En bloc resection of primary tumors has consistently demonstrated a long-term disease-free survival benefit over palliative intralesional resections.\(^9,11\) Originally conceived in 1982 by Roy-Camille for musculoskeletal tumors,\(^24\) this approach has been applied to tumors throughout the body. In patients with bony metastasis from distant cancer, en bloc resection may also provide benefit. By including barrier tissues with a wide margin or total en bloc resection, local control may be improved.\(^11\) In cases of a single bony spine metastasis, en bloc resection may also improve overall survival.\(^25,29,30,32\) However, the anticipated survival benefit must be weighed against the complexity and potential morbidity of an en bloc tumor resection. In patients with malignant or aggressive primary pelvic tumors, traditional surgical treatment has consisted of radical external hemipelvectomy or “hindquarter amputation.”\(^79,26\) More recently, limb-sparing internal hemipelvectomy was deemed appropriate in patients in whom 1 of 3 areas was spared by the tumor: the iliac wing, the periacetabular region, or the pubic and ischiatic rami.\(^7\)

Usually, internal hemipelvectomy is approached laterally using a utilitarian pelvic incision extending from the superior aspect of the tumor (near the anterior superior iliac spine) along the ilioinguinal ligament medially to the pubic symphysis, with a second incision extending more laterally along the length of the anteromedial thigh.\(^15\) While it is possible to approach the sacroiliac (SI) joint and resect a portion of the sacrum from this approach, in patients with disruption of S-1, this trajectory will not allow adequate exposure for lumbopelvic fixation. Biomechanically, the disruption of more than one-half of the SI joint necessitates lumbopelvic fixation and transiliac reconstruction to maintain pelvic stability; thus, resection of tumors in this region must be accompanied by lumbopelvic fixation for weight bearing and ambulation.\(^13,16,20\)

Previously, investigators described a posterior-only approach to total sacrectomy, which allows, through a midline posterior approach, to perform a lumbosacral reconstruction, necessary in cases in which the S-1 body is iatrogenically disrupted during tumor resection. (http://thejns.org/doi/abs/10.3171/2014.4.SPINE13482)

**Object.** Traditionally, hemisacrectomy and internal hemipelvectomy procedures have required both an anterior and a posterior approach. A posterior-only approach has the potential to complete an en bloc tumor resection and spinopelvic reconstruction while reducing surgical morbidity.

**Methods.** The authors describe 3 cases in which en bloc resection of the hemisacrum and ilium and subsequent lumbopelvic and pelvic ring reconstruction were performed from a posterior-only approach. Two more traditional anterior and posterior staged procedures are also included for comparison.

**Results.** In all 3 cases, an oncologically appropriate surgery and spinopelvic reconstruction were performed through a posterior-only approach.

**Conclusions.** The advantage of a midline posterior approach is the ability to perform a lumbosacral reconstruction, necessary in cases in which the S-1 body is iatrogenically disrupted during tumor resection.

**Key Words** • hemisacrectomy • internal hemipelvectomy • sacral • posterior approach • lumbosacral reconstruction

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Abbreviations used in this paper: ASIS = anterior superior iliac spine; PSIS = posterior superior iliac spine; SI = sacroiliac.
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the L5–S1 disc space and lumbopelvic fixation in a single stage,\(^1\) and a study from our group documented the successful use of a posterior-only approach for en bloc sacrectomy in a series of 36 patients.\(^2\) By extending the dissection laterally and, in some cases, making a second incision perpendicular to the first over the iliac crest, we have been able to perform an internal hemipelvectomy and hemisacrectomy in a single procedure. We present 3 cases of SI tumors successfully treated using a posterior-only hemisacrectomy and internal hemipelvectomy with subsequent reconstruction. For comparison, we also describe 2 similar cases treated using the traditional 2-stage anterior and posterior approach. For the posterior-only cases, the first case illustrates the typical positioning and surgical approach, with subsequent cases highlighting clinical points of interest.

**Methods**

Following institutional review board approval for the research of primary and metastatic tumors, we retrospectively reviewed the records of all patients who had undergone a combined hemisacrectomy and internal hemipelvectomy performed by a single surgeon between 2002 and 2011. Patients who were offered a procedure were medically cleared for surgery and had disease progression despite chemotherapy or radiation therapy or a chemo- and/or radio-insensitive tumor, rapidly progressive neurological deterioration, severe intractable pain, or evidence of spinal mechanical instability. Patients were excluded from the study if they were not sufficiently stable for intervention, if they refused surgery, or if their projected life expectancy was less than 3 months. A multidisciplinary team including radiation and medical oncology personnel determined life expectancy, which incorporated considerations of functional status, presence of metastatic disease, patient age, and comorbid disease.

**Results**

In total, 343 patients underwent surgery for metastatic disease and 177 patients underwent resection for primary tumors in all levels of the spine during the study period. From this population, only 3 patients underwent hemisacrectomy and hemipelvectomy via a posterior-only approach in a single stage (Fig. 1). Two additional patients underwent a combined anterior-posterior approach and have been included here for comparison. A sixth patient underwent transpedicular resection of the S-1 vertebral body and lumbopelvic fixation with a transiliac bar; however, this patient was excluded from the study because of the use of a transpedicular resection and minimal resection of the SI joint.

**Illustrative Cases**

**Posterior Approach**

The posterior-only approach combines the basic tenants of primary tumor surgery with an extended midline approach. To be considered an oncological success, the tumor capsule cannot be violated; thus, surgeons will take great pains to avoid tumor on exposure and plan to sacrifice vital structures such as nerve roots. Instrumentation may be placed early to facilitate rapid patient repositioning in case a catastrophic surgical event, such as a major vascular injury requiring retroperitoneal access, occurs at a time when there is no lumbopelvic stability. Careful osteotomies free the hemisacrum and hemipelvis, allowing the specimen to be removed in an en bloc fashion. Finally, complex skeletal and wound reconstructions are undertaken. These points are illustrated in the following examples.

**Case 1**

**History and Examination.** A 24-year-old woman had a 2-year history of progressive left-sided sciatic pain and weakness. Magnetic resonance imaging demonstrated an SI joint mass, which was diagnosed as Ewing’s sarcoma on CT-guided biopsy. Of note, baseline PET-CT demonstrated FDG uptake in the anterolateral eleventh and twelfth ribs, suggestive of metastatic disease. The patient was initially treated with radiation and chemotherapy but became severely immunosuppressed and exhausted her chemotherapeutic options. Preoperative imaging showed a left SI joint mass involving at least half of the sacrum, including the ala, with pelvic extension. The mass involved the left-sided S1–3 nerve roots and the traversing L-4 and L-5 roots, along with the iliac vessels and pelvic soft tissue (Fig. 2). As this was the only site of disease in an aggressive primary bone tumor, an en bloc resection was advised despite the likelihood of flail foot due to anticipated nerve root sacrifice.

**Operation.** Initially a 2-stage procedure involving a posterior followed by a retroperitoneal approach was planned; however, the entire procedure was accomplished solely from the posterior approach. The patient was brought to the operating room, placed under general anesthesia, and positioned on the Andrews table in a knee-to-chest position with her head secured in a Mayfield head fixator to prevent facial decubitus ulcers. A complete bowel preparation was performed, irrigating the rectum with saline and povidone iodine solution until the effluent was clear. Preoperative antibiotics were administered prior to incision. Neuromonitoring was used throughout the case.

A posterior approach was used, with care taken to avoid disrupting the tumor margins during the procedure. A midline incision extending from the spinous process of L-2 to the tip of the coccyx was made and carried down to the posterior lumbosacral fascia. The incision was then T’d (converted to a T shape) to the left side, exposing the posterior iliac crest completely in a subcutaneous extrafascial pattern. At this point, in the midline, fascia was incised, and a subperiosteal dissection was performed over L-3, L-4, and L-5 bilaterally and the right side of the dorsal aspect of the sacrum. Muscle was carefully retracted to ensure adequate exposure while preserving blood supply. The left paraspinous muscle was left detached and amputated at the L5–S1 level. More laterally, the gluteus maximus muscle was completely mobilized from the lat-
eral aspect of the ilium to the sciatic notch and, further laterally, the acetabulum. A ventral plane was established lateral to the sacral ala and SI joint. A complete laminectomy was performed at the L4–5 level and was extended to the tip of the coccyx on the right side.

This exposure allowed identification of the nerve roots. All sacral roots from the right side were identified and preserved. Because of their involvement in the tumor, the L-4 to S-5 roots on the left side were individually ligated lateral to the spinal canal and left attached to the tumor mass.

Attention was then directed to the completion of the hemisacrectomy. Using the ligated left sacral root stumps, we gently rotated the thecal sac out of the path of the drill. Using a high-speed bur, we then drilled the sacrum in the midline while carefully preserving the nerve roots on the right side. The osteotomy was carried up to the L5–S1 disc space and was curved distally to the sciatic notch.

Fig. 1. Artist’s illustration of a hypothetical hemisacrectomy and reconstruction including exposure (A), osteotomies (B), and reconstruction of pelvic ring and lumbosacral interface (C). Copyright Mayo Foundation for Medical and Education Research. Published with permission.

Fig. 2. Case 1. Preoperative coronal (A), axial (B and C), and sagittal (D) MR images of the sarcoma centered in the left hemi-sacrum and the SI joint. White arrow indicates invasion of the ilium. Lateral (E) and anteroposterior (F) views of the lumbopelvic reconstruction on scout CT scans. Since the left hemipelvis was resected, it is notable how far lateral the pelvic fixation is relative to the right side (black arrow). Coronal CT (G) demonstrates the location of the femoral strut.
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at the S4–5 level, below the level of the femur. Once the osteotomy was completed, the left hemisacrum was detached from the right side. Then the L5–S1 disc was detached on the left side as well, in a circumferential fashion. Annulotomy was performed using a No. 15 blade, Leksell rongeurs, and Kerrison punches.

An internal hemipelvectomy was necessary to free the tumor. Using a high-speed bur lateral to the SI joint, the ilial osteotomy was connected to the sciatic notch. At this point, we detached the sacroccygeal ligament and transverse ligaments laterally, mobilizing the tumor mass. Under direct vision, iliac vessels were dissected free from the tumor, multiple feeding vessels were individually ligated, and the rectum was dissected from the tumor. The distal attachments of the sacral roots, L-4, and L-5 remained attached to the tumor mass. This allowed the tumor to be removed from the operative field in an en bloc fashion.

Pelvic reconstruction and lumbopelvic fixation were required for skeletal stability. The left side of the pelvis was reconstructed using a femur shaft extending from the medial aspect of the remaining ilium to the remaining right S-1 hemivertebra and contacting the L-5 endplate superiorly (Fig. 2). This shaft was secured using screws through the graft into the S-1 vertebral body and the remaining ilium. Pedicle screws were then inserted at the L-3, L-4, and L-5 levels bilaterally. Two pelvic screws were inserted on the left side, two on the right side, one on the rostrum, and one on the caudal end of the remaining ilium. These screws were then connected to the lumbar screws with several different rod attachments and multiple cross connectors. In this fashion, a lumbar-sacral-pelvic reconstruction was performed with pedicle screws and rods, extending from L-3 down to the ilium on both sides. Attention was then directed to the fusion procedure. Dorsally exposed parts of the lumbar spine were decorticated and bone graft was packed within this area, creating an arthrodesis from L-3 to the ilium on both sides. Plastic surgeons then placed acellular dermal matrix to prevent rectal herniation and closed the incision with bilateral elevation of the paraspinal and gluteus muscles over the pelvic instrumentation. There were no intraoperative complications. We monitored her lower extremity electromyography and sphincter activity throughout the procedure. Appropriate responses were obtained while sectioning the nerve roots.

Postoperative Course. At the end of the procedure, the patient was taken to the neurosurgical intensive care unit in a stable neurological condition.

The patient suffered a complicated hospital course as a result of a persistent CSF leak, likely attributable to an incompletely ligated nerve root. She required multiple wound revisions, lumbar drain attempts, and ventriculoperitoneal shunt placement. A wound vacuum-assisted closure device (VAC) was ultimately placed to allow the majority of the wound to heal, with the final portion of the incision closed secondarily via skin graft by plastic surgery. Otherwise, the patient had the expected flail foot due to nerve root sacrifice requiring ankle foot orthotics. On 6-month follow-up scanning, remote metastases were apparent. The patient was discharged to hospice. The hospital international office confirmed that she had died but was unable to provide a date of death.

Case 2

History and Examination. Seven years earlier, a teratocarcinoma with rhabdomyosarcomatous features had been diagnosed in this 30-year-old man who now had metastasis consistent with embryonal cell carcinoma, which was treated with chemotherapy. At the time of the current admission the patient was neurologically intact. A right sacral lesion was noted on surveillance imaging (Fig. 3), and biopsy confirmed the metastasis with extensive rhabdomyosarcomatous features. As this was not a radiation-sensitive tumor, en bloc resection was undertaken.

Operation. This operation was approached in a manner similar to that in the previously described case. We made a midline incision, which was T’d to expose the lateral ilium. The paraspinal and gluteus maximus muscles were dissected off the lateral aspect of the ilium in a subperiosteal fashion. On the right hand side, the ilium was exposed laterally beyond the sciatic notch.

This unusually wide exposure was needed to perform the hemisacrectomy. An L5–S3 laminectomy was performed, and an L5–S1 hemidiscectomy was completed to visualize the tumor (Fig. 3). A transforaminal lumbar interbody fusion (TLIF) spacer was placed on the left side to provide anterior lumbosacral arthrodesis. The S-1 and S-2 roots were identified and ligated on the right, along with the dorsal root of S-3. A caudal sacral osteotomy was performed from the midline to the sciatic notch, through the sacrum following the S-3 nerve root. A lateral osteotomy was then completed, starting from the sciatic notch and progressing laterally to the top of the ilium, lateral to the SI joint. A midline sacral osteotomy was performed from S-1 to S-3. Finally, a rostral lateral osteotomy was performed from the mid S-1 vertebral body laterally through the sacral ala through to the ilium. After this step was completed, the specimen was mobilized and rotated laterally, allowing the L-5 root to be dissected from the specimen. The entire specimen was delivered en bloc, including the hemivertebrae of S-1, S-2, and S-3 as well as the entire SI joint and ilium and the distal paraspinous muscles and the tumor (Fig. 4).
In this case, pedicle screw instrumentation was placed from L-4 to S-1 bilaterally, and from S-2 to the ilium on the right (Fig. 4). This placement shifted the weight-bearing potential to the left-hand side of the ilium, which remained intact. After this had been completed, a femoral allograft strut was placed to span from the remaining S-1 vertebral body to the ilium on the right-hand side, producing the anterior arthrodesis from S-1 and S-2 to the ilium. An arthrodesis from L-4 through the ilium posterolaterally was performed, and a complex plastic surgery closure was completed.

**Postoperative Course.** The patient had no complications and was discharged toconstantly facility on postoperative Day 10 with anticipated right planter flexion weakness, and he received postoperative radiation to the tumor bed at another institution. One year after surgery, he had recovered full strength in his extremities except for the sacrificed S-1 distribution. Twenty months after surgery, radiographs demonstrated pseudarthrosis and instrumentation loosening, and thus he underwent revision surgery. His postoperative course was complicated by a pulmonary embolus, and on spiral CT, a pulmonary metastasis from his disease was discovered. At the last follow-up 1 month after reinstrumentation, his pulmonary lesion remained stable, and oncology was consulted for further treatment of his metastatic disease.

**Case 3**

**History and Examination.** This 44-year-old woman presented with a several-month history of pain in her right lower extremity. Magnetic resonance imaging demonstrated a mass at the S-1 vertebral body with extension to the S-2 body and right SI joint. A CT-guided biopsy specimen was consistent with a giant cell tumor with extensive aneurysmal bone cyst change. Posterior en bloc removal of the neoplasm with preoperative embolization was planned. Preoperative embolization of the giant cell tumor was performed 2 days before surgery (Fig. 5).

**Operation.** Subsequently, the patient was brought to the operating room and placed prone on the Jackson table. Through an L3–S4 midline incision and dissection, pedicle screw instrumentation was placed in L3–5 bilaterally, an L5–S3 laminectomy was performed, and the L5–S3 nerve roots and right SI joint were identified. The right iliac crest was harvested for autograft and to provide access to the right SI joint.

A midline osteotomy extending from the L5–S1 interspace to the S-2 level was performed. The lateral osteotomy extended through the S-2 vertebral body to meet the midline osteotomy. Finally, a sagittal osteotomy through the ilium lateral to the SI joint was completed and followed by an L5–S1 discectomy. The L4–5 nerve roots and sciatic nerve were dissected from the ventral aspect of the tumor, and the specimen was rotated, allowing the surgeon to cut the ligamentous attachments and clip a vascular pedicle from the internal iliac artery.

Iliac screws were then placed on the left-hand side in a traditional fashion; on the right side, however, because of the extent of resection, the screws were placed in an unconventional fashion along the posterior superior iliac spine (PSIS; Fig. 5). Rods were fitted, and arthrodesis was completed from L-3 through the ilium bilaterally. Plastic surgery assisted in wound closure, with primary closure of the thoracolumbar fascia and bilateral paraspinal muscle flaps.

**Postoperative Course.** Ten days after surgery, external fixation of the anterior pelvis was performed to improve pelvic ring stability (Fig. 5). Postoperatively, the patient had transient urinary retention that resolved independently and a fever and fluid collection in the operative site requiring antibiotics and drainage by interventional radiology. Three months after surgery, external pelvic fixation was removed, and the patient reported improvement in her pain. Scans taken at the 3-month follow-up demonstrated proper alignment of the spinal instrumentation.

**Anterior and Posterior Approach**

The combined approach has the same surgical goals as the posterior-only approach; however, extensive planning must be undertaken to ensure that all necessary steps are completed prior to moving on to the next surgical trajectory in the two-staged approach. For instance, the specimen must be completely freed anteriorly before moving to the definitive posterior stage so that the specimen can be removed. Failure to do so may be impossible to remedy, resulting in injury to structures no longer readily accessible. The following cases outline the complexities of the combined approach.

**Case 4**

**History and Examination.** This 19-year-old man with a 4-month history of bilateral hip and thigh pain was found to have an enlarging sacral mass. Results of a CT-guided biopsy were consistent with Grade 1 sarcoma. At the time of surgery, imaging studies demonstrated a
sacral mass involving the right S-1 and S-2 vertebral bodies, which did not cross the SI joint or the midline (Fig. 6). Because of the diagnosis, a decision was made to proceed with en bloc resection of the mass in 2 stages.

**Operation.** The first stage of the operation was approached in a manner similar to those in the previous cases. An L3–4 midline incision exposed approximately 13 cm of the left iliac crest to the level of the sciatic notch and approximately 3 cm of the right iliac crest for future stabilization. Once instrumentation was placed, attention was turned to tumor resection. A complete L-5 laminectomy and left S-1 to S-4 hemilaminectomy were performed. As it was involved in the tumor, the right S-1 root was sacrificed. A vertical sagittal osteotomy was carefully performed using a high-speed bur between the sacral nerve roots. A horizontal sacral osteotomy was then performed through the S-3 vertebral body following the right S-3 root out to the sciatic notch. A radical L5–S1 discectomy was then performed, and the sagittal osteotomy was connected to the disc space.

BrainLAB frameless stereotactic navigation was used during tumor resection, as previously described. The iliac osteotomy was also planned with this navigation system to be lateral to the SI joint yet outside the tumor to the sciatic notch. When the osteotomy had been completed, only a small portion of bone remained. The frameless navigation system was then used to place the right iliac screw in the remaining bone while avoiding tumor disruption. It appeared that the superior gluteal artery might have been injured at its exit from the sciatic notch; thus, it was packed off and embolized through vascular surgery, as hemorrhage into the pelvis would not be controllable from a posterior approach. As all surgical goals had been reached for Stage 1 of the procedure, instrumentation was assembled and closure commenced. Laminectomy bone was saved, placed in a sterile baggie, and placed in the patient for retrieval at the second stage of the procedure. The patient fared well and was transferred to the neurosurgical intensive care unit.

The following day he was taken to the operating room for the planned second stage. He was placed in the left lateral decubitus position, and a retroperitoneal approach exposed the aorta, inferior vena cava, and right common iliac artery and vein. Of note, coils were seen in the superior gluteal artery following embolization, and no retroperitoneal hematoma was identified. The L5–S1 disc space was identified, and the major vessels were dissected away. Additionally, the ventral osteotomy from the previous Stage 1 posterior approach was identified. The L-4 and L-5 roots were identified and dissected to the level of the formation of the sciatic nerve. The posterior incision was reopened at this point, and a Tomita saw was used to cut the L5–S1 disc, freeing the sacrum from the lumbar spine. The iliac osteotomy was completed via the anterior approach. The anterior incision was formally closed, the posterior incision was temporarily closed, and the patient was repositioned on a Jackson table.

Once the patient was positioned, the posterior incision was reopened. As the specimen was freed from the previous midsagittal vertical osteotomy, L5–S1 discectomy, inferior S-3 horizontal osteotomy, and vertical iliac osteotomy, the specimen was carefully rotated free of the surgical site. Ultimately, the S-1, S-2, and S-3 roots on the right were ligated and cut distal to the specimen but...
proximal to the sciatic nerve. The en bloc specimen contained the tumor; the right half of the S-1, S-2, and S-3 vertebral bodies; the SI joint; and the medial aspect of the right ilium. Pelvic ring and lumbosacral reconstruction was similar to those in previous cases (Fig. 6). Appropriate arthrodesis was undertaken at all levels, and a complex plastic surgery closure was completed using bilateral paraspinal muscle flaps.

**Postoperative Course.** At 1 year after surgery, the patient was ambulating well, with 5/5 strength in all extremities, and taking Tylenol and Lyrica for pain control. At the follow-up 18 months after surgery, radiographs demonstrated solid arthrodesis, although rod fracture was noted as well. At the 2-year follow-up, he continued to demonstrate solid arthrodesis and no disease recurrence.

**Case 5**

**History and Examination.** This 76-year-old man complained of pain in the left hip with weakness in the left lower extremity. Imaging at presentation revealed a large tumor of the left hemipelvis and hemisacrum involving the L4–S2 nerve roots and lumbar plexus with a significant anterior soft-tissue component (Fig. 7). Biopsy revealed chondrosarcoma. The patient underwent 3 cycles of chemotherapy without response and elected to undergo resection of the tumor. A staged procedure was planned.

**Operation.** The patient was brought to the operating room and placed prone on the Jackson table, and a midline L3–S4 incision was made for exposure. Once preliminary exposure and bone work were completed, pedicle screw and iliac instrumentation was placed (Fig. 7) and the left-side nerve roots at L4–S3 were identified and ligated. The thecal sac was gently reflected from left to right, allowing ventral exposure for the L4–S3 vertebral bodies.

A modified midline osteotomy essentially created a hemivertebrectomy of L-4 and L-5 and a hemisacrectomy to allow the specimen to be delivered en bloc during the second stage. A midline osteotomy was performed, starting at the caudal aspect of the S3–4 level laterally at the sciatic notch and then to the midline at the level of the S-4 pedicle. It was extended superiorly to L-4 where it veered laterally through the L-4 pedicle and connected to the lateral aspect of the vertebral body above the transverse process of L-4. This allowed the entire specimen to remain in place but free from the midline and the rostral aspect of L-4 and the inferior aspect of the pelvis in the sacrum. Because of significant epidural bleeding and a concern that the patient was going into pulmonary edema, the incision was closed and Stage 1 was terminated.

For Stage 2 of the procedure, ureteral stents were placed, and the patient was placed in the right lateral decubitus position. An incision was made on the left side midway between the anterior superior iliac spine (ASIS) and the PSIS extending over the ASIS. The abdominal muscles were dissected from the iliac crest, the spermatic cord was retracted medially, and the external iliac vessels were identified. The posterior incision was then extended to the PSIS with a curvilinear incision proximal to the ASIS and a right angle incision down across the greater trochanter to the mid posterior thigh. The resultant large posterior flap was raised with the gluteus maximus muscle, retracted posteriorly, and dissected from the posterior ilium and sacrum. The previous incision was then met, and the gluteus medius muscle was released from the iliac crest. The sciatic notch was exposed posteriorly, and the gluteus minimus muscle was transected posteriorly, extending to the anterior inferior iliac spine. The tensor fascia lata and sartorius were then reflected from the anterior iliac crest. The anterior abdominal muscles were released anteriorly, and the femoral nerve was identified. The psoas muscle was then transected anteriorly proximal and distal to the tumor. A Gigli saw was then used to make the acetabular cut. Extensive soft-tissue dissection was performed to facilitate exposure of the iliac vessels, cutting through the pelvic floor. The tumor and hemipelvis were removed en bloc (Fig. 7).

The patient then experienced a profound drop in blood pressure and bleeding from the iliac vein requiring direct venous repair by the vascular surgeon. An air embolism was suspected. The patient was resuscitated and the plastic surgery team performed a left intermediate thigh closure of 50 cm, followed by placements of acellular dermal matrix and a vacuum-assisted device for wound closure.

**Postoperative Course.** The patient’s postoperative course was complicated by protracted respiratory failure.
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and difficulty weaning from the ventilator. His hospital stay was further complicated by inferior vena cava filter placement, low platelet counts, tachycardia requiring repeated echocardiography, Enterococcus sepsis, percutaneous endoscopic gastrostomy tube placement, and bilateral subdural hematomas. Eighteen months after surgery, the patient continued to experience urinary incontinence and short-term memory loss. He reported no pain but was using a wheelchair given the loss of the left-sided L4–S3 nerve roots. Heterotopic ossification of the right sciatic notch developed, resulting in decreased right lower extremity function. His incision was well healed, and imaging demonstrated no recurrence of local disease or development of metastatic disease.

Discussion

A posterior-only approach to hemisacrectomy and internal hemipelvectomy has 2 major advantages over a traditional procedure: surgical morbidity is reduced by avoiding the anterior approach, and appropriate lumbopelvic reconstruction can be performed. Hemipelvectomy from the traditional utilitarian incision along the ASIS and PSIS to the midthigh generates a massive surgical defect that may be accompanied by excessive blood loss and poor wound healing. Large, complex closures may also necessitate skin grafting or pedicled flap reconstructions. Further, this approach requires dissection of a significant amount of soft tissue, and recurrent or persistent infection, failure of the autograft and allograft, and transplant dislocation have been reported as complications.\textsuperscript{2,19,23,31} While the classic hemipelvectomy approach and incision allow exposure of the iliac crest and acetabulum for resection of the proximal femur and access to the pelvic floor, they do not allow the surgeon access to place instrumentation for lumbopelvic reconstruction.

Biomechanically, skeletal reconstruction presents a challenge in cases in which both the pelvic ring and the lumbosacral junction have been destabilized, either iatrogenically or by tumor. Effectively, the S-1 body is the platform upon which the axial spine sits, and it is this body that is the major interface between spine and pelvis. Thus, destabilization of this platform by removing more than half of the SI joint demands appropriate reconstruction.\textsuperscript{13,16,20} In cases of total sacrectomy (including removal of the S-1 body) or of L-5 vertebral body resection, instrumentation is extended to include pelvic fixation in the form of iliac or S-2 screws.\textsuperscript{12,21} In hemipelvectomy cases, spinal reconstruction is further complicated by resection of at least a portion of the ipsilateral iliac wing, requiring a more creative plan for reconstruction.\textsuperscript{2,19,23} The patients in Cases 1 and 3 illustrate this unusual reconstruction, with far lateral placement of iliac screws. The challenges of such reconstructions are evidenced by our series. Before the 2-year mark, both patients with long-term follow-up had evidence of instrumentation failure or pseudarthrosis. However, as performing a complex lumbopelvic fixation necessitates a posterior midline incision with access to the contralateral iliac wing, the posterior-only approach decreases overall surgical morbidity by allowing access to tumor and exposure for instrumentation placement through the same surgical incision.

Lumbopelvic Reconstruction

Motion Preservation

For patients with tumors of the SI joint, en bloc resection with wide or marginal surgical margins may require hemipelvectomy with hemisacrectomy and vertebrectomy of adjacent lumbar levels. Because the acetabulum is outside the surgical margin, these patients, when undergoing a more limited procedure, have the possibility of retaining lower limb function on the affected side. In the first four cases described above, the acetabulum was not affected by the tumor, and the iliac osteotomy was performed posterior to femoral articulation, making it possible to avoid a more complex reconstruction. In the more traditional fifth case, the acetabulum was transected, eliminating function of the left lower extremity. When a more extensive internal hemipelvectomy is required (beyond the sciatic notch), this approach is unlikely to provide the access necessary to perform an adequate reconstruction. In cases involving resection of the femoral acetabulum, moving the hip joint to another location on the remaining pelvis is possible to maintain functional ambulation but would likely require a lateral approach and is beyond the scope of this technique.

Anterior Exposure

One drawback of the posterior-only approach to hemisacrectomy and internal hemipelvectomy is decreased access to the structures anterior to the ilium and sacrum. Thus, the surgeon must take care to understand the normal regional anatomy and subsequent pathological disturbances to avoid injuring these structures. It is notable in this case series that the osteotomies were performed by aggressively drilling the posterior cortex and

Fig. 7. Case 5. Preoperative T2-weighted fat-suppressed MR image (A) demonstrates a large left-sided mass with a large central cavity (arrow) and significant ventral extension. A T1-weighted MR image (B) shows lesion hypointense to bone with a central cavity (arrow). Pedicle and iliac screw placement as seen in scout coronal CT image (C). Postoperative radiograph (D) highlights the extent of bony resection.
cancellous bone before carefully completing the procedure with a diamond bur or Kerrison rongeur to minimize trauma. Additionally, the surgeon should consider the bailout procedures if there is a problem. For instance, before performing the anterior osteotomies, instrumentation was placed to ensure the iatrogenically destabilized lumbopelvic junction and pelvic ring would be stable in the event that rapid repositioning was required for a retroperitoneal approach. Other options available to the surgeon include interventional vascular procedures such as that used in the third case.

As described, our approach effectively eliminates the retroperitoneal component of a traditional sacrectomy/hemipelvectomy approach. The horizontal incision, which was T’d to the midline posterior incision, provided additional lateral access for resection and reconstruction. Note, however, that the posterior-only approach is limited when the tumor extends ventrally with significant soft tissue involvement or bowel invasion, when the tumor extends above the lumbosacral junction, or when the surgical exposure must incorporate the acetabulum for a complete internal hemipelvectomy to obtain adequate surgical margins, as seen with the fifth patient in our series.

Wound Closure

Use of the posterior-only approach limits the options for wound closure. While multiple techniques, including mesh, myocutaneous flaps, and vascularized free flaps, have been used to repair the soft-tissue defects following en bloc sacrectomy, the mobilization of some structures, such as the vertical rectus abdominus flap, are only possible using a combined approach. In our cohort, none of the patients required a vertical rectus abdominus flap. Instead, acellular matrix with or without an elastic mesh was used for closure, as have been well described. Facilities for wound closure varied, with other groups reporting infection rates up to 66.7%.

Oncological Considerations

From an oncological standpoint, it is difficult to assess whether the posterior-only approach offers a disadvantage based on the 3 presented cases. The first patient presented with questionable metastatic disease that rapidly progressed after surgery, whereas the second patient had metastatic disease on presentation and the third presented with a benign pathology (giant cell tumor). The goal of en bloc resection is potential cure: if the primary disease site is removed in its entirety without disruption and the disease has not yet metastasized, the patient is theoretically cured. Notably, the reduction in wound area facilitated by the posterior-only approach may allow patients to resume chemotherapy at an earlier time. In previous studies, we have demonstrated no increased incidence of disease recurrence and/or metastasis in primarily operated non-metastasized primary sacral tumors following the posterior approach compared with historical data involving combined procedures. Only further study will determine whether the reduced exposure offered by the posterior approach increases the risk of tumor violation and negatively affects oncological outcome as compared with a combined procedure in patients undergoing hemisacrectomy and hemipelvectomy.

Conclusions

The posterior-only approach for hemisacrectomy and hemipelvectomy allows sufficient exposure for the resection of tumors involving the SI joint. Resection of tumors at this level destabilizes the interface of the spine and pelvis and requires lumbopelvic reconstruction to support weight bearing and lower extremity function on the affected side. Through the use of a single midline posterior incision, we demonstrated that a surgeon can resect the tumor and place the necessary lumbopelvic hardware to restore the pelvic ring and allow functional ambulation.

Disclosure

Dr. Gokaslan owns stock in US Spine and Spinal Kinetics. Dr. Scibba is a consultant for Medtronic, DePuy, Globus, and NuVasive. Dr. Witham has received non–study-related support from Eli Lilly. The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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