14 Reconstruction of Pelvic Tumor with Sacrum Involved

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14.1 Fundamental Principles of the Reconstruction

1. No compromise to the surgical margins
   In pelvic tumor cases involving the sacrum, unexpected accidents including massive hemorrhage may prevent surgeons from keeping to the surgical margins. In addition, orthopedic surgeons are apt to emphasis too much on functional reconstruction when performing limb salvage surgeries. In that way, surgical margins are sometimes compromised to facilitate instrumentation and implant fixation. For example, when malignant pelvic tumor invades great proportion of the ipsilateral sacral wing, opening of the sacral canal and ligation of certain nerve roots are inevitable under these circumstances. However, these procedures may lead to severe destruction to the lumbosacral conjunction and functional loss of the sacral nerves. So intralesional curettage after bulk resection is sometimes adopted to save more bones, which are necessary to prosthesis or allograft anchoring. It might be applicable in benign tumors, but if the neoplasm is malignant, a second chance for surgical resection is unquestionably mere as recurrence occurs.
2. Recovery of limb length
   It is controversial whether reconstruction of pelvic girdle integrity and recovery of suffered limb length be beneficial to the patient. Some surgeons preferred not to reconstruction of pelvic girdle after iliosacral resection due to prolonged surgical duration and poor lower limb function led by injuries to the lumbosacral plexus. Other surgeons are used to iliofemoral arthrodesis or hip transposition to stabilize the salvaged limb [1, 2]. One of the major drawbacks of these procedures is that the suffered limb is dramatically shortened. And the patient has to face more difficulties in practicing standing and restoring normal gait function. Hence, although much of the muscle origins are cut off and the muscle innervations are destroyed by the nerve sacrifice, reconstruction of pelvic defect and limb length recovery can still benefit the patients' rehabilitation. Moreover, patients tend to participate in social life more easily with less mental disturbance.
3. Restoring of lumbopelvic continuity and three-column stabilization of lumbosacral conjunction
   Besides from the disruption of the sacroiliac joint, lumbosacral discontinuity and spinal instability caused by partial or total sacral defect are also challenging to the orthopedic surgeons. The lumbosacral conjunction is considered as a key structure responsible for strength loading of the body weight on the pelvic girdle. According to the three-column concept [3], the lumbosacral conjunction is unstable when the vertebral body of the sacrum, the anterior lumbosacral ligament, or the lamina and the spinal process of the sacrum is resected. Although techniques for lumbopelvic reconstructions after total or subtotal sacrectomy have inspired the surgeons in reconstructions after sacropelvic resections [4], the classic pedicle screw and rod system could not thoroughly make three-column stabilization to the major sacropelvic defects due to lack of screw insertion sites. Introduction of computer-assisted design and manufacture of sacropelvic implant may provide solutions to this problem.
4. Preservation of hip range of motion
   The acetabulum is frequently involved in massive tumors of the sacropelvic region. It is extremely difficult to restore the function of both the sacroiliac joint and the hip joint. Some surgeons believe that arthrodesis and pseudarthrosis repair should provide superior stabilization comparing to prosthetic reconstructions by sacrificing hip mobility. However, as great progress has been made in the prosthesis design and manufacture, range of motion of the hip joint could be preserved under most circumstances. This would not only prevent limb discrepancy but also facilitate muscle strength recovery of the lower limb

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through early rehabilitation. Complications including hip dislocation and mechanical failure may occur. Improvement in surgical techniques and prosthetic design should help preservation of the hip joint function in the future.

5. Avoidance of endoprosthetic-related complications
Endoprosthetic-related complications are common. As for the sacropelvic reconstruction, endoprosthetic loosening, deep infection, dislocation, and neuralgia are all catastrophic events which can lead to a secondary surgery. Particularly, neuralgia is sometimes inevitable after resection of massive tumors and stimulation of lumbosacral bundles, while endoprosthetic-related neuralgia is evitable in most cases if neural interference with the prosthesis is successfully avoided. Herein, transient and persistent neuralgia could be prevented with subtle surgical procedures and dedicate prosthetic designs.
6. Prepare for revisions
No matter the orthopedic surgeon choose reconstructions using allograft or prosthesis, revision may happen particularly in young patients, in whom physical demand is fairly high and structural complications including screw loosening and rod breakage are common. For the purpose of facilitating secondary revision surgeries, it is noticed to adjust mechanical conduction of the prosthesis or allograft-prosthetic composite and optimize the prosthetic design. To some extent, modular hemipelvic prosthesis has its advances in easy part changing, which could avoid unnecessary extensive exposure in a secondary revision surgery. Besides, introduction of computer-assisted design for a custom-made modular prosthesis may further help in a revision surgery.

14.2 Reconstructions Under Different Conditions

1. Partial sacral wing defect with continuous sacroiliac joint
Such minor defect usually appears after intralesional resection of benign or invasive tumors involving the sacroiliac joint. Both ilium and sacrum are destructed, while anterior bone cortex and strong sacroiliac ligaments stay intact. Whether the mechanical reconstruction is necessary fully depends on the surgeon's experience and the patient's physical demand.

Reconstruction methods include bone grafting with allogeneic or autogenic bones, bone cement filling with or without internal fixation such as cancellous screws, or pedicle-iliac screw and rod system. As for younger patient, biological reconstruction is preferable. Mechanical strength of weight-bearing tends to fully recover after ideal bone fusions (Fig. 14.1). As for invasive tumors or lesions with high recurrent propensity, bone cement filling is comparatively more feasible. Local recurrence is easily verified by distinct osteolytic appearance surrounding the bone cement in lesions such as giant cell tumor (Fig. 14.2). Moreover, the mechanical strength is enough for weight-bearing and physical activity shortly after the surgery.

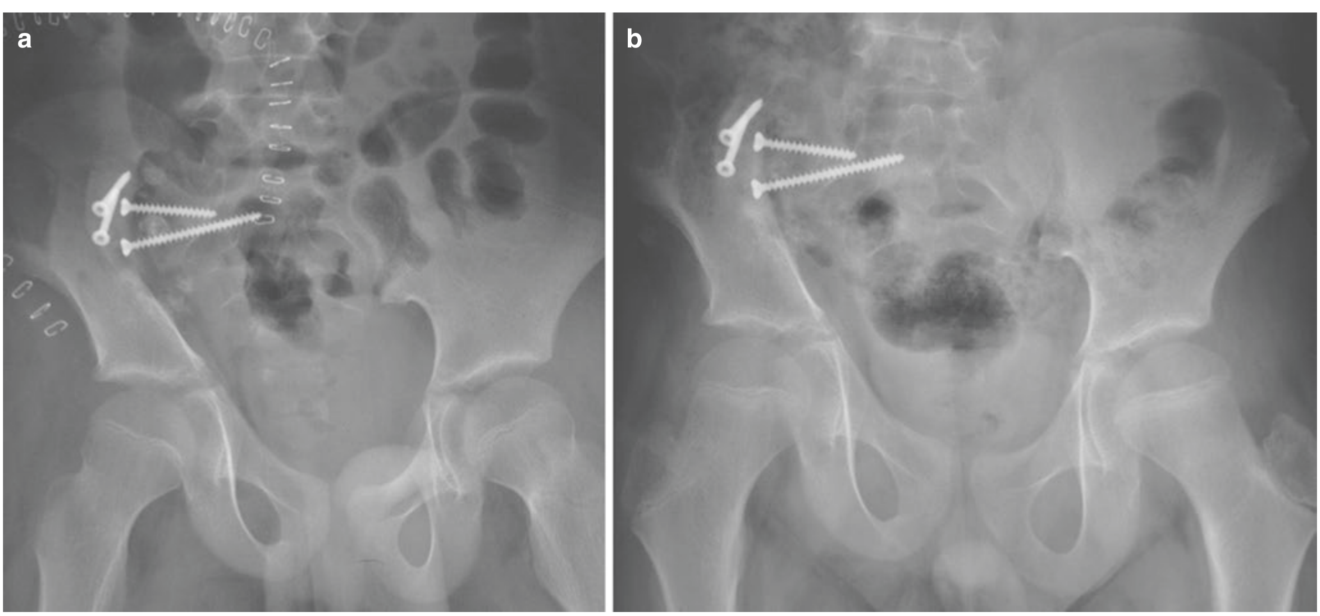

Fig. 14.1 A 12-year-old boy diagnosed with sacroiliac angiolipoma. After intralesional type I + IV resection, the biological reconstruction with the autogenic bone of the ipsilateral ilium was performed. Cancellous screws were also inserted for fixation of this structural reconstruction (**a**). Bone fusion was achieved at the 6-month follow-up (**b**). A PKUPH case

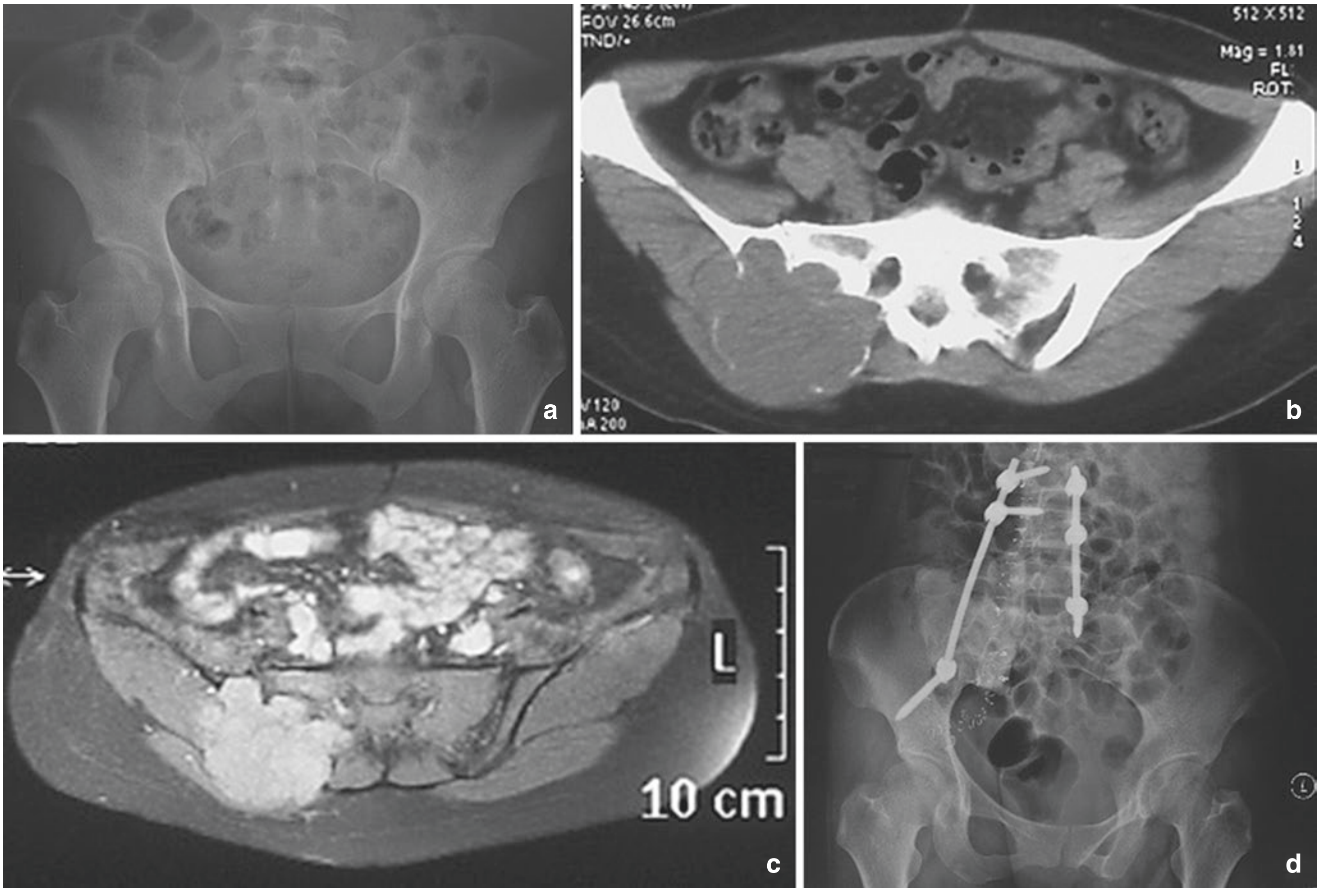

Fig. 14.2 A 38-year-old female diagnosed with sacroiliac giant cell tumor (**a**–**c**). After the intralesional resection and curettage, bone cement was adopted for the defect filling. Pedicle-iliac screw and rod internal fixation was also performed to enhance the lumbosacroiliac conjunction (**d**). A PKUPH case

2. Sacral wing defect with complete sacroiliac joint destruction

   Reconstruction of this type of sacroiliac defect is similar to that of partial iliac defect. The sacroiliac continuity or lumbopelvic conjunction should be restored by means of bone grafting and internal fixations. Nishida et al. prefer to adopt vascularized iliac bone graft for the reconstruction of iliosacral bone defect [5] (Fig. 14.3).

   Aydinli et al. chose autogenic fibula as the structural bone graft for reconstruction within the gap between the residual ilium and the sacrum. The screw and rod system was used to enhance the mechanical strength (Fig. 14.4) [6].

   Unlike the solitary iliac defect, difficulties in reconstruction for concurrent iliac and sacral defects include the following: (1) lack of anchoring sites for the screws in sacral ends due to major sacral bony defect and (2) injuries to the neighboring lumbosacral chunk easily causing loss of neural functions and neuralgia. Herein, although the lumbosacral conjunction is primarily intact, the direct lumbopelvic instrumentation is obligatory.

   Guo et al. led in the reconstruction using pedicle screw system for major sacroiliac defect of total iliac loss (Fig. 14.5) [7, 8]. Two screws were respectively inserted into the superior ramus of pubis and the ramus of ischium through the osteotomy plane above the ceiling of the acetabulum. By aligning these screws with the pedicle screws with double rods and enhancing the acetabular ceiling with bone cement, the mechanical strength for weight-bearing is fully achieved. The precision of screw insertion is essential. Besides from judging the screw direction by anatomical landmarks, intraoperative CT scan was also a powerful manner for precise screw insertions.

   If the residual sacrum is enough, a pedicle screw could also be inserted into the sacrum resulting a lumbosacropelvic fixation (Fig. 14.6).

   Ogura et al. also adopted lumbopelvic fixation with screw and rod system [9]. However, screws were not inserted into the pubis and ischium, while double-barrel vascularized fibula was counted on for combination with biological reconstruction instead of bone cementing. Bone union was achieved in five of eight patients (63%)

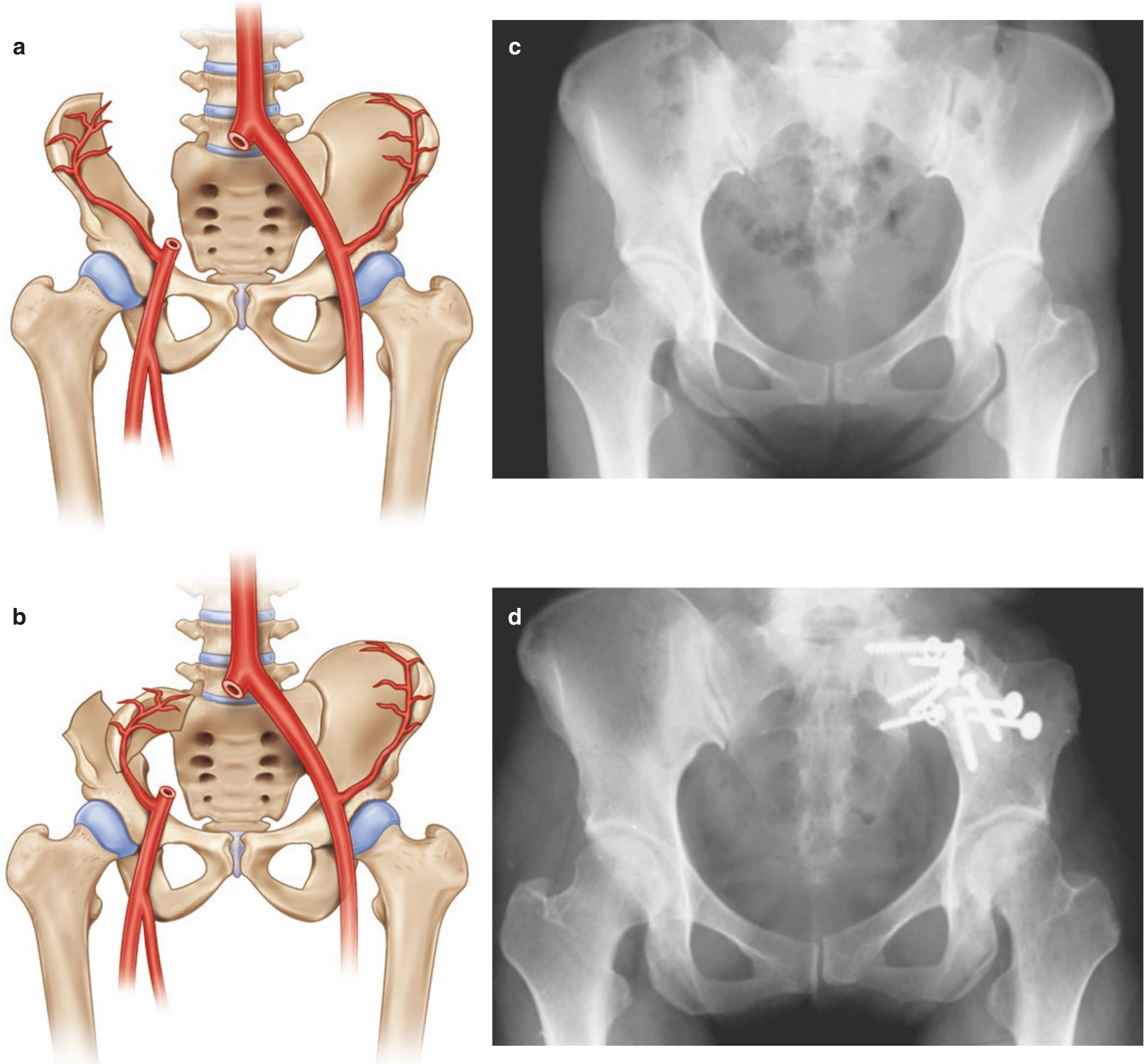

Fig. 14.3 The diagrams show reconstruction using a vascularized iliac graft (**a**) before and (**b**) after the iliac crest transfer. (**c**) A radiograph of the pelvis shows an ill-defined osteolytic lesion in the left ilium. (**d**) A plain radiograph taken 3.5 years postoperatively shows a well-united, transferred iliac graft

over a 1-year follow-up. There were three early postoperative complications: two deep infections resulting in graft removal and one implant failure resulting in nonunion. Among three patients, two developed scoliosis within 5 years. One patient developed lumbar disc hernia as a result of scoliosis, for which surgical intervention was required. At PKUPH, we adopted a 3D-printed sacroiliac endoprosthesis (Fig. 14.7) for reconstruction of sacroiliac defect and had demonstrated its durability in the short term.

Besides from instrumentations, C. Hoffmann et al. established hip transposition as a universal tool for periacetabular tumors excelling in small foreign parts and resulting in acceptable complication rates with good functional outcome [2]. However, its feasibility when the sacrum is involved needs further validation.

3. Subtotal sacral resection with complete sacroiliac joint destruction

   After a subtotal sacral resection, the lumbosacral conjunction is so weak and unstable that direct sacropelvic

Fig. 14.4 (**a**) Preoperative radiologic workup image suggests a mass involving the right iliac bone and sacroiliac joint. (**b**, **c**) Radiographs and 3D CT scans 3 years after type I + IV pelvic resection

reconstruction is difficult to achieve. Lumbopelvic reconstruction is the only method eligible. Instrumentation using bilateral pedicle-iliac screw and rod system remains predominant. Unlike minor iliac defect after sacrectomy, the iliac defect is major, and the residual bone ilium is usually lack of posterior iliac crest, which renders a great proportion of mechanical strength for screw anchoring and weight-bearing. Alternative methods of screw fixation in the residual ilium include inserting the screws into the iliac crest or more stably into the body of the ilium upon the weight-bearing surface of the acetabulum (Fig. 14.8). Transverse rod connectors or transiliac bars may be necessary for the prevention of the pelvic separation. And bone grafting is also preferable, aiming at lumbopelvic fusions, which could stop descent of the lumbar spine in the long term.

As for the hindquarter amputations along with subtotal sacrectomy, the contralateral sacroiliac joint needs stable reconstruction for weight-bearing of the salvaged limb. Ehud Mendel et al. chose to use autologous vascularized femur and fibula bone flaps harvested from the amputated lower extremity for lumbopelvic reconstruction [10]. At the 18-month follow-up, he was able to ambulate with the assistance of his custom-made prosthesis.

4. Bilateral sacroiliac discontinuity after internal hemipelvectomy and total sacrectomy
Extraordinarily massive tumor tends to invade the total hemipelvis and the total sacrum. En bloc surgery leaves the lumbar spine, and the uninvolved hemipelvis and the salvaged limbs totally separated. Though the nerves innervating the lower limb might be cut or damaged due to extensive surgical interventions, many patients still refuse to be amputated while the prognosis is unfortunately dim. Under this condition, the aim of reconstruction is to stabilize those anatomical structures in a manner that provides a one-stage solution for the defect and

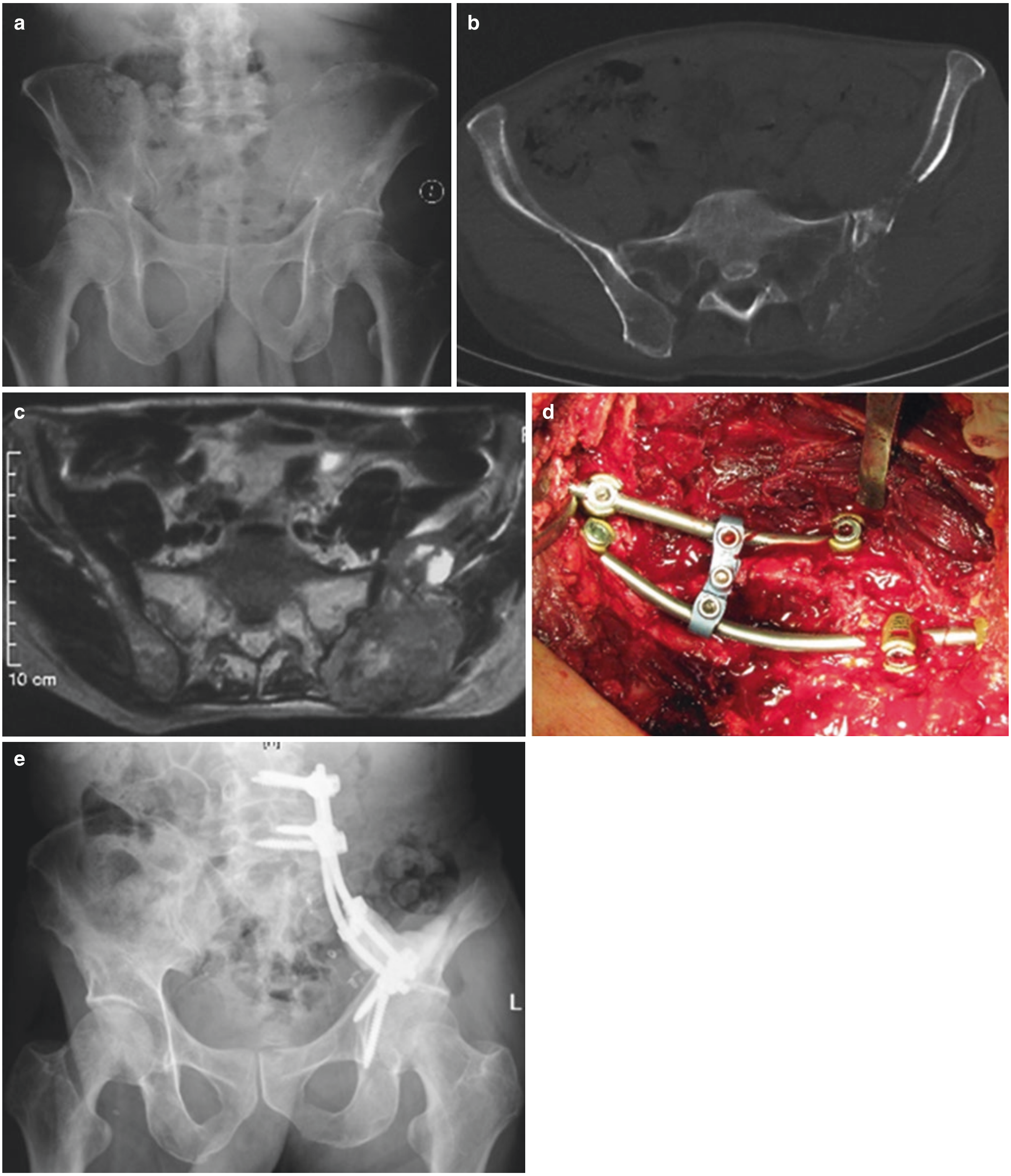

Fig. 14.5 A 69-year-old male diagnosed with poorly differentiated sarcomatoid carcinoma (**a**–**c**). After subtotal resection of the ilium and ipsilateral sacral wing, the lumbopelvic conjunction was reconstructed with pedicle-pubic-ischial screw and rod fixation system and bone cementing. Additional pedicle screws were also inserted laterally into the lumbar vertebra to provide additional anchoring sites for titanium rod (**d**, **e**). A PKUPH case

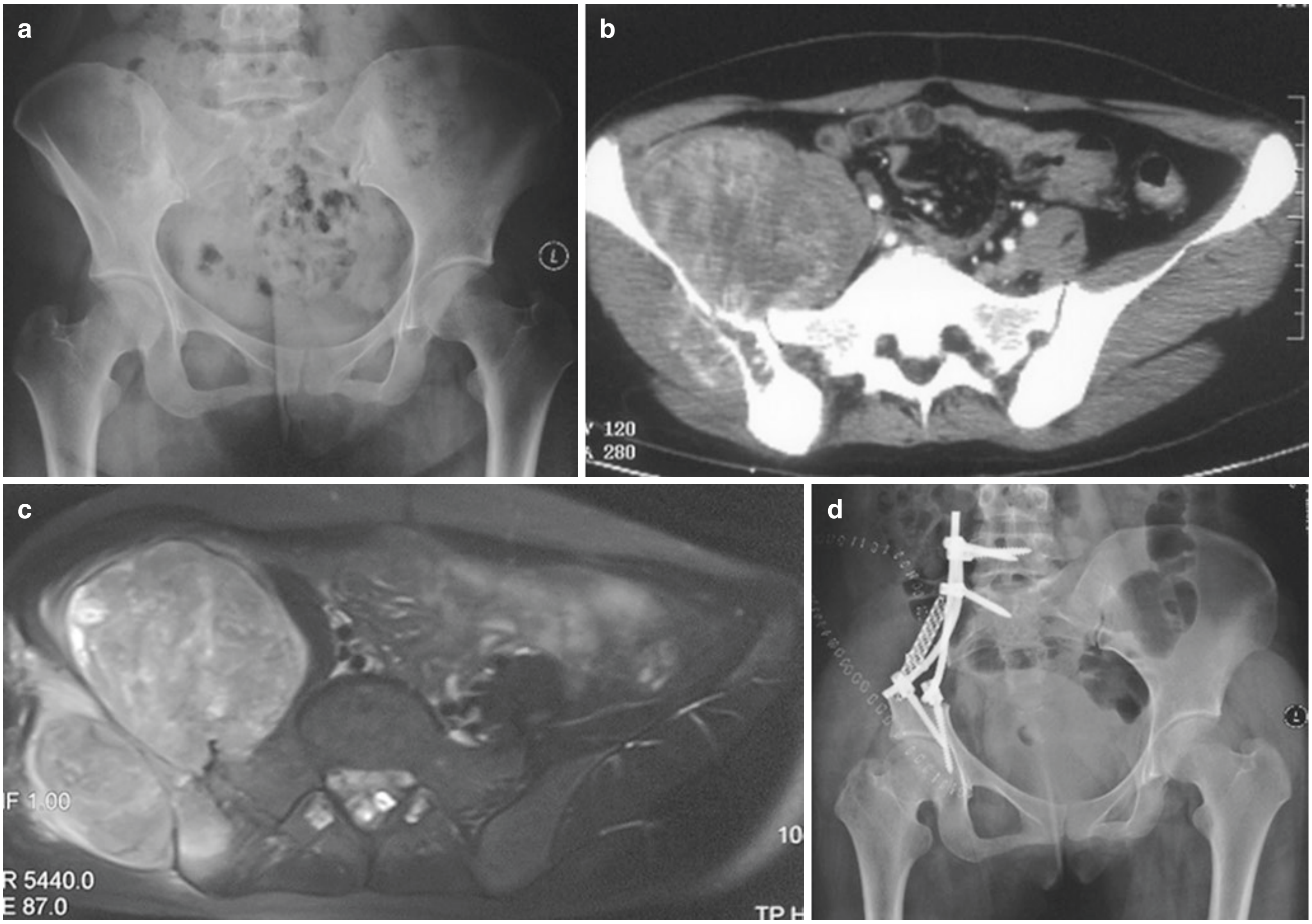

Fig. 14.6 A 28-year-old female was diagnosed with Ewing's sarcoma (**a**–**c**). After resection of the ilium and partial sacrum, the lumbosacropelvic fixation was performed and an allografted titanium mesh cage was stuck between the gap, in order to facilitate bone union (**d**). A PKUPH case

minimize the related complications as much as possible. Favorably, the reconstruction should relieve pains regarding the pelvic instability and give chances to a better rehabilitation (Fig. 14.9).

14.3 Development in Prosthetic Reconstruction of the Hemipelvis with Hip Involvement

The *pseudarthrosis*, femorosacral arthrodesis, and hip transposition all lead to irreversible limb discrepancies, which affect patient's normal gait significantly. Though the early periacetabular prosthesis such as the saddle prosthesis and the pedestal prosthesis could restore most of the hip range of motion, they are not eligible for reconstruction with major defect involving the sacrum, in that they both anchor to the residual ilium and rely on continuity of the sacroiliac joint. Herein, it relies on development in newly designed hemiprosthesis to achieve such major defect involving both the sacroiliac joint and the hip joint. Early solutions include caudal-flanged hip cage connected to pedicle screw and rod system (Fig. 14.10) and custom-made megaprosthesis [2]. Novel prosthesis used for hemipelvic reconstruction including the hip joint includes modular hemipelvic prosthesis connected to pedicle screw and rod system (Fig. 14.11) [11]. For more extensive resections when part of the sacrum is included, standardized surgical procedures were proposed (Fig. 14.12), and an updated version of the hemipelvic prosthesis was demonstrated to be durable in the short term (Fig. 14.13) [12, 13].

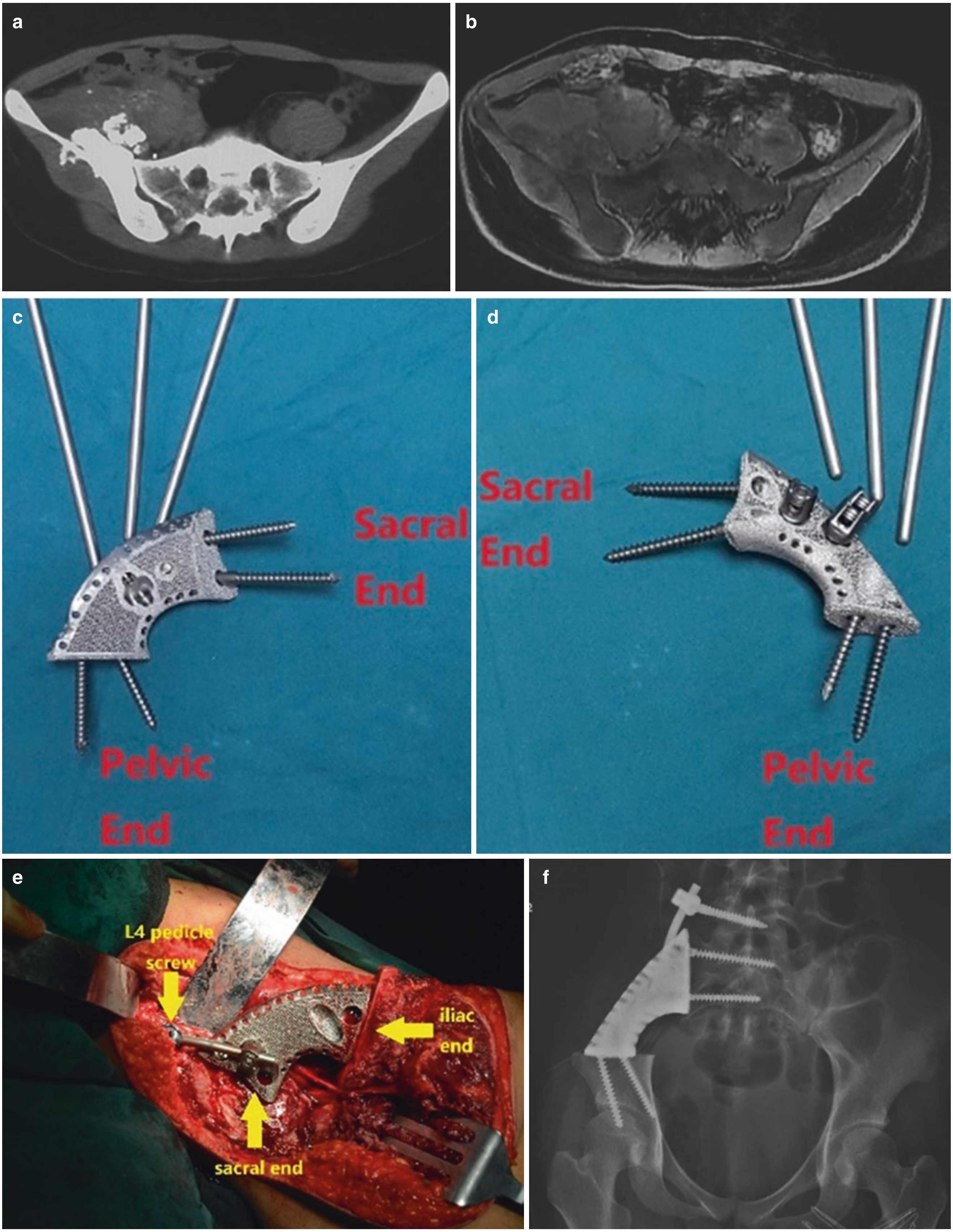

Fig. 14.7 An 18-year-old female was diagnosed with osteosarcoma (**a**, **b**). After resection of the ilium and partial sacrum, a 3D-printed titanium iliac implant (**c**, **d**) is fixed to the residual ilium and sacrum using four cancellous screws. Another lumbar pedicle screw was connected to a multiaxial screw within the implant to provide additional stabilities (**e**, **f**). A PKUPH case

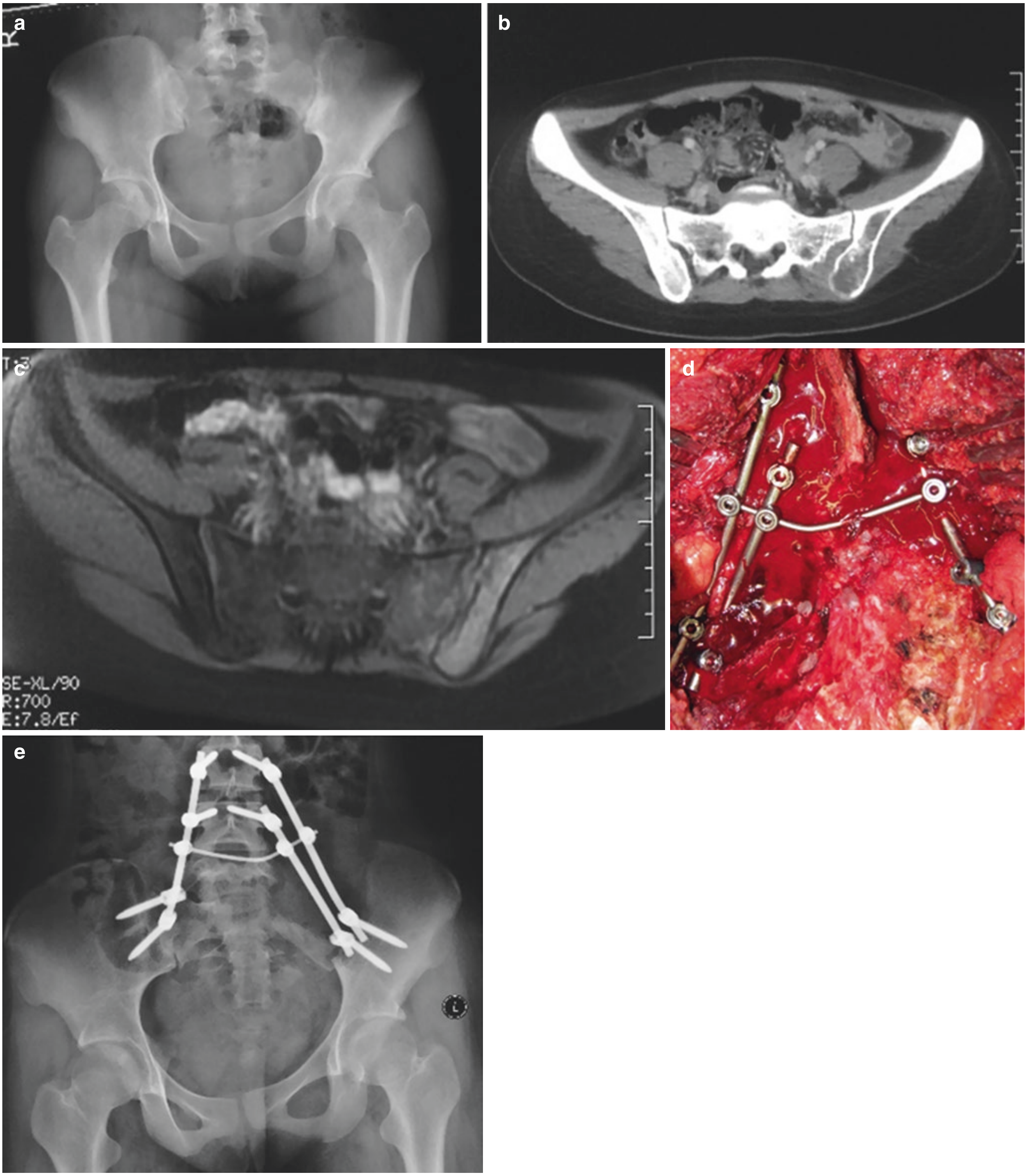

Fig. 14.8 A 15-year-old female was diagnosed with Ewing's sarcoma (**a–c**). After subtotal sacrectomy and partial iliac resection, bilateral spino-pelvic reconstruction using pedicle-iliac screw and rod was performed (**d**, **e**). A PKUPH case

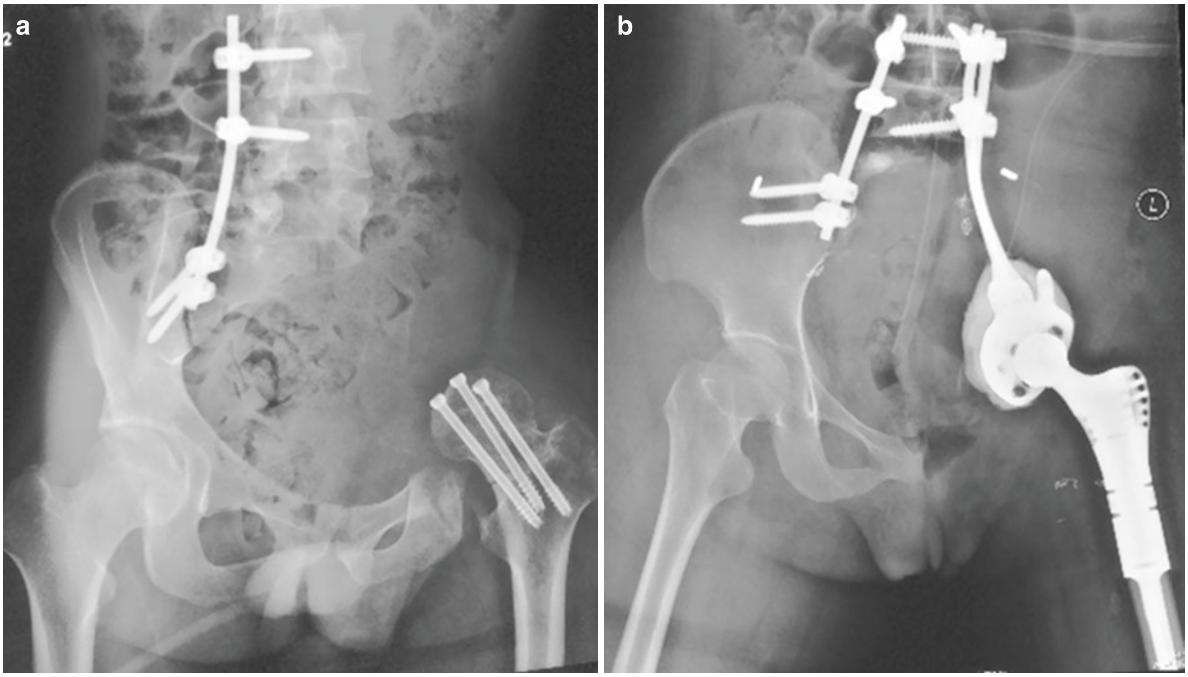

Fig. 14.9 (**a**) A 24-year-old male was diagnosed with chondrosarcoma. After total sacrectomy and internal hemipelvectomy, contralateral spinopelvic reconstruction using pedicle-iliac screw and rod was performed, leaving a spared left lower limb. (**b**) A 24-year-old female was diagnosed with osteosarcoma. After total sacrectomy and internal hemipelvectomy of the involved proximal femur, bilateral spinopelvic reconstruction using pedicle-iliac screw and rod connecting to a hemipelvic prosthesis articulated with a proximal femoral prosthesis was performed. Two PKUPH cases

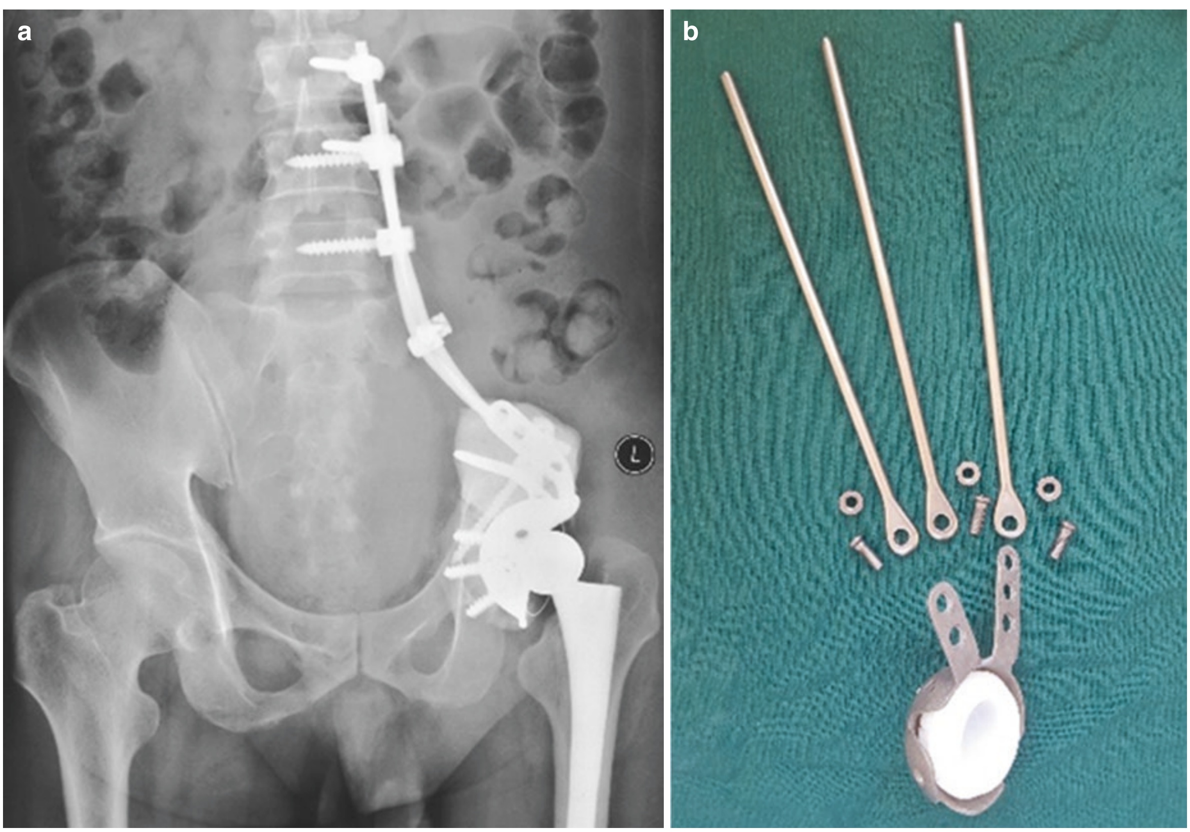

Fig. 14.10 A 43-year-old male was diagnosed with chondrosarcoma. After type I + II + IV pelvic resection, endoprosthetic reconstruction using a caudal-flanged hip cage connected to pedicle screw and rod system was performed with enhancement of periprosthetic bone cement. A PKUPH case

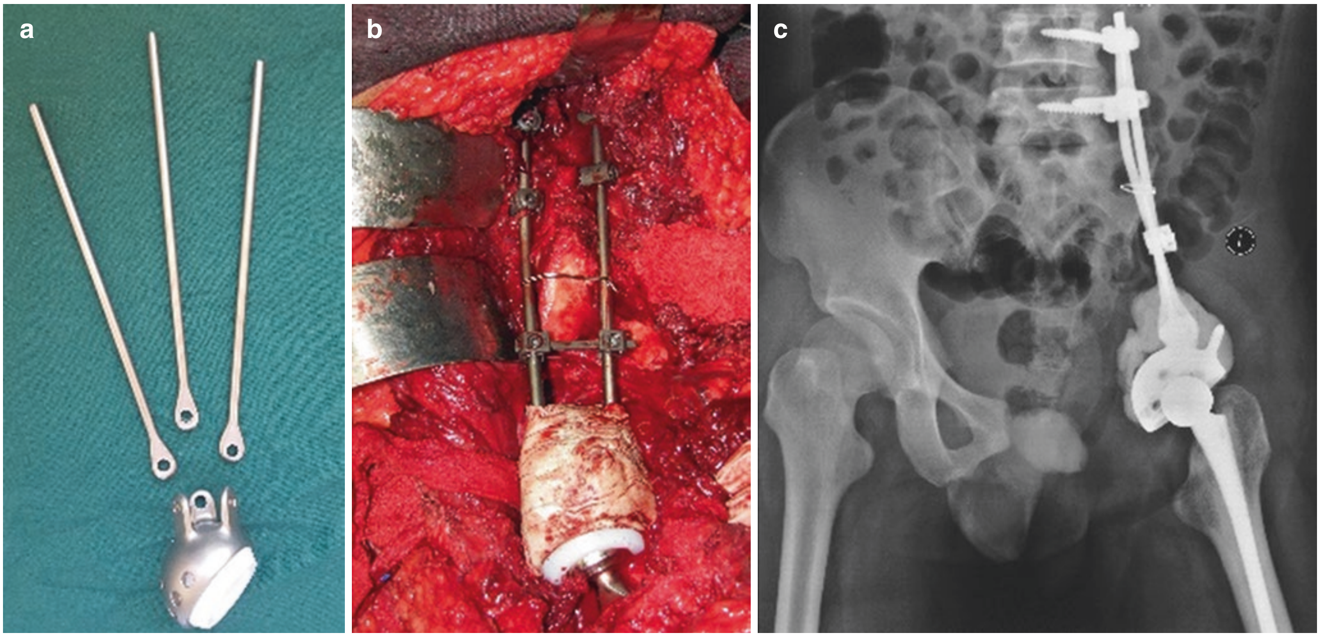

Fig. 14.11 A 33-year-old male was diagnosed as malignant inflammatory myofibroblastoma. After type I + II + III + IV pelvic resection, endoprosthetic reconstruction using a modular hemipelvic prosthesis connected to pedicle screw and rod system was performed with enhancement of periprosthetic bone cement. A PKUPH case

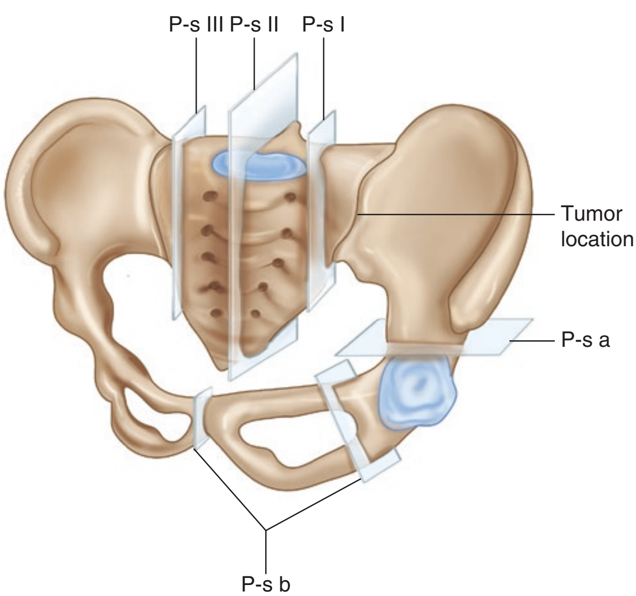

Fig. 14.12 Illustration of the new surgical classification for pelvic tumors with sacral invasion

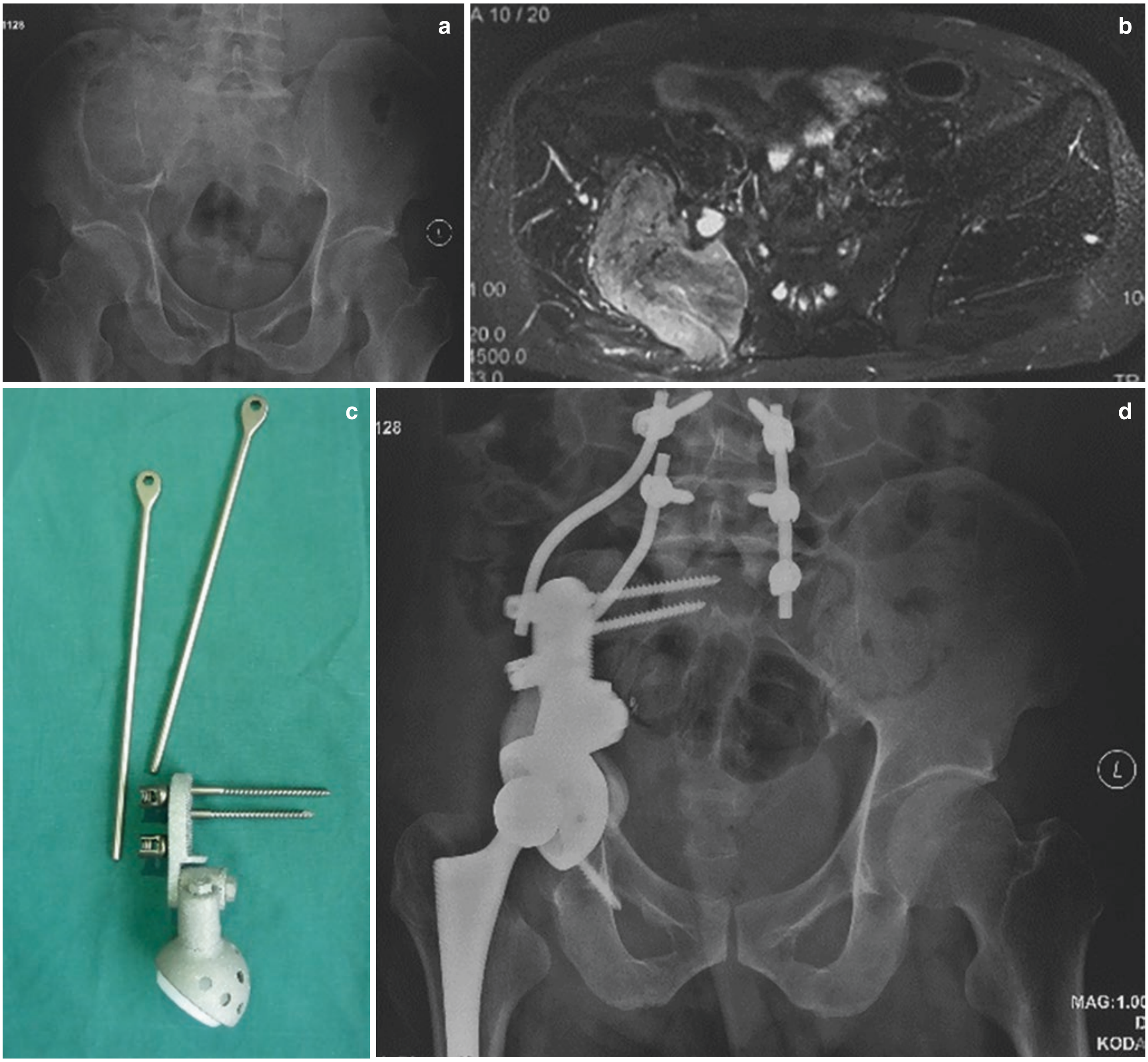

Fig. 14.13 A 35-year-old male was diagnosed with malignant peripheral neurofibroma (**a**, **b**). After type I + II + IV pelvic resection, endoprosthetic reconstruction using a newly designed modular hemipelvic prosthesis connected to pedicle screw and rod system was performed with enhancement of periprosthetic bone cement (**c**, **d**). A PKUPH case

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