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SURGICAL TECHNIQUE

Decancellation Sacral Osteotomy in Iliosacral Tumor Resection

A Technique for Precise Sacral Margins

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Abstract En bloc resection of iliosacral sarcomas is a surgical challenge. There are substantial risks of inadequate margins, local recurrence, and nerve root loss when pelvic sarcomas involve sacral root canals and foramina. The decancellation technique uses principles similar to transpedicle decancellation in spinal deformity correction to perform the sacral osteotomy in iliosacral tumor resection. The technique aims at improving sacral margins and minimizing loss of neural function. We performed a decancellation osteotomy in five patients with sarcomas requiring difficult oblique or sagittal sacral osteotomies and selective root sacrifice. Through laminectomy and without anterior exposure, a precise full-thickness osteotomy of the sacrum was performed without major technique-related morbidities or complications. This was followed by formal pelvic resection and reconstruction. Surgical margins were adequate in all patients and all tumor-free nerve roots were preserved.

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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.

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Introduction

En bloc resection of malignant tumors of the posterior pelvis and sacrum is a surgical challenge. Eight percent to 25% of posterior pelvic tumors may have sacral extension [13, 17, 27]. Tumors extending only slightly into the sacrum may be excised with an osteotomy through the lateral sacral mass whereas resection of tumors involving sacral nerves and vertebrae or the lumber spine is more complex. These tumors are either inoperable or en bloc resection is possible with limited room for error. The complex local anatomy and the surgeon's desire to protect neural function may increase the likelihood of inadvertent tumor penetration [4, 20]. In addition to neural injury or sacrifice, substantial morbidity may result from disruption of major weightbearing joints [4, 16, 17].

Some authors have suggested delayed diagnosis and inferior outcomes of patients with pelvic tumors compared with those of the extremities [3, 24, 30]. In one study of multimodal therapy for nonmetastatic Ewing's sarcoma of the pelvis, the 5- and 10-year event-free survival rates were 46% and 44% in pelvic lesions compared with 64% and 69% in extremity lesions [3]. The prognosis in tumors with sacral infiltration is even worse, and difficulty obtaining adequate resection margins and local control in iliosacral lesions has been reported [4, 16, 17, 20]. In one series, the surgical margins were grossly positive in six of 15 pelvic tumors infiltrating the sacrum [20]. In another series of limb salvage in patients with pelvic sarcomas, local recurrence after surgical excision was 8% for acetabular, 17% for ischiopubic, and 27% for iliosacral tumors. Moreover, O'Connor and Sim reported local recurrence was 38% when iliosacral tumors extensively infiltrated the sacrum or the spinal column [17]. Although improved local control and disease-free survival after massive adequate resection of the sacrum and lower lumbar spine have been reported [11], this is technically difficult when limb salvage is attempted: surgery may leave an anesthetic, paralyzed, and unstable limb with unacceptable function and uncertain outcome regarding local control, distant metastases, and patient survival [4, 10, 16]. The exaggerated sacral concavity below S1 and the ventral soft tissue mass are responsible for most technical difficulties. Despite adequate anterior exposure, limited accessibility and observation required for precise sacral osteotomy and handling of the sacral plexus may increase the risk of neural injury, dural tear, and tumor violation [4, 16, 17]. Unlike transverse sacrectomy [8, 18, 29], technical guidelines for sagittal hemisacrectomy are limited.

In 1945, Smith-Petersen et al. [25] described correction of a fixed spinal flexion deformity by posterior element wedge resection and controlled fracturing of the ossified anterior longitudinal ligament through a posterior approach. A transpedicle decancellation or pedicle subtraction osteotomy subsequently was used to correct larger, dorsal and lumbar kyphotic deformities without anterior exposure [5, 6, 28].

Using a similar surgical principle, we propose a technique for sacral osteotomy in iliosacral resections. We presumed sacral laminectomy and decancellation with selective root sacrifice and precise sacral osteotomy would improve the sacral resection margin, maximize protection of uninvolved roots, and permit preservation or reconstruction of lumbosacral stability. A full-thickness sagittal or oblique sacral osteotomy without anterior exposure may be safely performed. This is followed by anterior intrapelvic dissection to remove the tumor.

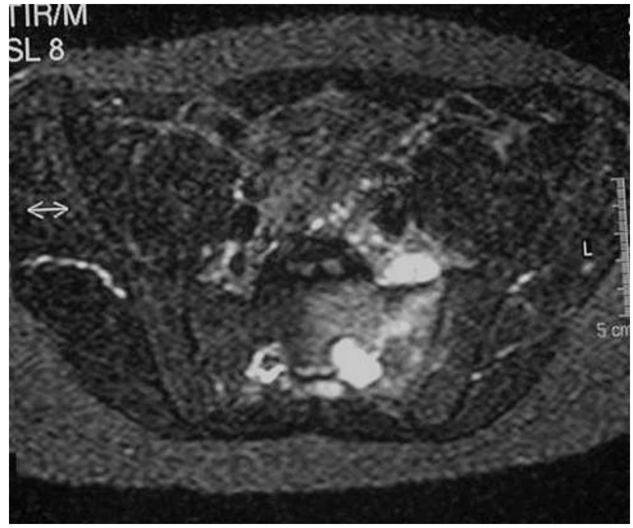

Fig. 1 A MR image shows an osteosarcoma of the sacrum with extension into the left ilium (detected in lower cuts). The anterior soft tissue mass involves the left lumbosacral trunk. The tumor expands the left S1 foramen. Despite close proximity to the right S1 root canal, it neither is infiltrated nor circumferentially surrounded and root preservation was possible.

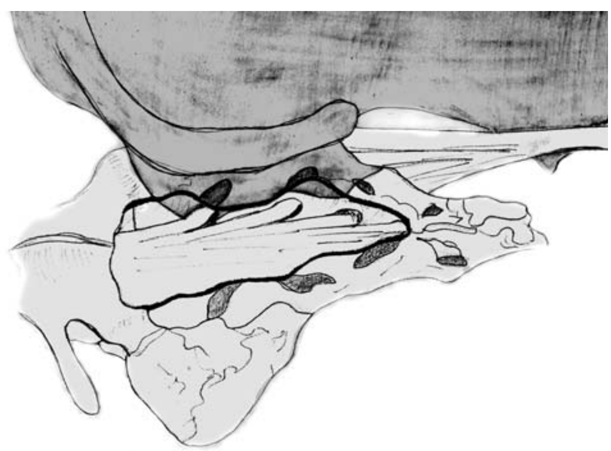

Fig. 2 A diagram illustrates a sacral laminectomy. A generous laminectomy is performed to expose the central sacral canal and sacral roots as they enter their bony confines. Tilting the table away from the surgeon improves exposure.

Surgical Technique

In addition to routine staging, MRI allows precise mapping of sacral infiltration (Fig. 1). Surgery is recommended if adequate resection is prognostically important and feasible with tolerable morbidity. Thorough evaluation determines the feasibility of a generous sacral laminectomy without tumor violation, which is crucial for exposure. The path of the sacral osteotomy that provides adequate resection margins with minimal functional and neural losses is identified. Excision of a nerve root whose bony canal and/or ventral foramen either were infiltrated or encircled is planned. Any intrapelvic soft tissue component infiltrating the lumbosacral trunk is identified. Sacroiliac and lumbosacral stability are evaluated and reconstruction is planned if possible.

In the prone position, a midline posterior incision and sacral laminectomy allow exposure of sacral roots. The ventral foramina are located directly anterior to the dorsal foramina (Fig. 2). In principle, a sacral osteotomy begins by dividing the posterior sacral cortex using the high-speed burr (Fig. 3A). Curettes are used to remove the cancellous bone along the osteotomy down to the anterior cortex (Fig. 3B). Sacral depth substantially increases in the midline in S1 particularly in the promontory. The anterior sacral cortex then is divided using the burr or rongeurs (Fig. 3C).

In iliosacral resection, a sagittal hemisacrectomy requires three connected sacral osteotomies: a vertical, a cranial oblique (or a transverse cut through the disc), and a caudal oblique osteotomy. Division of involved roots

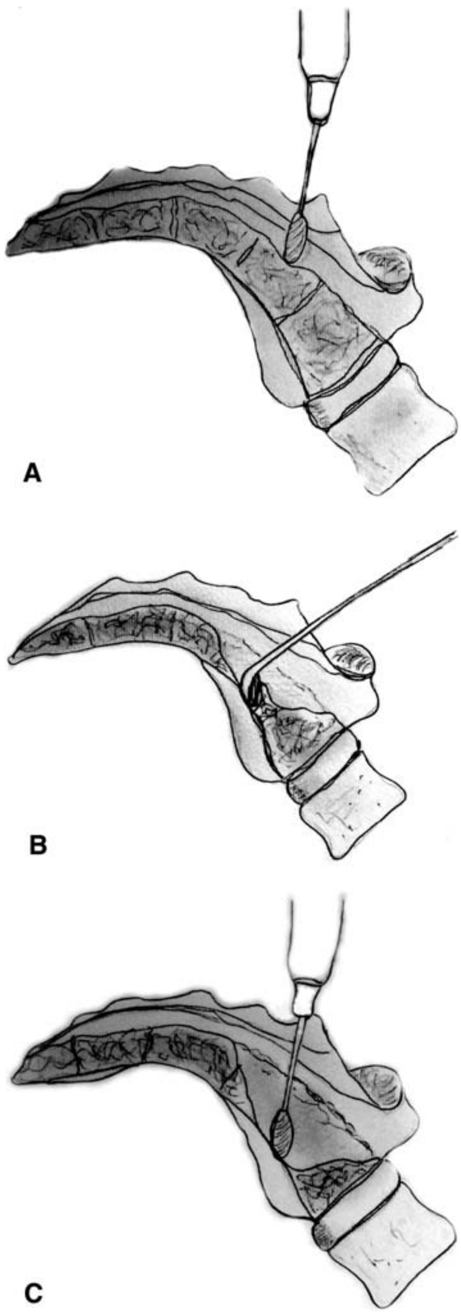

Fig. 3A–C The osteotomy technique is shown. (**A**) The posterior cortex is divided using a high-speed burr. (**B**) Cancellous bone is removed along the osteotomy with curettes to preserve bone fragments. These should be labeled and sent for pathologic evaluation of the sacral margins. (**C**) The anterior cortex is divided using a high-speed burr down to the presacral fascia.

allows dural retraction and facilitates the vertical osteotomy (Fig. 4). This is followed by the cranial osteotomy. If tumor extension spares the upper part of the lateral mass of S1 and the base of the articular process, an oblique cranial osteotomy is performed to preserve lumbosacral stability (Fig. 5A). It begins at the upper end of the vertical

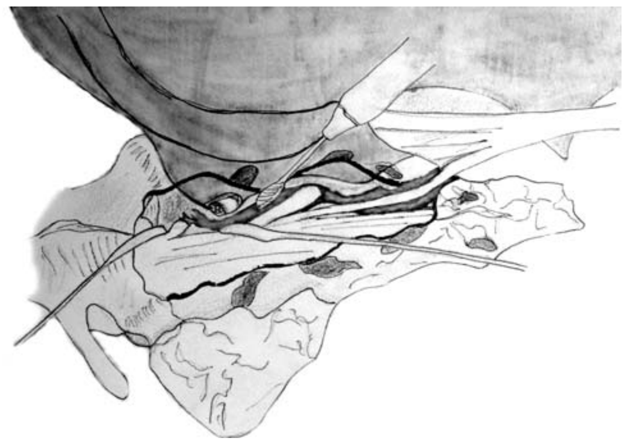

Fig. 4 A diagram illustrates the vertical osteotomy. The S1 root canal is infiltrated. The root is ligated and divided, allowing safe dural retraction, and the vertical component of the sacral osteotomy is performed.

osteotomy and passes laterally between the articular process and S1 foramen. However, if the tumor extends into the body of S1, the vertical osteotomy should extend cranially to the tip of the sacral promontory. Then, transverse division of the L5–S1 disc and the facet joint is performed (Fig. 5B). The superior end plate of S1 is divided vertically to join the vertical osteotomy at the promontory (Fig. 6). This osteotomy destabilizes the lumbosacral articulation and may require instrumentation and fusion. Finally, the osteotomy surrounds the tumor caudally. The vertical osteotomy may extend into the coccyx or an oblique caudal component is performed to exit the lateral sacral border (Fig. 7).

Sacral roots enclosed in foramina lateral to the osteotomy are divided. Occasionally, tumor infiltration may approach the lateral wall of a root canal without invasion or encirclement of its bony confines. A gutter may be created in the medial wall as far anteriorly as its ventral foramen to extract the root. This gutter should be wide to avoid root tethering when the specimen is rotated during resection (Fig. 8). The osteotomy remains a narrow linear trough. Full-thickness division down to the presacral fascia should be confirmed by probing the entire length of the osteotomy. Whenever possible, curettes and rongeurs rather than the burr are used to preserve bone fragments for pathologic evaluation.

If staged resection is planned, postoperative CT scanning ensures completeness of all sacral cuts. Anterior resection is performed in the semilateral position allowing simultaneous access to the posterior wound. When the specimen is mobilized, the sacral osteotomy can be identified anteriorly despite the intact presacral fascia, which then is divided. As the specimen is rotated, preserved sacral roots are released carefully from their bony gutters. Finally,

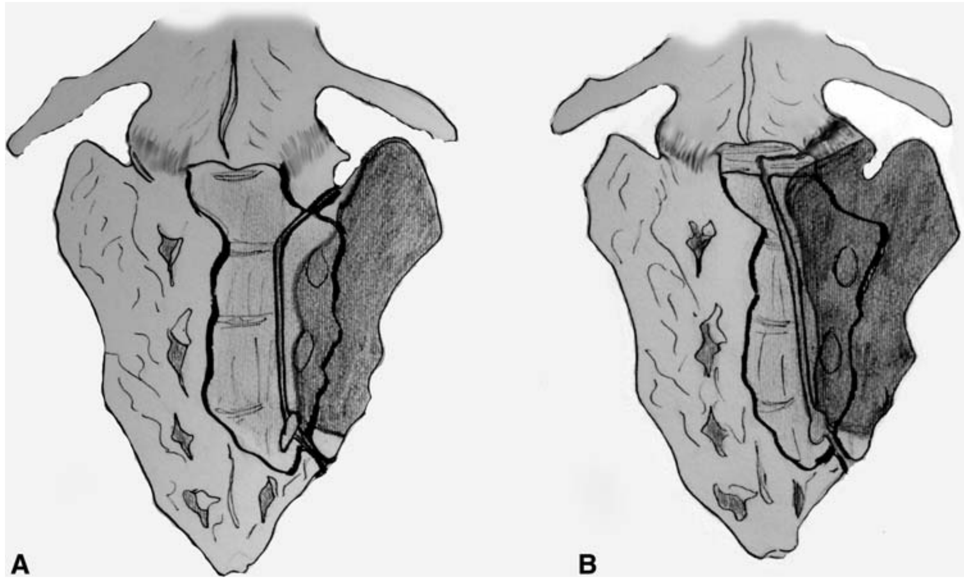

Fig. 5A–B The diagrams illustrate a cranial osteotomy. (**A**) A stability-preserving oblique cranial osteotomy begins at the upper end of the vertical osteotomy, passes between the S1 foramen and articular process, and exits the lateral mass. (**B**) Tumors extending more medially and cranially into S1 require a transverse cut through the L5–S1 disc and facet joint, causing lumbosacral instability.

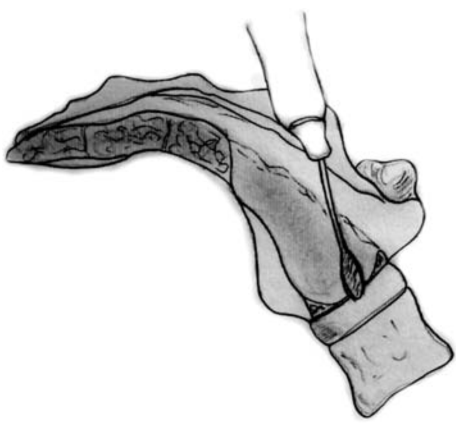

Fig. 6 A diagram illustrates the end plate osteotomy. With a destabilizing cranial osteotomy, the end plate of S1 is divided with a high-speed burr starting at the transverse cut of the disc on the posterior border of the end plate down to the vertical osteotomy at the sacral promontory.

involved roots are divided close to the sciatic nerve before specimen removal to allow resection of an intervening segment en bloc with the tumor (Fig. 9).

Patients and Materials

Between September 2000 and March 2006, we performed the described technique in five patients with nonmetastatic iliosacral tumors in which the risk of tumor violation or nerve injury by sacral osteotomy was considered high owing to extensive sacral infiltration (Table 1). There were four pelvic lesions with sacral extension (two osteosarcomas, one chondrosarcoma, and one Ewing's sarcoma) and one osteosarcoma of the sacrum involving the ilium. Four patients received preoperative and postoperative chemotherapy. The minimum followup was 2 months (median, 38 months; range, 2–98 months).

Overall operative time and blood loss were 10 to 21 hours and 2000 to 5500 mL, respectively. Lumbosacral reconstruction was performed only in the sacral osteosarcoma using the Galveston technique and nonvascularized fibular grafts. One patient (Patient 3) had an intraoperative gross osteosarcoma thrombus in the internal iliac vein. The vein was resected en bloc with the tumor followed by postoperative radiotherapy to maximize local control. In all patients, surgical margins were negative.

Results

Five surgical complications occurred in three patients. These included two patients who had posterior flap necrosis develop. Wound healing was achieved after débridement and secondary sutures in one and rectus abdominus myocutaneous flap in the other; both patients had undergone ligation of the internal iliac vessels. Wound infection occurred in one patient with sacral osteosarcoma and resolved after two operations for débridement and removal of a synthetic mesh. In two patients, an ischiofemoral arthrodesis failed and the hardware was removed. Limited bone stock precluded further reconstructive attempts. Proximal and medial migration of the femoral head was allowed thus creating pseudarthroses against the sacrum. This permitted temporary ambulation with a walker in one patient who subsequently had hindquarter amputation for local recurrence. In the other patient, scarring provided

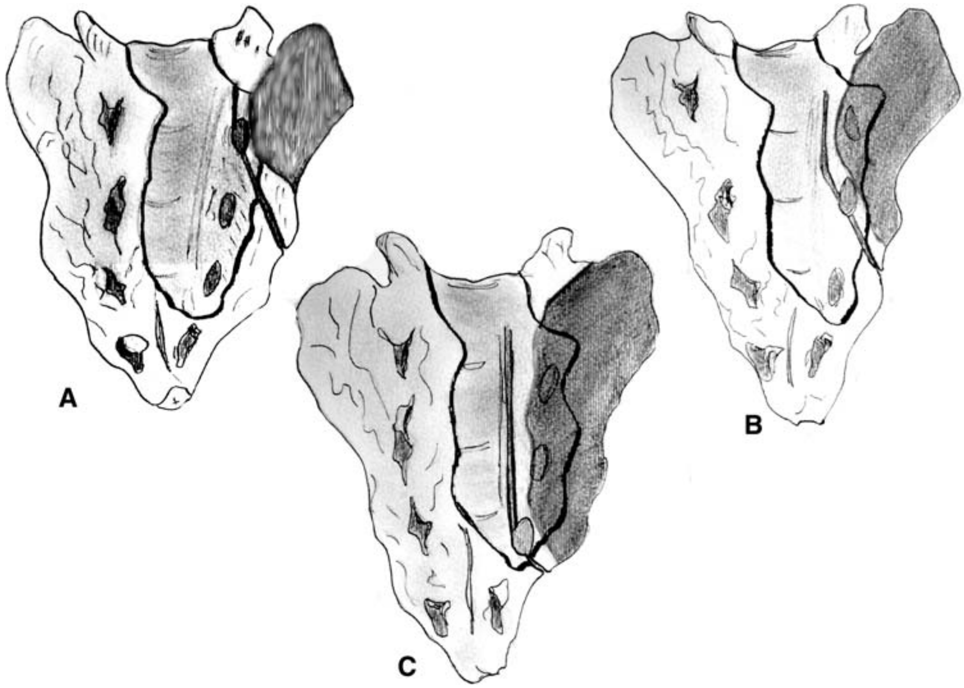

Fig. 7A–C The diagrams illustrate the caudal osteotomy. The oblique caudal osteotomy may exit the lateral sacral border at different levels: (**A**) between S1 and S2, (**B**) between S2 and S3, and (**C**) between S3 and S4. The osteotomy may pass through a sacral root canal to preserve the nerve root by creating a gutter in its wall. Otherwise, nerve roots above the osteotomy have to be sacrificed.

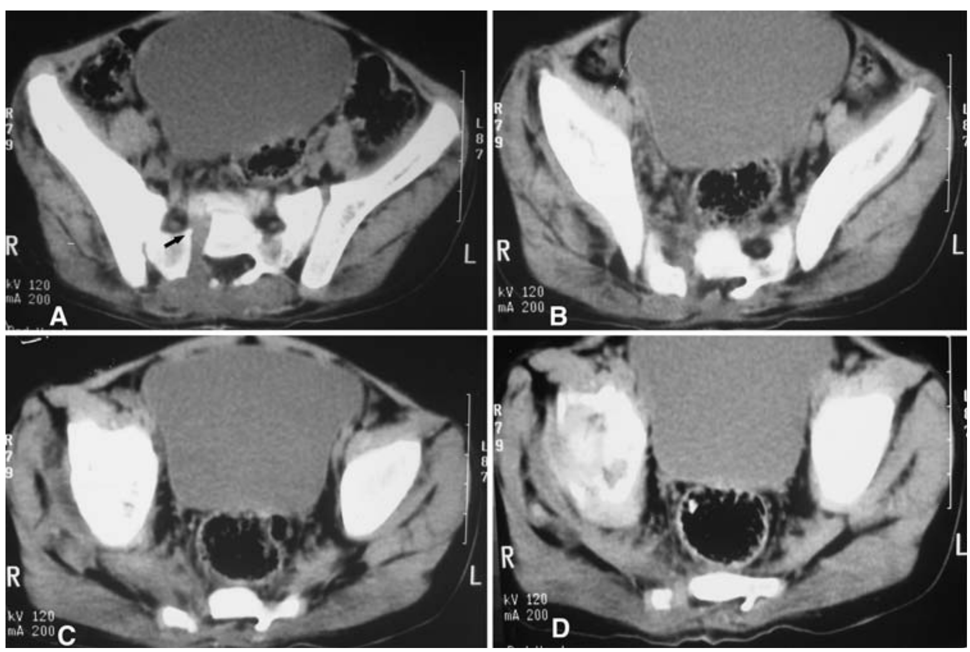

Fig. 8A–D Postoperative CT (in staged procedures) ensures completeness and appropriate location of sacral cuts. Medial wall gutters were created to extract all sacral nerve roots. (**A**) The S1 gutter was not wide and smooth, creating a spike that could tether S1 as the specimen is rotated during removal (arrow). Wide and smooth gutters are seen for (**B**) S2, (**C**) S3, and (**D**) S4 roots, respectively, and confirm completeness of the sacral osteotomy.

sufficient stability for the pseudarthrosis allowing ambulation without support at 98 months after tumor resection.

One patient died of chemotherapy-related toxicity 2 months postoperatively. One patient with gross invasion of the internal iliac vein had local recurrence and lung metastases at 20 months, required hindquarter amputation, and died of disease 8 months later. The remaining three patients were continuously disease free at 38, 50, and 98 months postoperatively (Table 2). Functional evaluation of survivors showed all three patients were community ambulatory. One patient required two crutches and a lumbosacral orthosis for bracing of unreconstructed lumbosacral instability whereas two patients had relatively stable gaits without walking supports. No iatrogenic nerve injuries occurred. However, loss of neural function attributable to intentional sacrifice of the lumbosacral trunk resulted in foot drop in one patient who used an ankle-foot orthosis, whereas no substantial morbidity occurred owing to planned division of S2, S3, and S4 nerve roots in another patient.

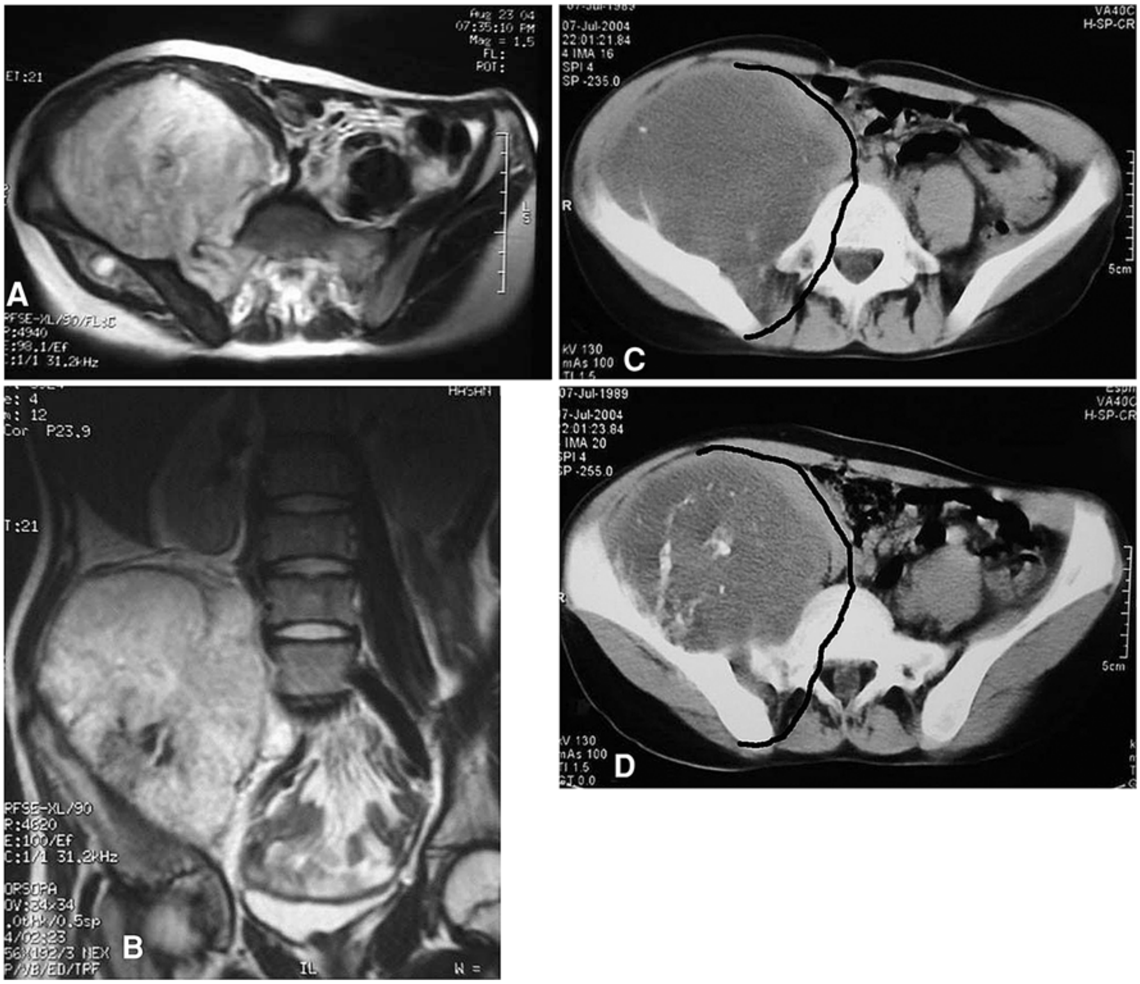

Fig. 9A–L The case of a 15-year-old boy with high-grade chondrosarcoma of the right hemipelvis (Patient 2) is illustrated. (**A**) An axial MR image shows the tumor infiltrating the sacroiliac joint into the sacrum, overhanging the upper sacrum ventrally and engulfing the lumbosacral trunk. The cranial end of the trunk cannot be exposed and divided extraspinally without tumor violation. More caudally, tumor infiltration approached the lateral aspects of all sacral root canals. (**B**) A coronal MR image shows close tumor proximity to the L4 and L5 vertebrae. Axial CT scans show the proposed (**C**) lumbar and (**D**) sacral osteotomies required to achieve negative resection margins. The risk of neural injury or tumor contamination is high if the osteotomy is attempted without laminectomy. (**E**) Sacral and (**F**) lumbar laminectomies allowed intraspinal division of the L4 and L5 (white arrow) root contributions to the infiltrated lumbosacral trunk and protection of all sacral roots (black arrows). This was followed by full-thickness osteotomy of L5 and the sacrum through the sacral foramina. Negative margins were achieved and all preserved roots retained their function. (**G**) At the end of a second-stage Type IA/II/S resection, the specimen is seen attached to the sciatic nerve by the infiltrated lumbosacral trunk. Dividing the trunk's caudal end (arrow) is the last step to free the specimen. (**H**) The superior gluteal vessels were preserved to maintain buttock flap vascularity. No wound-related problems occurred. (**I**) The medial aspect of the specimen with a precise osteotomy is shown: (1) resected L5–S1 disc, (2) superior articular process of S1, (3) intraspinally divided L4, (4) L5; both contributed to (5) the infiltrated lumbosacral trunk, (6) resected lateral wall of the S1 canal, and (7) lateral wall of S2; both roots were preserved. The arrows point to the osteotomy through L5, S1, S2, and S3 from above downward exiting medial to the tumor mass to provide negative resection margins. (**J**) The instrument points to the caudal end of the lumbosacral trunk after being divided off the sciatic nerve. (**K**) The instruments represent the direction of the S1 and S2 roots as they would exit the respective root canals and join the lumbosacral trunk (arrow). Both roots were preserved in continuity with the sciatic nerve. (**L**) A postresection radiograph shows resection of the right acetabulum, ilium, hemisacrum, and part of the fifth lumbar vertebra.

Discussion

Despite advances in the treatment of bone sarcomas, the large size and delayed diagnosis of pelvic tumors worsen their prognosis [24, 30]. Some authors could not correlate surgical margins and survival [24], whereas others considered resection margins an independent prognostic factor for local control and survival [11, 13]. Generous margins around neurovascular structures frequently are not permissible in pelvic tumors owing to anatomic and functional considerations when limb salvage is attempted. Hindquarter amputation has been recommended when the

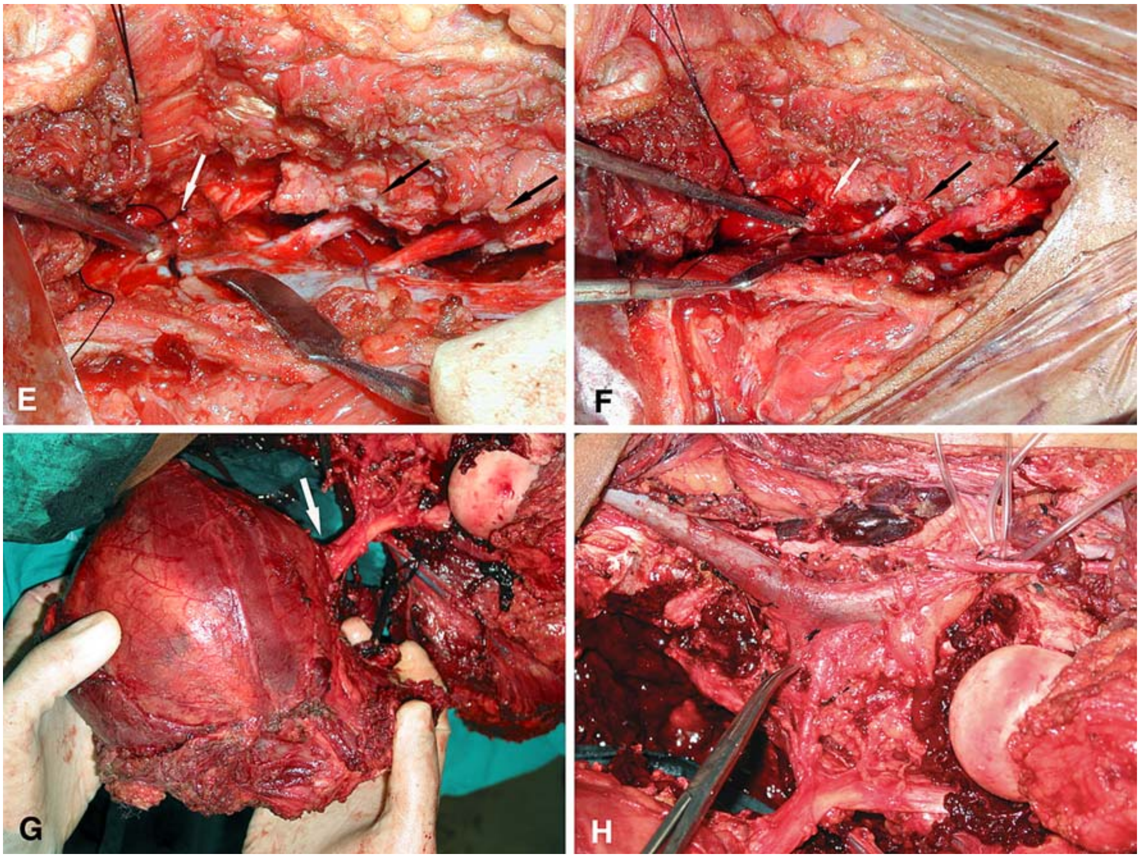

Fig. 9A–L continued

sacrum is infiltrated [13]. Although amputation may reduce surgical complications in proximal limb girdle lesions [15], it does not necessarily provide wider resection margins [2, 7, 24].

A pelvic sarcoma is a particularly difficult surgical problem when the posterior ilium is involved [4, 16, 17, 20]. Unlike sarcomas of the extremities that rarely cross nearby joints, posterior iliac tumors frequently infiltrate the sacroiliac joint probably owing to relative joint immobility, increased local vascularity, and the large size of most pelvic lesions [1, 4, 9, 11, 19, 20]. Despite difficulties caused by peritumoral edema, marrow signal changes, and unevenness of sacroiliac joint plane, interpretation of MR images in iliosacral lesions has a sensitivity of 100% and specificity of 92% [20]. In one study, 15 of 51 lesions abutting the sacroiliac joint infiltrated the sacrum [20]. Risk factors included large tumor volume, contact with the posterior ligamentous part of the joint, and diagnoses of chondrosarcoma and osteosarcoma rather than Ewing's sarcoma. Tumor extended medially to involve the sacral foramina in almost ½ of iliosacral lesions in some studies and nerve root resection did not improve sacral margins and local control [4, 16, 17, 20].

Since early reports on pelvic resection and reconstruction [10, 26], surgical techniques and medical support have improved considerably. Currently, more pelvic sarcomas are being considered for limb-sparing surgery, including lesions infiltrating the sacrum. Although numerous authors have reported the oncologic outcomes of pelvic sarcomas [3, 11–14, 16, 21–24, 27, 30], technical articles remained scarce. My proposed technique uses the principles of transpedicle decancellation in spinal deformity correction to perform a precise sacral osteotomy in malignant tumors spanning the sacroiliac joint. The decancellation technique was most useful when sagittal hemisacrectomy was required, particularly when some sacral roots were involved. In addition, one iliosacral sarcoma overlying the lower lumbar spine and one primarily sacral sarcoma with iliac extension were resected using the proposed technique. Through a generous laminectomy, sacral osteotomy was performed while all tumor-free roots were protected and remained functional. Tumors subsequently were resected through a formal anterior exposure. In all but one patient, tumor resection was performed a few days after a first-stage osteotomy. The staged approach was not mandatory, but the interval allowed patient recovery while pathologic

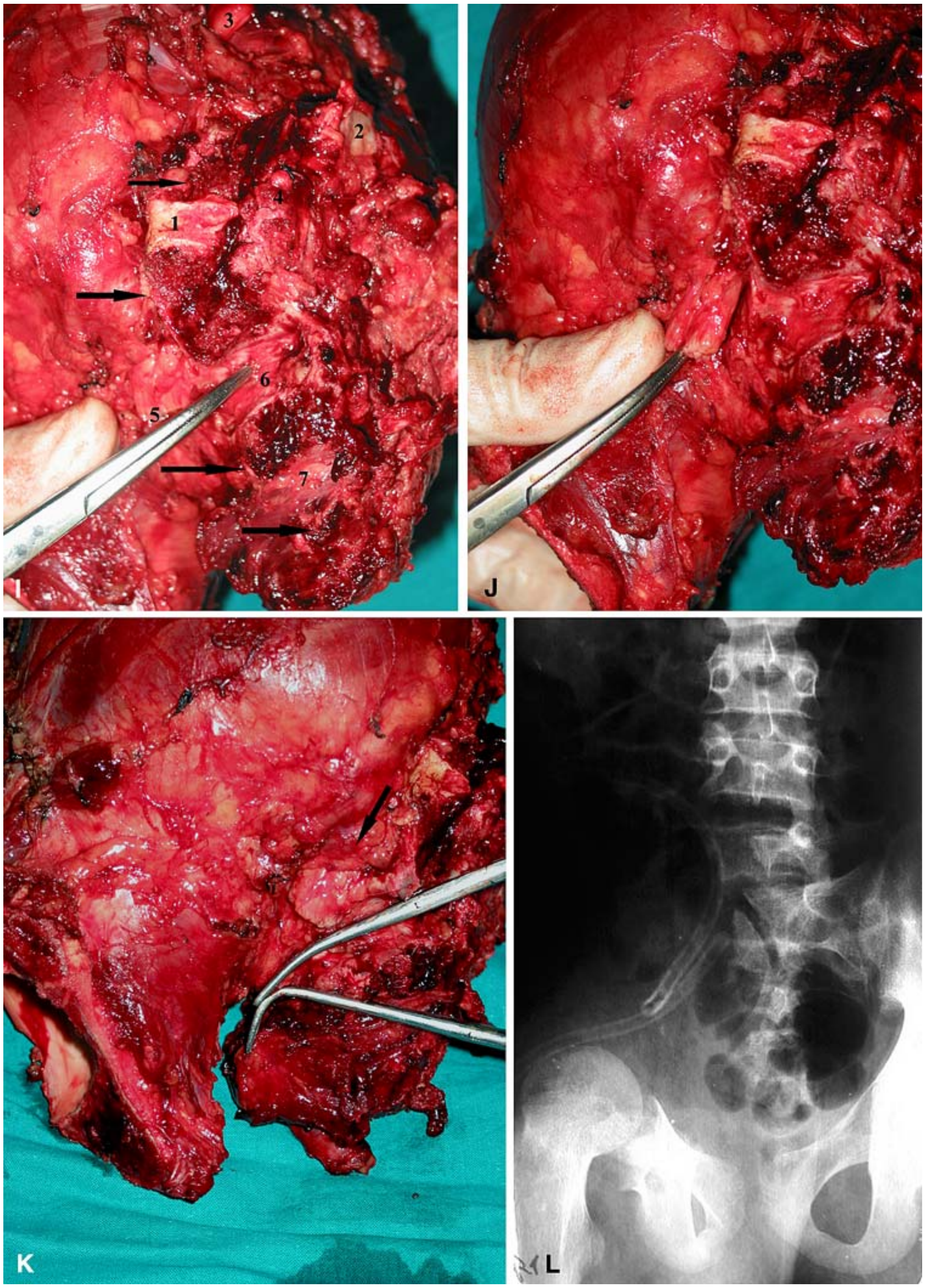

Fig. 9A–L continued

confirmation of negative sacral margins was performed. Positive margins may discourage the surgeon to proceed with a morbid resection, especially in radiosensitive tumors or when surgical morbidity outweighs the benefits of inadequate resection.

Major limitations of the proposed technique were related to the potential for substantial sacral bleeding. Hypotensive anesthesia and free abdominal respiratory movements reduced bleeding and improved observation. Optical magnification and the use of high-speed burr with constant suction-irrigation substantially facilitated the procedure. A full-thickness sacral osteotomy was performed safely in all patients without excessive blood loss, intrapelvic injuries, or technique-related morbidities. Surgical complications occurred in three of five patients and involved skeletal reconstruction or wound healing. Failure of ischiofemoral arthrodeses occurred in two patients and required hardware removal. This was followed by proximal and medial

Table 1. Patient demographics and surgical data

Patient	Age (years)	Gender	Diagnosis	Indication of decancellation technique	Resection type* and reconstruction	Operative time (hours)	Blood loss (mL)	Surgical complications and treatment
1	18	Male	Osteosarcoma right hemipelvis	Transforaminal sacral osteotomy, S1 preservation, and division of infiltrated S2, 3, 4 roots	IA/II/S, ischiofemoral arthrodesis	12	3000	(1) Posterior flap necrosis, débridement and secondary sutures (2) Failed arthrodesis, stable pseudarthrosis after hardware removal
2	15	Male	Chondrosarcoma right hemipelvis	Transforaminal sacral osteotomy, preservation of all sacral roots, resection of L4, L5 roots and lumbosacral trunk	IA/II/S with part of L5 body and disc, mesh reconstruction of acetabular dome	16	4000	None
3	16	Male	Osteosarcoma right hemipelvis	Ventral soft tissue overlapped the sacrum and required midline sacral osteotomy	IA/IIA/S, ischiofemoral arthrodesis	13	2700	(1) Flap necrosis, débridement, rectus myocutaneous flap (2) Failed arthrodesis, hardware removal, flail hip
4	4	Male	Ewing's sarcoma right hemipelvis	Transforaminal sacral osteotomy, preservation of all sacral roots	IA/II/S, flail hip	10	2000	None
5	18	Male	Osteosarcoma sacrum with left iliac wing extension	Subtotal sacrectomy, oblique sacral osteotomy, preservation of right lumbosacral trunk and S1, resection of remaining roots on both sides	Subtotal sacrectomy and left iliac resection, Galveston reconstruction with nonvascularized fibular autograft and mesh reconstruction of pelvic floor	21	5500	Wound infection, débridement and mesh removal

* Modification [16] of the Enneking and Dunham system [10] for pelvic resections: I = resection of ilium; IA = resection of ilium and gluteal muscles; II = resection of acetabulum; IIA = en bloc extracapsular resection of acetabulum and femoral head; S = portion of sacrum or spine is resected.

Table 2. Surgical margins and oncologic results

Patient	Surgical margins	Local relapse	Distant relapse	Disease status	Followup (months)
1	Free	No	No	CDF	98
2	Free	No	No	CDF	50
3	Free	At 20 months	At 20 months	DOD	28
4	Free	No	No	CDF	38
5	Free	No	No	Died of chemotherapy-related toxicity	2

CDF = continuously disease free; DOD = dead of disease.

migration of the femoral head to a stable pseudarthrosis against the sacrum. One patient had infection that required repeated débridements. Two patients had buttock flap necrosis requiring débridement and wound closure in one and myocutaneous flap in the other. Wound-related problems are the most frequent complications in pelvic resections [4, 16]. In one series of limb salvage for malignant pelvic tumors, 23% of patients had wound infections or flap necrosis [16]. The division of the internal iliac vessels to allow tumor control in the sciatic notch is associated with an increased incidence of buttock flap necrosis, especially when combined with sacral osteotomy and gluteus maximus detachment [15]. Therefore, tumor infiltration into the sacrum reportedly is associated with a higher surgical complication rate. Wound-related problems were observed in seven of 16 patients in one series of iliosacral resections [4]. The operative time and blood loss reached 12 hours and 17,000 mL, respectively, reflecting the magnitude of surgery when the sacrum is involved [4]. Neural, vascular, and urologic injuries also have been observed [10, 16, 17].

Limb salvage in pelvic sarcomas resulted in local recurrence in 17% to 34% and distant metastasis in 30% to 37% [13, 16, 17]. Iliosacral resections have a higher probability of disease relapse owing to an increased incidence of intralesional margins in the sacrum [4, 16, 20]. In the current series, negative margins were achieved in all five patients. One patient died of chemotherapy-related toxicity, one patient succumbed after local and distant relapse, and three patients remained continuously disease free 38, 50, and 98 months postoperatively.

The decancellation sacral osteotomy is considered a technical tool to improve tumor resection margins and preserve neural function rather than a new surgical procedure. Therefore, indications and caveats are essentially those of massive pelvic resections in which the critical prognosis and the magnitude of surgery mandate careful patient selection. However, I did not use the described technique in patients with conditions in which decancellation was not expected to improve the sacral margins. These included patients with extensive infiltration of the posterior sacral elements precluding adequate laminectomy or when an epidural soft tissue component occupied the central sacral canal. Despite complexity of the procedure and potential morbidities, early experience is encouraging for the decancellation osteotomy to obtain negative sacral margins and safely expand the potential for functional limb salvage in patients with selected iliosacral tumors. In addition, its utility may include sacral tumors requiring difficult sagittal and oblique sacrectomies and pelvic-sacral tumors involving the lumbar spine. Variation in the extent of tumor may require varying the location of the osteotomy using the described guidelines.

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References

1. Abdelwahab IF, Miller TT, Hermann G, Klein MJ, Kenan S, Lewis MM. Transarticular invasion of joints by bone tumors: hypothesis. *Skeletal Radiol.* 1991;20:279–283.
2. Apffelstaedt JP, Driscoll DL, Spellmann JE, Velez AF, Gibbs JF, Karakousis CP. Complications and outcome of external hemipelvectomy in the management of pelvic tumors. *Ann Surg Oncol.* 1996;3:304–309.
3. Bacci G, Ferrari S, Mercuri M, Longhi A, Giacomini S, Forni C, Bertoni F, Manfrini M, Barbieri E, Lari S, Donati D. Multimodal therapy for the treatment of nonmetastatic Ewing sarcoma of the pelvis. *J Pediatr Hematol Oncol.* 2003;25:118–124.
4. 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..
5. Bezer M, Kucukdurmaz F, Guven O. Transpedicular decancellation osteotomy in the treatment of posttuberculous kyphosis. *J Spinal Disord Tech.* 2007;20:209–215.
6. Boachie-Adjei O. Role and technique of eggshell osteotomies and vertebral column resections in the treatment of fixed sagittal imbalance. *Instr Course Lect.* 2006;55:583–589.
7. Carter SR, Eastwood, DM, Grimer RJ, Sneath RS. Hindquarter amputation for tumours of the musculoskeletal system. *J Bone Joint Surg Br.* 1990;72:490–493.
8. Dickey ID, Hugate RR Jr, Fuchs B, Yaszemski MJ, Sim FH. Reconstruction after total sacrectomy: early experience with a new surgical technique. *Clin Orthop Relat Res.* 2005;438:42–50.
9. Drnovsek V, Zafiroski G, Brogdon BG, Plavsic BM. Transarticular spread of Ewing's sarcoma across the sacroiliac joint: CT and MRI correlation. *Orthopedics.* 1999;22:977–979.

10. Enneking WF, Dunham WK. Resection and reconstruction for primary neoplasms involving the innominate bone. *J Bone Joint Surg Am.* 1978;60:731–746.
11. Fuchs B, Yaszemiski MJ, Sim FH. Combined posterior pelvic and lumber spine resection for sarcoma. *Clin Orthop Relat Res.* 2002;397:12–18.
12. Grimer RJ, Carter SR, Tillman RM, Spooner D, Mangham DC, Kabukcuoglu Y. Osteosarcoma of the pelvis. *J Bone Joint Surg Br.* 1999;81:796–802.
13. Kawai A, Healey JH, Boland PJ, Lin PP, Huvos AG, Meyers PA. Prognostic factors for patients with sarcomas of the pelvic bones. *Cancer.* 1998;82:851–859.
14. Kawai A, Huvos AG, Meyers PA, Healey JH. Osteosarcoma of the pelvis: oncologic results of 40 patients. *Clin Orthop Relat Res.* 1998;348:196–207.
15. Masterson EL, Davis AM, Wunder JS, Bell RS. Hindquarter amputation for pelvic tumors: the importance of patient selection. *Clin Orthop Relat Res.* 1998;350:187–194.
16. O'Connor MI. Malignant pelvic tumors: limb-sparing resection and reconstruction. *Semin Surg Oncol.* 1997;13:49–54.
17. 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.
18. Ohata N, Ozaki T, Kunisada T, Morimoto Y, Tanaka M, Inoue H. Extended total sacrectomy and reconstruction for sacral tumor. *Spine.* 2004;29:E123–E126.
19. Ozaki T, Lindner N, Hillmann A, Link T, Winkelmann W. Transarticular invasion of iliopelvic sarcomas into the sacrum: radiological analysis of 47 cases. *Acta Orthop Scand.* 1997;68:381–383.
20. Ozaki T, Rodl R, Gosheger G, Hoffmann C, Poremba C, Winkelmann W, Lindner N. Sacral infiltration in pelvic sarcomas: joint infiltration analysis II. *Clin Orthop Relat Res.* 2003;407:152–158.
21. 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.
22. Scully SP, Temple HT, O'Keefe RJ, Scarborough MT, Mankin HJ, Gebhardt MC. Role of surgical resection in pelvic Ewing's sarcoma. *J Clin Oncol.* 1995;13:2336–2341.
23. Sheth DS, Yasko AW, Johnson ME, Ayala AG, Murray JA, Romsdahl MM. Chondrosarcoma of the pelvis: prognostic factors for 67 patients treated with definitive surgery. *Cancer.* 1996;78:745–750.
24. Shin KH, Rougraff BT, Simon MA. Oncologic outcomes of primary bone sarcomas of the pelvis. *Clin Orthop Relat Res.* 1994;304:207–217.
25. Smith-Petersen MN, Larson CB, Aufranc OE. Osteotomy of the spine for correction of flexion deformity in rheumatoid arthritis. *J Bone Joint Surg Am.* 1945;27:1–11.
26. Steel HH. Partial or complete resection of the hemipelvis: an alternative to hindquarter amputation for periacetabular chondrosarcoma of the pelvis. *J Bone Joint Surg Am.* 1978;60:719–730.
27. Sucato DJ, Rougraff B, McGrath BE, Sizinski J, Davis M, Papandonatos G, Green D, Szarzanowicz T, Mindell ER. Ewing's sarcoma of the pelvis: long-term survival and functional outcome. *Clin Orthop Relat Res.* 2000;373:193–201.
28. Thiranont N, Netrawichien P. Transpedicular decancellation closed wedge vertebral osteotomy for treatment of fixed flexion deformity of spine in ankylosing spondylitis. *Spine.* 1993;18:2517–2522.
29. Wuisman P, Harle A, Matthiass HH, Roessner A, Erlemann R, Reiser M. Two-stage therapy in the treatment of sacral tumors. *Arch Orthop Trauma Surg.* 1989;108:255–260.
30. Wurtz LD, Peabody TD, Simon MA. Delay in the diagnosis and treatment of primary bone sarcoma of the pelvis. *J Bone Joint Surg Am.* 1999;81:317–325.