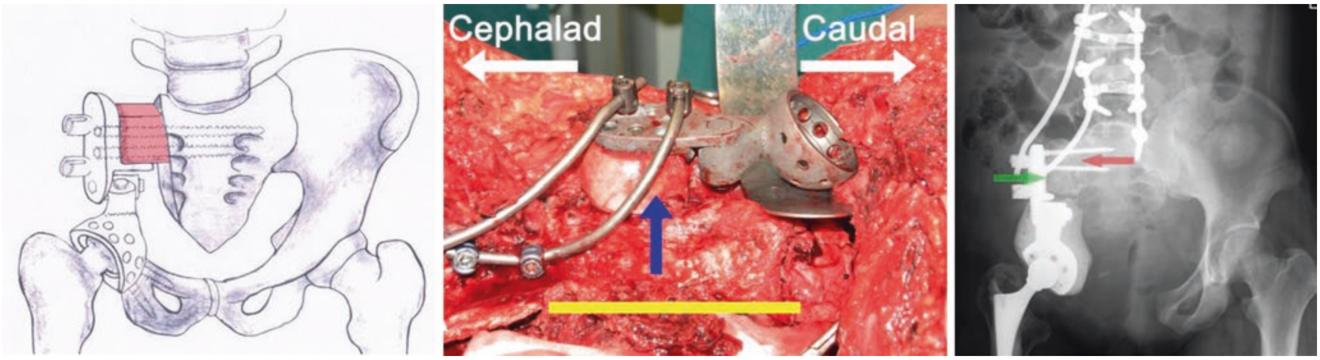

Fig. 13.6 The reconstruction after pelvic Type I + IV + II rsection. The autogenous femoral head was shaped into proper size and was fixed between the impalnt and osteootmy site at sacrum. The intraoeprative photo showed the connection of screw-rod system to the pelvic endoprosthesis. Also the postoeprative x-ray showed the whole reconstruction system

13.4 Saddle Prosthesis

The saddle prosthesis was designed by Nieder in Germany in 1979. Initially, this prosthetic concept was used for pelvic reconstruction of large acetabular defects following total hip arthroplasty. Since 1984, it is also indicated as replacement after resection of periacetabular tumors. The advantage of this method has been in the simplicity of its design, alleviating the need for an acetabular implant. However, the disadvantage is the need for postoperative immobilization to ensure soft tissue healing. Certain aspects of notch preparation are more challenging. Poor range of motion, dislocation, and progressive upward migration were common complications after saddle endoprosthesis reconstruction. Progressive erosion of bone and upward migration of the saddle resulted from the direct application of load and movement between metal and bone, but development of bone sclerosis at the interface led to stabilization of the saddle after a short-period migration. Migration was not found to be associated with osteoporosis, activity level, preoperative diagnosis, and site of implantation. Dislocation was reported to be ranging from 2% to 20% in literature. Heavy sutures will help secure the saddle component to the ilium. Also, optimal soft tissue tension balanced against excessive stretch on the neurovascular structures once a pseudocapsule forms and begins to ossify around the saddle component.

Stryker PAR (periacetabular reconstruction) endoprosthesis was designed to be secured with internal fixation and bone cement to the remaining ilium and support a reconstructed acetabulum. To address the previous mechanical complications found in Mark I and Mark II saddle prosthesis, loosening, migration, and dissociation, PAR endoprosthesis was developed which was a modular third-generation saddle prosthesis. The PAR endoprosthesis consists a wide iliac wing component that is secured to the ilium with cross bolts and cement, a constrained bipolar ball and socket joint, and a modular standard or endoprosthetic femoral stem. The complication rate of PAR endoprosthesis was reported to be 56%, and implant survivorship was 60% at 5 years. The dislocation rate was decreased to 12% [17] (Figs. 13.7 and 13.8).

13.5 Pedestal Cup

Pedestal cup (Zimmer, Freiburg, Germany) was originally designed for severe acetabular revision. It was firstly used in oncological condition since 2001 reported by Hipfl et al. in Vienna, Austria [18]. The so-called iliac stemmed-cone prostheses are effectively modified versions of the McMinn acetabular reconstruction component. In their retrospective review of a series of 48 cases reconstructed by stemmed pedestal cup (Schoellner cup, Zimmer Biomet, Inc.), a complication rater of 40% was found at a median follow-up of 6.6 years. Deep infection was the most common complication which affected 17% of the patients. The mean function score by MSTS 93 was 71%.

A modification type of pedestal endoprosthesis LUMiC® (implantcast, Germany) was introduced in 2003. The LUMiC prosthesis is a modular device, built of a separate cemented or uncemented stem with HA-coated and acetabular cup. The cup is also available with silver coating for anti-infection effect. The cup is connected to the stem by sawteeth allowing for rotational adjustment of cup position after implantation of the stem. A multicenter study during 6 years including 47 patients showed a dislocation rate was 13 for single time and 9% for recurrent dislocations. The infection was the most common type of complication which was 28%.

"Ice-cream" cone reconstruction of the pelvis was developed in 2003 by Stanmore Implants, and the system was named as coned hemipelvis. The concept was based on the old design of the McKee-Farrar stemmed hip replacement and has become known as the "ice-cream" cone prosthesis, as it looks like an inverted ice-cream cone. The prosthesis is inserted into the remnant of the pelvis and surrounded by antibiotic-laden bone cement. The overall complication rate was 37% with dislocation as the most common type (14.8%), followed by deep infection (11.1%) [19] (Fig. 13.9).

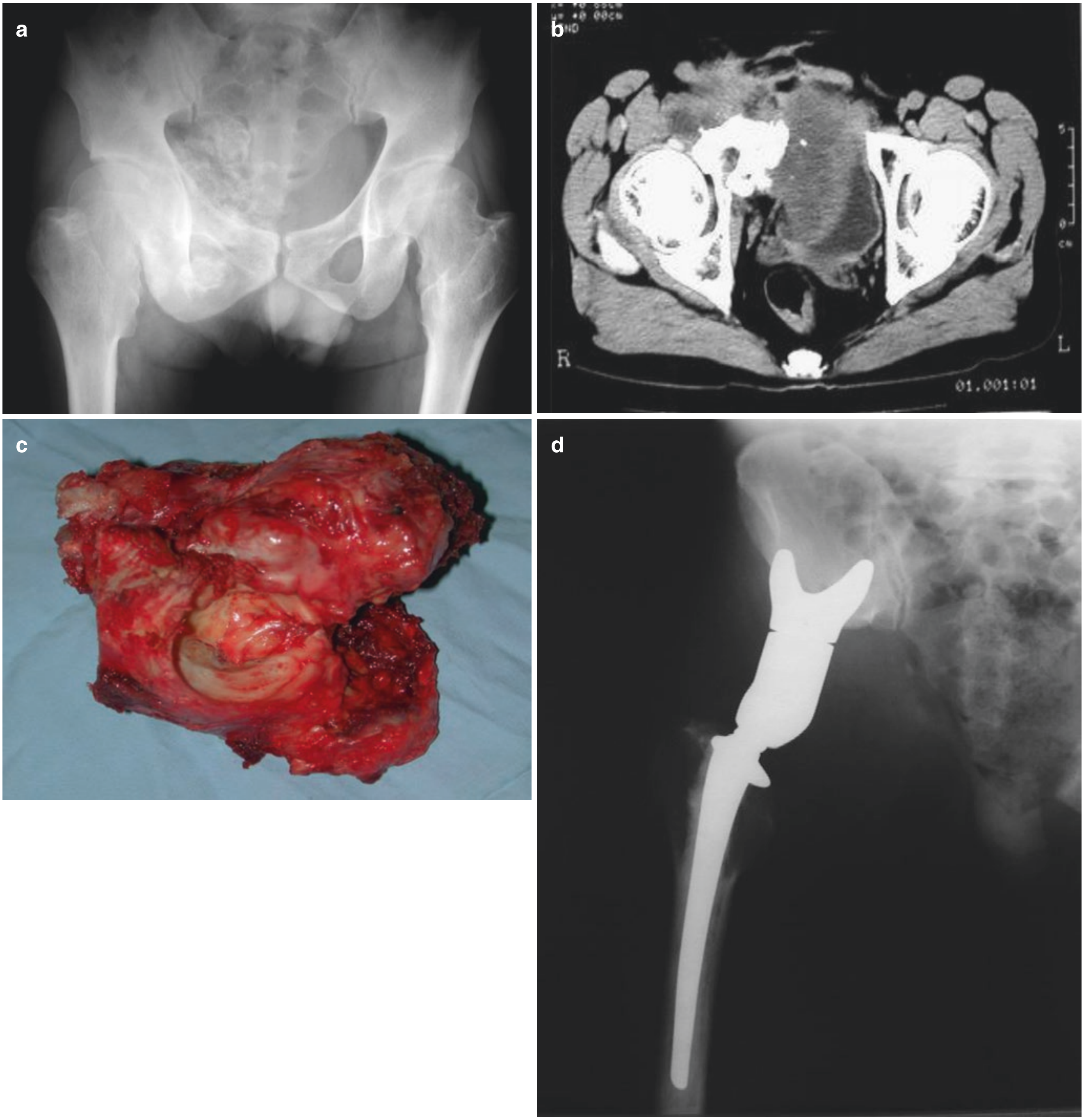

Fig. 13.7 The patient was a 34-year-old male with chondrosarcoma in the right pelvis involving the acetabulum, pubis, and ischium. Preoperative radiography (**a**, **b**) showing the tumor mass. (**c**, **d**) Intraoperative photos and gross specimen after type II + III resection. (**e**) Postoperative pelvis AP showing the link saddle prosthesis was in position

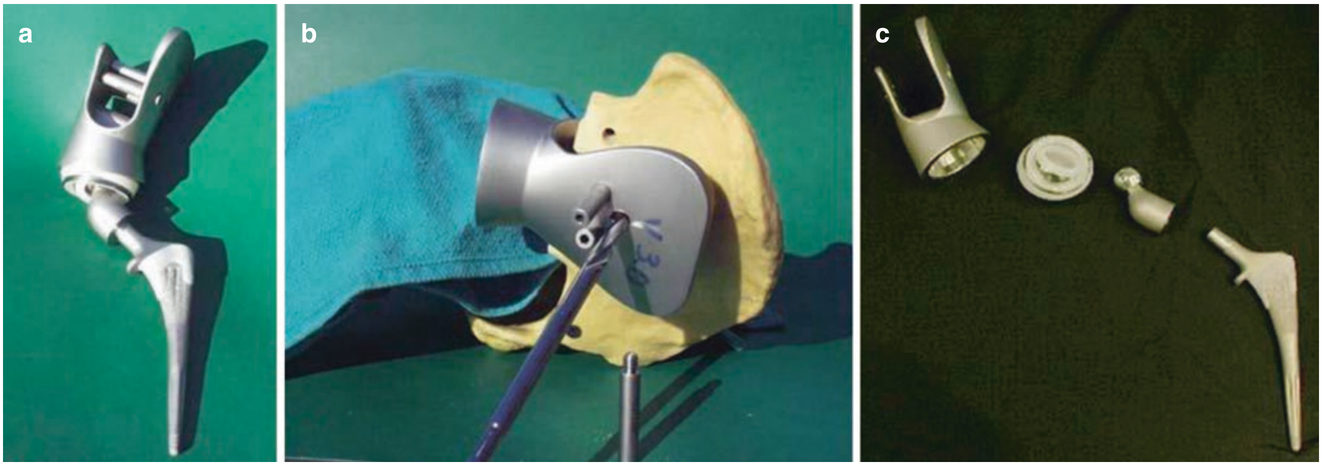

Fig. 13.8 The PAR endoprosthesis

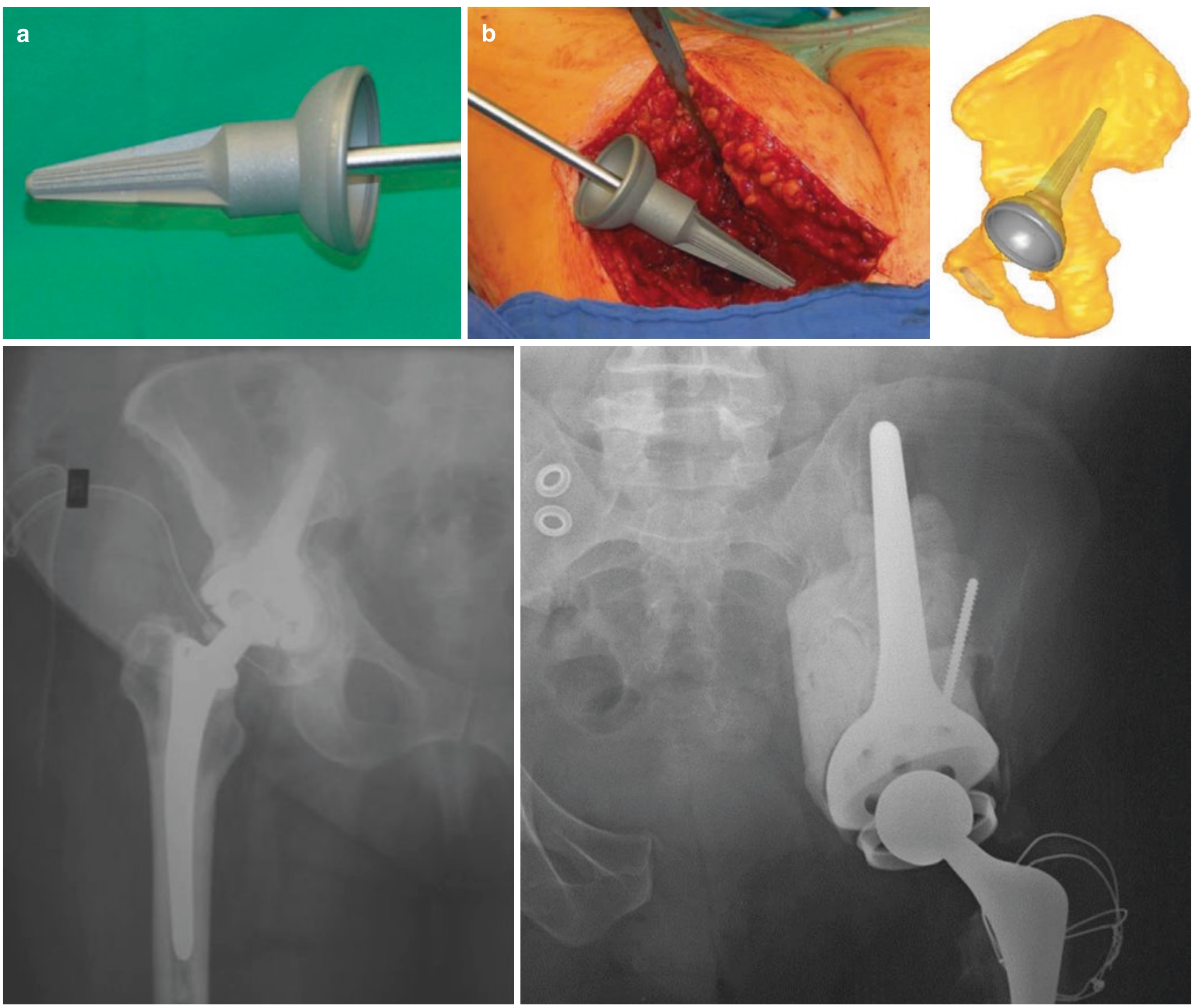

Fig. 13.9 The pedestal endoprosthesis reconstruction after periacetabular tumor resection (Copyright © Wolters Kluwer Health | Lippincott Williams & Wilkins)

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