Surgical Technique

Iliosacral Reconstruction With Minimal Spinal Instrumentation

Nader A. Nassif MD, Jacob M. Buchowski MD,
Kelly Osterman RN, Douglas J. McDonald MD

Received: 20 April 2012 / Accepted: 1 October 2012 / Published online: 13 October 2012
© The Association of Bone and Joint Surgeons® 2012

Abstract

Background Posterior pelvic ring reconstruction can be challenging and controversial. The choice regarding whether to reconstruct and how to reconstitute the pelvic ring is unclear. Many methods provide stability but often are technically difficult and require excessive dissection.

Description of Surgical Technique This unique reconstructive technique uses the anterior aspect of the iliac crest with its attached muscle pedicle to provide a biologic scaffold for healing. The construct is secured with pedicle

screws into the posterior column and S1 vertebral body with a spinal rod locked in compression. No additional fixation is used proximally into the lumbar spine. The iliac crest remains attached to the gluteus medius, allowing potential abductor function.

Methods We retrospectively reviewed six patients who underwent iliosacral resection with this reconstruction. The mean age of the patients was 41 years. Complications were recorded. One patient died 6 months postoperatively. Musculoskeletal Tumor Society 1993 (MSTS '93) score and Toronto Extremity Salvage Score (TESS) were obtained at a minimum 1-year followup in five patients. Healing was assessed radiographically. The minimum followup was 6 months (median, 33 months; range, 6–53 months).

Results The mean MSTS '93 score was 72% and mean TESS was 66. All posterior column graft sites healed. At last followup, four of the five surviving patients had a stable pseudarthrosis at the proximal sacral site. One patient had a local recurrence and experienced failure of instrumentation without collapse or rotation of the hemipelvis 3 years postoperatively.

Conclusions This technique provides a simple way to reconstruct the pelvic ring after iliosacral resection with clinical outcomes comparable to those for other methods. The method is a potential alternative for reconstruction of the posterior pelvic ring after resecting the ilium although reliable healing of the sacral site needs to be improved.

One of the authors (JMB) certifies that he has or may receive payments or benefits, during the study period, an amount in excess of \$10,000–\$100,000, from Stryker, Inc (Mahwah, NJ, USA), CoreLink, Inc (St Louis, MO, USA), Globus Medical, Inc (Audubon, PA, USA), DePuy, Inc (Warsaw, IN, USA), K2M, Inc (Leesburg, VA, USA). One of the authors (DJM) certifies that he has or may receive payments or benefits, during the study period, an amount in excess of less than \$10,000, from Stryker, Inc (Mahwah, NJ, USA) and Smith and Nephew, Inc (Memphis, TN, USA). The institution of one of the authors (JMB) has received funding from Complex Spine Study Group/K2M, Inc (Leesburg, VA, USA).

All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request.

Clinical Orthopaedics and Related Research neither advocates nor endorses the use of any treatment, drug, or device. Readers are encouraged to always seek additional information, including FDA-approval status, of any drug or device prior to clinical use. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

N. A. Nassif (✉), J. M. Buchowski, K. Osterman,
D. J. McDonald

Department of Orthopaedic Surgery, Washington University
School of Medicine, One Barnes-Hospital Plaza, Suite 11300
West Pavilion, St Louis, MO 63110, USA
e-mail: nnassif@post.harvard.edu

Introduction

Primary malignancy of the bony pelvis presents a unique and challenging problem regarding resection and reconstructive options. The tumors often are large and close to vital neurovascular structures at the time of diagnosis. Despite the

potential for local recurrence, numerous authors suggest limb salvage provides better quality of life compared with hemipelvectomy [10, 12, 13, 16, 19]. With the goal of limb salvage, resection still needs to be adequate with wide and clear margins while preserving vital neurovascular structures. The difficulty in reconstruction arises in providing a stable construct that would reconstitute the integrity of the pelvic ring and allow for use of the leg with minimal collapse or rotation of the residual portion of the hemipelvis and help support function and maintain quality of life.

Depending on the location of the tumor in the pelvis, Enneking and Dunham [8] described three resection zones. A Type I resection includes wide excision of a portion, or the entirety of, the ilium, and a Type I-S resection involves resection of a portion of the sacrum [9]. Many authors [1, 2, 4, 11, 15] have suggested different strategies to deal with the discontinuity of the pelvis. Some have forgone any reconstruction of Type I resections [2, 8], leaving the pelvic ring in discontinuity. Not reconstructing the pelvic ring, however, resigns the patient to a protracted period of bed rest for the anterior pelvis to form scar and prevent collapse and rotation of the hemipelvis. If, however, the patient is allowed to bear weight, a progressive leg-length discrepancy occurs as the anterior pelvis collapses to articulate with the sacrum. Furthermore, there is no reconstruction of the abductor muscles to allow for better function of the hip. Some authors have described constructs using strut grafts [1, 2], vascularized iliac pedicles [11], or vascularized fibulas [4, 15, 20] to connect remaining periacetabular bone to the sacrum. Although these techniques address the problems produced by not reconstructing the pelvis they have tended to be technically challenging, can result in high complication rates, and may not provide reliable union [2, 15].

We developed a method of reconstruction after Type I-S iliosacral resection that uses a gluteus medius muscle pedicle iliac bone graft and minimal spinal fusion instrumentation to reconstruct the pelvic ring. This method provides a simpler construct for posterior pelvic reconstructions and allows for reconstitution of the pelvic ring using the host bone with its muscular attachment. We describe our surgical technique and subsequent function, graft healing, and complications in a small group of patients.

Surgical Technique

The indications for this technique were: (1) a malignant neoplasm of the posterior ilium not involving the anterosuperior iliac crest, inferior posterior column, or acetabulum. Sacral involvement must be none or minimal such that a safe resection can be made lateral to the sacral foramen, (2) a resection plan is needed that would disrupt continuity of the pelvic ring, and (3) there must be a desire for limb salvage.

A specific contraindication, in addition to bone extent, was involvement of the neurovascular structures of the sciatic notch precluding safe resection, or major tumor involvement of the anterior gluteus medius muscle.

The patient is positioned in a semimobile lateral position so that the pelvis can be seen from a near supine position to a full lateral position. An extensile incision is made from the posterosuperior iliac spine extending anteriorly along the area of the iliac crest to the anterosuperior iliac spine, then directed distally down the Smith-Petersen interval, curving posteriorly, ending just distal to the ischial tuberosity. The anterior abdominal wall is detached from the iliac crest throughout its entire length using electrocautery and the retroperitoneal space is entered. The dissection then is developed between the iliacus and psoas. The femoral nerve is identified and protected, being retracted medially. The dissection then is carried down to the anterior portion of the sacrum. The L4-L5 conjoined nerve roots are identified and reflected in a medial direction and the ala of the sacrum is identified anteriorly, superiorly, and inferiorly toward the direction of the sciatic notch. The iliacus muscle then is identified at the level of the intended iliac osteotomy just at the line of the anteroinferior iliac spine directly toward the sciatic notch.

The patient is turned to a full lateral position. A large gluteal flap is made. If the gluteus maximus is involved, a wide margin is taken through the muscle belly; otherwise, the tumor mass is dissected from the muscle. The inferior portion of the dissection is developed between the gluteus medius and gluteus maximus muscle. The entire maximus then is reflected posteriorly. The sciatic nerve and all posterior pelvic contents are protected. The flap then is turned around posteriorly such that the entire flap could be pulled away from the tumor.

After developing the gluteal flap, attention is directed at harvesting the anterior iliac crest pedicle graft (Fig. 1). A portion of the anterior iliac crest is sized to fit into the defect left by the resection (approximately 1.5 cm deep and 6–8 cm long). The bone pedicle started from the anterosuperior iliac spine directly posteriorly. Using an osteotome, the bony pedicle is created while leaving the origins of the gluteus medius attached.

The remainder of the gluteus medius and minimus is transected along the line of intended resection from the sciatic notch up toward the anteroinferior iliac spine. When the inner and outer tables were thoroughly exposed, a sponge was passed beneath the sciatic notch to protect the contents of the notch. A Gigli saw then was passed through the notch and the osteotomy was performed just superior to the hip at the level of the anteroinferior iliac spine. Once full exposure had been gained and the nerve roots protected, a large osteotome was passed through the sacral ala directly posteriorly and distally (Fig. 2).

Two screws were anchored into the sacrum and posterior column as anchors for the reconstruction using a spinal instrumentation system. Typically, we recommend using a 6.5-mm titanium rod system or a 5.5-mm, 6.0-mm, or 6.5-mm diameter cobalt-chrome rod system to perform the reconstruction (Medtronic, Inc, Memphis, TN, USA). We do not recommend using a 5.5-mm diameter titanium rod system, as it may not be strong enough to support the reconstruction. The parasagittal osteotomy of the sacrum was exposed for insertion of the pedicle screw. We used a start point in the S1 body, approximately 2 cm distal to the superior end plate, and then followed a medial trajectory toward the anteromedial aspect of the promontory of the sacrum using a pedicle finder. Either a 7.5-mm or 8.5-mm

Fig. 1 The planned resection of a tumor in the posterior left ilium is shown in this drawing. The uninvolved anterior iliac crest graft is harvested as part of the exposure with a portion of the gluteus medius attached.

Fig. 2 The pelvis and anterior iliac crest pedicle graft after tumor resection is shown.

diameter titanium multi-axial pedicle screw was placed in the sacrum. The screw lengths ranged from 40 to 60 mm depending on the size of the patient. We then identified another start point medially along the cut portion of the ischium and used a pedicle finder to probe in a lateral-to-medial direction distally in the remainder of the posterior column. An image intensifier was used to ensure the trajectory did not violate the notch or acetabulum. We then implanted a 7.5-mm or 8.5-mm diameter titanium multi-axial pedicle or iliac titanium screw after tapping the hole created by the pedicle finder. The screw lengths ranged from 50 to 75 mm depending on the size of the posterior column remaining. Final placement of both screws was confirmed with biplanar fluoroscopy.

After confirmation of the screw position, we measured a 6.5-mm titanium or 5.5-, 6.0-, or 6.5-mm cobalt-chrome rod to fit the distance spanned between the two screws, then cut and contoured the rod, placed it into the screws, and secured it in place with the appropriate set screws using the torque and countertorque device. Once the rod was in position, the muscle pedicle iliac crest graft was fashioned to fit on the inside of the pelvis keyed into the ischium and sacrum. After the graft was placed, compression was applied across the construct, ensuring that the graft did not kick out. After compression was applied, we finalized tightening of the set-screws using the torque and countertorque device (Fig. 3).

The gluteus maximus muscle and the entire Smith-Petersen interval were repaired. We then repaired the abdominal wall back to the gluteus maximus fascia. The skin was closed in layers and a large bulky dressing was applied.

Patients were permitted toe-touch weightbearing for 6 weeks and then were advanced to 50% weightbearing for an additional 6 weeks. Radiographs were taken at 2, 6, and 12 weeks, 6 months, and then yearly (Fig. 4). If there was

Fig. 3 The graft inserted as a strut between the acetabulum and sacrum with the instrumentation in place can be seen in this illustration of the lateral side.

evidence of bridging trabecular bone or consolidation between the strut autograft and pelvis [3] at 12 weeks, the patient was allowed to advance weightbearing as tolerated. Patients with concerns for delayed union or pseudarthrosis were still advanced in weightbearing as long as they had no pain.

Patients and Methods

We retrospectively reviewed six patients with sarcoma of the posterior pelvis treated with this procedure from November 2006 to July 2010. During that time we treated a total of 19 patients with primary malignant tumors of the ilium. The mean age of the patients was 41 years (range, 17–73 years). Three patients were younger than 35 years. The cohort included two males and four females. Two patients had postradiation sarcoma, two had chondrosarcoma, one had fibrosarcoma, and one had Ewing's sarcoma (Table 1). All but one patient had a minimum of 12 months of followup: one patient died 6 months after surgery as a result of her disease. The minimum followup for the five surviving patients was 12 months (median, 33 months;

range, 13–53 months). Institutional review board approval was obtained to review patient records retrospectively.

Patients were followed with serial radiographs and physical examinations at 2, 6, and 12 weeks, 6 months, and then annually thereafter. The Toronto Extremity Salvage Score (TESS) [5] and the Musculoskeletal Tumor Society 1993 score (MSTS '93) [7] were collected at latest followup. Four patients were seen in followup and one was contacted by phone. No MSTS '93 score or TESS was available for the patient who died at 6 months.

Postoperative complications were recorded and graded based on the complication classification system described by Dindo et al. [6] and recently adapted for orthopaedic surgery by Sink et al. [18]. Grade I complications had no clinical relevance on outcome; these included postoperative fever, nausea, constipation, and urinary tract infection. Grade II complications were events that resulted in deviation of postoperative care, pharmacologic treatment, or closer observation. These included superficial skin infection, transient neurapraxia, delayed union, or an asymptomatic nonunion. Grade III complications required surgical interventions. These included a superficial or

Fig. 4A–D (A) An AP radiograph of the pelvis of a 17-year-old girl with a fibrosarcoma of the posterior left ilium is shown. Her (B) T1 and (C) T2 axial MR images show a localized mass sparing the acetabulum and anterosuperior iliac spine. (D) Four years after reconstruction, the patient occasionally takes NSAIDs for pain. She

had an asymptomatic, stable pseudarthrosis at the sacral site. Her MSTS '93 score was 93% and TESS was 87.5. She has no restriction of function and can walk for unlimited distances with nearly normal gait and good abductor function.

Table 1. Patient demographics and outcomes

Patient number	Age (years)	Diagnosis	Followup (months)	Margins	Adjuvant therapy	MSTS	TESS	Radiographic healing	Complications
1	31	Chondrosarcoma	53	Wide	None	87	74	Complete	None
2	17	Fibrosarcoma	49	Wide	Preoperative chemotherapy, postoperative radiation therapy at 63 Gy	93	88	Posterior column	Delayed wound breakdown (12 months)
3	73	Postradiation osteosarcoma	6	Marginal	Postoperative chemotherapy	N/A	N/A	Posterior column	Death (6 months)
4	58	Chondrosarcoma	34	Marginal	None	76	53	Posterior column	Recurrence (34 months), hardware failure
5	21	Ewing's sarcoma	32	Wide	Preoperative and postoperative chemotherapy	33	62	Posterior column	Scar Necrosis, delayed wound healing
6	48	Postradiation osteosarcoma	13	Marginal	Postoperative chemotherapy	70	54	Posterior column	Infection (12 months)

MSTS = Musculoskeletal Tumor Society 1993 score; TESS = Toronto Extremity Salvage Score; N/A = not available.

deep wound infection that required surgical débridement, symptomatic failure of hardware that required revision surgery, or local recurrence. Grade IV complications result in permanent disability and include permanent nerve injury, major vascular injury, pulmonary embolism, or stroke. A Grade V complication is death. Radiographic evaluation of the construct was obtained at the latest office followup to assess union of the acetabular and sacral sites.

Results

Procedures lasted for a median of 256 minutes (range, 212–339 minutes). The median reported blood loss was 1400 cc (range, 900–6000 cc). Patients received a median of 6.5 units of packed red blood cells (range, 4–16 units) during their hospitalization.

The average MSTS '93 score was 72% (range, 33–93) and the average TESS was 66.2 (range, 53–88). On clinical examination, two patients (both younger than 35 years) had adequate abductor function with no Trendelenburg sign. The remaining patients had a positive Trendelenburg sign. One patient (Patient 5) continued to have substantial pain and limitations of function after surgery. The reason for the pain could not be elucidated despite multiple evaluations at our institution and at other quaternary referral centers. All six patients had radiographic union of the vascularized iliac crest with the posterior column, but only one achieved healing of the junction of the iliac crest autograft and sacrum (Fig. 5).

Several complications were noted in the postoperative evaluations of this cohort. Grade I complications included

one patient with a postoperative ileus which resolved with observation. Grade II complications included two patients who had urinary retention that ultimately resolved but required prolonged catheterization in the meantime. Grade III complications developed in four patients. One patient experienced asymptomatic loosening of the sacral screw and rod fracture at 34 months postoperatively noted on his annual radiographs. The same patient had a local recurrence, which required reexcision (Fig. 6). At the time of re-excision, the instrumentation was removed because the patient had a stable pseudarthrosis intraoperatively. One patient experienced wound necrosis that was treated with repeat surgical débridement and a vacuum-assisted closure. Another patient had a radiation-induced injury to her incision 1 year after surgery and required débridement and revision of her scar. One patient was diagnosed with a deep wound infection 12 months after the index surgery. The patient had débridement with removal of all hardware and retention of the iliac graft. The posterior column site was well healed and the sacral site had a stable pseudarthrosis. There were no Grade IV or Grade V complications.

The first patient of the series was a 31-year-old woman who carried two pregnancies to term postoperatively without any medical complications. Both children were delivered by Cesarean section.

Discussion

Reconstruction of the pelvic ring is a challenging task without a clear method to restore the strength or anatomy

Fig. 5A–B (A) AP and (B) lateral radiographs of the pelvis of a 31-year-old woman obtained at her 4-year followup show the reconstruction after Types I/IV resection. There is healing of the acetabular and sacral sites.

Fig. 6A–C (A) An AP radiograph of the pelvis of a 58-year-old man and (B) a T1-weighted MRI axial cut are shown. The patient had a diagnosis of chondrosarcoma of the right ilium. He underwent a

primary excision and reconstruction. (C) At 34 months, he had slight pain with a loose sacral screw and stable pseudarthrosis. He walks with a cane, and his MSTs '93 score was 76 and TESS was 53.

of the resected bone. Forgoing reconstruction of the pelvic ring, although reported, is not a demonstrably superior option to reconstructing the pelvic ring [2]. Skeletally

immature patients also may have hip dysplasia, leg length discrepancy and progressive hip pain may develop. Current reconstructive options may not be robust enough [2, 11] or

tend to be complex, requiring excessive dissection to stabilize the construct to the lumbar spine [15]. The purpose of our study was to investigate a novel reconstructive option, which uses autologous bone with its muscular pedicle to augment a simple pedicle screw construct. We describe our surgical technique and subsequent function and healing in a small initial cohort of patients.

We note limitations of our study. First, this is a small cohort of patients as a result of the rarity of pelvic tumors. This small cohort reflects the rarity of these reconstructions as one surgeon would see in his or her practice. A larger cohort and multicenter trial would help delineate the potential benefits of this reconstructive technique on a larger scale. Second, the complication rate in this series was high. The complication rate was similar to complication rates for pelvic surgery and reconstructions that have been reported in the literature, with some reporting the complication rates ranging from 40% to 75% [2, 14]. Third, we noted a high incidence of pseudarthrosis at the sacral site. All but one of the patients who had a pseudarthrosis develop received either postoperative chemotherapy or radiation. For four of the five patients, this was asymptomatic. Additionally, the pseudarthrosis may mimic the normal sacroiliac joint which has shown physiologic micromotion [17]. We anticipate that if late hardware failure occurs, there should be minimal effect on the patient as the posterior pelvis had scarred in a stable position. The one patient with hardware failure in this series was asymptomatic and underwent reoperation only for local recurrence.

We have noted similar or improved function using this technique compared with other reported methods (Table 2). Beadel et al. [2] argued against reconstruction after iliosacral resection. At a mean followup of 45 months, they reviewed 16 patients who underwent Type I pelvic resections. Twelve patients had no reconstruction and four had reconstructions with contralateral iliac crest autograft or fibular allograft. The MSTS scores for the two groups were comparable (58% nonreconstruction versus 51% reconstruction), but their scores were lower than those of our patients. The mean TESS in their series was higher than the TESS for our autograft reconstructions (72 versus 66). According to Beadel et al. [2], patients who underwent reconstructions had a greater need for chronic pain medication and use of walking aids after surgery. They attributed the higher incidence of complications and difficulty with ambulation to the lack of abductor function. Sabourin et al. [14] followed 24 patients with tumors affecting the sacroiliac joint for a mean of 4.8 years. They used spinal instrumentation along with nonvascularized iliac autograft, tibial autograft, or allograft. At final followup, the average MSTS score was 61% in 12 patients but they noted a substantially lower score in patients who had a hemisacrectomy. If the patients who had a hemisacrectomy were excluded, the MSTS score increased to 77%, which

was comparable to our findings. Akiyama et al. [1] reported their experience using nonvascularized fibula single- or double-strut autograft fixed with small fragment plates and screws in 10 patients. The mean MSTS score of their patients was 75% with no reported postsurgical complications and minimal pelvic shortening after the procedure.

Using this construct, our patients obtained excellent healing of the autograft at the posterior column but reliable healing of the graft to the lateral aspect of the sacrum was not achieved. At latest followup however, there was only one asymptomatic failure of fixation. For the reconstruction with allograft and screws used by Beadel et al. [2], only two of the four reconstructed pelves had long-lasting union of the bone graft. Similarly, Sabourin et al. [14] reported complete healing in 58% of their patients, whereas the remainder had a pseudarthrosis. They attributed nonhealing to adjuvant radiotherapy, chemotherapy, and use of allograft and metastatic recurrence. The double strut graft technique used by Akiyama et al. [1] did not fare any better, with union being achieved in at least one of the two strut grafts in all patients. Four of six patients who had a double-strut graft did not achieve healing of the upper graft.

Complications and reoperations are prevalent for pelvic tumor surgery. Using the Dindo-Clavien system [6], Grades III, IV, and V complications can be compared between techniques since they result in increased morbidity and mortality. Four of the six patients in our cohort required an additional surgical intervention. Although a high rate, it is similar to those reported in the literature for pelvic reconstructions. Beadel et al. [2] reported 33% Grade III complications in the unreconstructed pelves and 75% in the reconstructed ones. Sabourin et al. reported a 75% rate of Grade III complications [14]. In their cohort of 24 patients, 10 required débridement for scar necrosis and six for hematoma evacuation. Other authors who have used vascularized grafts have reported lower rates of complications. Sakuraba et al. [15] performed a double-barreled vascularized fibular graft on five patients with a mean followup of 12 months. There was only one Grade III complication, a reoperation for infection that required removal of the vascularized graft. Similarly Chang et al. [4] reported on six patients who underwent reconstruction with a vascularized double-barrel strut graft. They reported only one Grade II complication, a failure of fixation that required prolonged observation. Nishida et al. [11] reported on a small series of patients in whom they used vascularized iliac bone pedicle in Type I resections from the deep iliac artery with reconstruction with pedicle screw and rod construction. Only one patient had skin necrosis resulting from pedicle screw protrusion.

Our findings support the feasibility of using a gluteus medius muscle iliac crest pedicle graft in conjunction with minimal spinal instrumentation for reconstruction of the

Table 2. Comparison of similar studies for Type I reconstructions

Study	Graft	Fixation	Number	Mean length of followup (months)	MSTS '93	TESS	Complications/reoperations
Akiyama et al. [1]	Single or double nonvascularized fibular strut autograft	Screws + one-third tubular plate	10	29	75.4%	NR	None
Sabourin et al. [14]	Autograft iliac crest or strut allograft	Spinal instrumentation	24	48	61%	NR	8 scar necroses, 8 infections, 6 hematomas
Chang et al. [4]	Double vascularized fibular graft	Screws	6	18	NR	NR	1 hardware failure
Nishida et al. [11]	Vascularized iliac autograft	Spinal instrumentation or screws and plate	5	77	NR	NR	Skin necrosis resulting from pedicle screw
Beadel et al. [2]	None		12	45	58%	72	4 scar necroses or wound infections
	Allograft fibula	Screws	4	43	51%	68	1 allograft fracture, 3 scar necroses or wound infections
Sakuraba et al. [15]	Double-barreled vascularized fibula	Spinal instrumentation or screws and plate	5	12	NR	NR	1 infection with removal of fibular graft
Current study	Iliac crest with muscle pedicle autograft	Spinal instrumentation	6	31	72% ± 23%	66.2 ± 14	1 infection, 1 screw breakage, 2 scar necrosis

MSTS = Musculoskeletal Tumor Society 1993 score; TESS = Toronto Extremity Salvage Score; NR = not reported.

pelvic ring after Type I and I-S resections. Complications using this technique did not differ greatly from those of other published techniques. This technique has several advantages over others. Autogenous living bone is used and may contribute to better healing at the interfaces. A portion of the gluteus medius muscle remains attached to the iliac graft possibly providing abductor function. We also identified potential areas for improved stability of the construct to reduce nonunion rates at the sacral sites. Biomechanical studies can help elucidate weaknesses of the construct and potential modifications for improving its strength and stability.

Acknowledgments We thank Charles Lehmann MD for assistance in collecting some of the clinical data, and Vicki Friedman, the medical illustrator who provided Figures 1 through 3.

References

1. Akiyama T, Clark JC, Miki Y, Choong PF. The non-vascularised fibular graft: a simple and successful method of reconstruction of the pelvic ring after internal hemipelvectomy. *J Bone Joint Surg Br.* 2010;92:999–1005.
2. Beadel GP, McLaughlin CE, Aljassir F, Turcotte RE, Isler MH, Ferguson P, Griffin AM, Bell RS, Wunder JS. Iliosacral resection for primary bone tumors: is pelvic reconstruction necessary? *Clin Orthop Relat Res.* 2005;438:22–29.
3. Burkus JK, Sandhu HS, Gornet MF. Influence of rhBMP-2 on the healing patterns associated with allograft interbody constructs in comparison with autograft. *Spine (Phila Pa 1976).* 2006; 31:775–781.
4. Chang DW, Fortin AJ, Oates SD, Lewis VO. Reconstruction of the pelvic ring with vascularized double-strut fibular flap following internal hemipelvectomy. *Plast Reconstr Surg.* 2008;121: 1993–2000.
5. Davis AM, Wright JG, Williams JI, Bombardier C, Griffin A, Bell RS. Development of a measure of physical function for patients with bone and soft tissue sarcoma. *Qual Life Res.* 1996;5:508–516.
6. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg.* 2004;240:205–213.
7. Enneking WF, Dunham W, Gebhardt MC, Malawar M, Pritchard DJ. A system for the functional evaluation of reconstructive procedures after surgical treatment of tumors of the musculoskeletal system. *Clin Orthop Relat Res.* 1993;286:241–246.
8. Enneking WF, Dunham WK. Resection and reconstruction for primary neoplasms involving the innominate bone. *J Bone Joint Surg Am.* 1978;60:731–746.
9. Hugate R Jr, Sim FH. Pelvic reconstruction techniques. *Orthop Clin North Am.* 2006;37:85–97.
10. Kollender Y, Shabat S, Bickels J, Flusser G, Isakov J, Neuman Y, Cohen I, Weyl-Ben-Arush M, Ramo N, Meller I. Internal hemipelvectomy for bone sarcomas in children and young adults: surgical considerations. *Eur J Surg Oncol.* 2000;26:398–404.
11. Nishida J, Shiraishi H, Okada K, Ehara S, Shimamura T. Vascularized iliac bone graft for iliosacral bone defect after tumor excision. *Clin Orthop Relat Res.* 2006;447:145–151.

12. O'Connor MI, Sim FH. Salvage of the limb in the treatment of malignant pelvic tumors. *J Bone Joint Surg Am.* 1989;71:481–494.
13. Pring ME, Weber KL, Unni KK, Sim FH. Chondrosarcoma of the pelvis: a review of sixty-four cases. *J Bone Joint Surg Am.* 2001;83:1630–1642.
14. Sabourin M, Biau D, Babinet A, Dumaine V, Tomeno B, Anract P. Surgical management of pelvic primary bone tumors involving the sacroiliac joint. *Orthop Traumatol Surg Res.* 2009;95:284–292.
15. Sakuraba M, Kimata Y, Iida H, Beppu Y, Chuman H, Kawai A. Pelvic ring reconstruction with the double-barreled vascularized fibular free flap. *Plast Reconstr Surg.* 2005;116:1340–1345.
16. Sherman CE, O'Connor MI, Sim FH. Survival, local recurrence, and function after pelvic limb salvage at 23 to 38 years of follow-up. *Clin Orthop Relat Res.* 2012;470:712–727.
17. Simonian PT, Routt ML Jr, Harrington RM, Mayo KA, Tencer AF. Biomechanical simulation of the anteroposterior compression injury of the pelvis: an understanding of instability and fixation. *Clin Orthop Relat Res.* 1994;309:245–256.
18. Sink EL, Beaulé PE, Sucato D, Kim YJ, Millis MB, Dayton M, Trousdale RT, Sierra RJ, Zaltz I, Schoenecker P, Monreal A, Clohisy J. Multicenter study of complications following surgical dislocation of the hip. *J Bone Joint Surg Am.* 2011;93:1132–1136.
19. Wirbel RJ, Schulte M, Mutschler WE. Surgical treatment of pelvic sarcomas: oncologic and functional outcome. *Clin Orthop Relat Res.* 2001;390:190–205.
20. Yajima H, Tamai S. Twin-barrelled vascularized fibular grafting to the pelvis and lower extremity. *Clin Orthop Relat Res.* 1994;303:178–184.