Pelvic Resection: Current Concepts

Abstract
Pelvic resection is a technique that involves surgical resection of portions of the pelvic girdle. Historically, this procedure was known as internal hemipelvectomy. Hemipelvectomy is a resection that includes the ipsilateral limb. The main indication for these procedures is primary malignant tumors of the pelvis, but in rare cases they are indicated for metastatic lesions, infection, or trauma. Reconstruction is dictated by the extent of the resection and the remaining structures. Surgical technique is dictated by histology of the tumor and location of the lesion. A multidisciplinary team is required. The patient and family should undergo counseling preoperatively to discuss morbidity and mortality, the extensive rehabilitation process, and life expectancy.

Pelvic resection and hemipelvectomy are rare procedures that are used primarily in the management of primary malignant tumors but also, in rarer instances, in the management of metastatic tumors, severe trauma, and infection. One goal of pelvic resection is limb salvage of the ipsilateral lower extremity; this procedure involves local resection of all or portions of the involved hemipelvis.

Hemipelvectomy is a more ablative procedure in which the involved hemipelvis is removed in its entirety, along with the ipsilateral extremity. This procedure is also known as hindquarter amputation. The first reported hemipelvectomy was performed by Billroth in 1889;1 the procedure was unsuccessful. In 1895, Billroth’s contemporaries Jaboulay, Caciopoli, and Girard performed the first successful hemipelvectomy.1 In 1909, Ransohoff2 became the first surgeon in the United States to complete the hemipelvectomy successfully.

Limb salvage via pelvic resection marked a significant advancement in the management of pelvic neoplasms. Eilber et al3 were among the first to establish pelvic resections as an alternative to hemipelvectomy.

With proper patient selection and surgical technique, survival and recurrence rates are no worse for pelvic resections than for hemipelvectomy. Enneking and Dunham4 developed a classification system for pelvic resection based on the section or sections of bone to be resected (ie, iliac, periacetabular, pubic) and the degree of resection (wide or radical) (Figure 1). Early pelvic resections did not involve pelvic reconstruction and often left patients with poor functional outcome. Advancements in flap coverage techniques and megaprostheses have facilitated pelvic reconstruction and improvements in functional outcomes following limb salvage, although often at the expense of a higher incidence of complications.

Epidemiology
The true incidence of hemipelvectomy in the United States is unknown.
However, it has been estimated to be approximately 1 per 1 million annually.5

Primary Bone Tumors
Among all cancers, primary bone tumors account for <0.2% of all cases and mostly afflict patients aged <20 years or between 40 and 50 years.6 In the United States, the annual incidence of primary bone tumors is approximately 2,500, with annual mortality of approximately 1,400. Approximately 15% to 20% of all primary bone tumors are located in the pelvis. The three most common histologies are osteosarcoma (35%), chondrosarcoma (30%), and Ewing sarcoma (16%).6 Malignant fibrous histiocytomas and fibrosarcomas account for <1% of all primary bone tumors. Osteosarcoma and Ewing sarcoma most commonly occur in childhood. In the United States, an estimated 650 to 700 malignant bone tumors are diagnosed each year in children aged ≤19 years, of which 54% are osteosarcoma and 35% are Ewing sarcoma. Five percent of osteosarcomas occur in the central axis, whereas 45% of the cases of Ewing sarcoma occur in the central axis. Chondrosarcomas occur more frequently in older adults.6 Fewer than 20% of all primary bone cancer cases present with metastatic disease at diagnosis. Cases of metastatic cancer are best suited to aggressive surgical resection because they have the potential for cure.

Primary Soft-tissue Sarcomas
Approximately 10,000 cases of soft-tissue sarcoma are diagnosed each year in the United States, and the annual overall mortality rate is approximately 3,800 per year.7 Overall, sarcomas comprise <1% of all adult and approximately 15% of pediatric malignancies.6 Approximately 5% of all soft-tissue sarcomas are located in the pelvis.6 Depending on the clinical presentation, soft-tissue sarcomas rarely require bony resection or amputation. The most common sites are the extremities (60%), trunk (19%), retroperitoneum (15%), and head and neck (9%).7 Metastases are most likely to arise in the lungs, whereas sarcomas arising in the abdominal cavity are more likely to have metastasized to the liver. The local recurrence rate is 15% to 20%, with a 5-year mortality rate of 50% to 60% for high-grade lesions.6

Metastatic Tumors and Hematopoietic Malignancies
Pelvic skeletal metastases are most commonly due to cancers of the breast, lung, prostate, kidney, and thyroid; other primary sites include the colon, rectum, uterus, and endometrium.8 Metastasis due to breast and renal cancer is the type that most commonly requires surgery. Hematologic malignancies seen in the pelvis include lymphoma and myeloma. Most metastatic lesions of the pelvis can be readily managed with radiation and pain control.8 If pain is not controlled or if mechanical weakness persists, local curettage with cement or limited reconstruction typically is effective if the defect is contained and does not involve the hip joint or erosion through the acetabulum. Reconstructions that require complex acetabular reconstruction are beyond the scope of this review.

In general, hemipelvectomy is rarely indicated for palliative intent in the patient with systemic disease. However, it may be considered for isolated metastasis in the setting of renal cell carcinoma or a solitary plasmacytoma. One-year survival in patients with isolated bone metastasis from renal cell carcinoma is significantly better than that of patients with visceral metastasis, and wide resection may result in prolonged 5-year survival.9,10 If the malignancy encases the neurovascular structures or is seen to be fungating through the skin, more aggressive palliative resection may be required (Figure 2). The morbidity and mortality of the resection, the length
rehabilitation process, and limited life expectancy must be thoroughly discussed with the patient and family preoperatively.

**Anatomic Considerations**

The anatomy of the hip and pelvis is complex and challenges even the most experienced surgeon. The bony pelvis is divided into the iliac wing, the periacetabular region, and the obturator ring, which includes the pubic rami (Figure 3, A). The pubic rami join at the pubic symphysis anteriorly and articulate with the sacrum via the strong sacrotuberous and sacrospinous ligaments. The common iliac artery crosses and bifurcates along the sacral ala (Figure 3, B). The artery divides into the internal and external iliac arteries and their corresponding veins. The internal iliac vessels exit the pelvis through the greater sciatic notch, and the external iliac vessels exit the pelvis medial to the iliopectineal tendon to become the femoral artery. The ureter crosses near the division of the internal and external arteries from lateral to medial as it passes to the bladder. The major neural structures include the sciatic, femoral, and obturator nerves and their preceding nerve roots.

The iliacus muscle is located on the inner table of the iliac wing. The psoas major muscle originates on the vertebral bodies, traverses the pelvis, and joins the iliacus to form the iliopsoas tendon, which crosses over the pelvic brim en route to its insertion on the lesser trochanter. The femoral nerve runs between these two muscle bellies. The adductor muscle group, pelvic floor muscles, anterior thigh muscles, and posterior thigh muscle all originate from various locations on the pelvis and often require resection depending on the location of the tumor and bone to be removed. Depending on the specific location of the tumor, vital structures such as the urethra, prostate (in males), corpus of the penis (in males), rectum, and bowel can also be involved or require protection when removing these tumors. In female patients, the uterus, ovaries, and vagina may require removal or protection, as well, depending on the location of the mass.

**Surgical Indications**

Options for pelvic resection vary greatly depending on the histology of the tumor and the location of the lesion. A thorough knowledge of pelvic anatomy is required when considering surgical intervention for a malignant tumor. Preoperative planning is crucial to define the extent of the tumor, plan the surgical margins, and identify the location of the vital structures. Necessary imaging includes plain radiography, CT, and MRI. A multidisciplinary team is required, and the entire team should review the surgical plan before proceeding. This step will ensure the proactive consideration of all aspects of care, that is, potential neoadjuvant treatments, resection considerations,
reconstruction options, and postoperative care, in order to maximize outcomes.

Pelvic Resection
Tumors located in or eroding into the bony pelvis often require surgical resection. Most resections are performed with the goal of achieving negative margins (ie, no malignant cells identified at the bone edge). Given the complex anatomy, however, this outcome is often difficult to obtain.

Preoperative imaging is used to define the extent of the tumor, plan margins, and identify the location of the neighboring vital structures. Pelvic resection can be considered when the tumor does not involve the major neurovascular structures such that a functional limb can be preserved without compromising the margins necessary to minimize risk of tumor recurrence.

From a functional standpoint, Enneking and Dunham type I and type III resections are superior to periacetabular (type II) resection. Depending on the location of the tumor, a combined resection may be required. For example, a type II/III resection would involve both the periacetabulum and the pubic rami. These combined resections often influence the reconstruction options because there is less bone to work with following resection.

Hemipelvectomy
Hemipelvectomy for resection of tumors of the pelvic girdle should be considered if pelvic resection cannot be performed with adequate margins or if removal of the tumor will leave a functionless limb. O’Connor and Sim attempted to identify which patients should be treated with pelvic resection and which should undergo hemipelvectomy. The three anatomic structures that must be considered are the sciatic nerve, the femoral neurovascular bundle, and the hip joint (ie, periacetabular region). As a general rule, should two of these structures require resection to obtain an adequate margin, then hemipelvectomy should be considered.

Wound closure can be achieved with either an anterior flap or a posterior flap depending on the location of the tumor. Flap selection should be made preoperatively to allow proper planning. It may be necessary to involve plastic surgery experts at the index procedure in cases that would benefit from free flap closure. Consultation

Figure 3
with the plastic surgery service is highly surgeon- and institution-dependent. Prostheses are available for use following hemipelvectomy, and the decision to use them is made on a case-by-case basis. During preoperative counseling, the patient should be advised that the prosthesis is difficult to anchor and that it typically requires some combination of waist and shoulder strap. The hemipelvectomy prosthesis requires a great deal of energy expenditure secondary to the swing gait required. Older patients typically do not well tolerate such a prosthesis. Thus, most patients use crutches or are wheelchair-bound.13

Reconstruction Options

Reconstruction of the bony pelvis is considered on a case-by-case basis. Whether to reconstruct the skeletal defect is a complex issue that is fraught with controversy. No strong guidelines exist, and decisions should be individualized to each patient. Certain anatomic resections lend themselves more easily to a functional reconstruction, whereas some are better left unreconstructed.

Pelvic reconstruction should be considered for type II periacetabular resections and for combined resections in cases in which the continuity of the lumbopelvic articulation is compromised. In general, options consist of biologic (eg, arthrodesis, bone graft), prosthesis, or none.

Type I Resection

Type I resection of the iliac wing often is left unreconstructed, with minimal functional compromise. However, inclusion of the sciatic buttress in the resection results in disrupted continuity of the pelvic ring; this must be restored to preserve limb length. This can be achieved with allograft, autograft (often vascularized fibula), or a metallic prosthesis (Figure 4). In general, outcomes of type I resection are favorable, with most patients regaining independent ambulation.

Badel et al14 performed a case-control study of 16 patients treated with either reconstruction or no iliosacral repair (4 and 12 patients, respectively). The Toronto Extremity Salvage Score (TESS) and Musculoskeletal Tumor Society (MSTS) 1987 and 1993 scores were similar between the groups, and similar rates of local recurrence and survival were noted as well. However, patients who did not undergo reconstruction had a lesser need for ambulatory assistive devices and chronic pain medication. Electing for no reconstruction is a viable option in type I resections.
Type II Resection
Resection of the periacetabular region is the most challenging type from both a resection and reconstruction perspective. The surgical procedure is associated with the highest complication rate of all the types. A variety of reconstructive options exist.

Resection Arthroplasty
The Friedman-Eilber resection arthroplasty, in which the pelvis is left unreconstructed (ie, flail hip), has gained increasing support and popularity (Figure 5). Although this technique has a long recovery time of approximately 2 years, when maximal function obtained, it avoids the high complication rate noted in conjunction with many of the reconstructive options.13 Complications include infection, nonunion, and neurapraxia. Prior studies have estimated a 30% to 50% complication rate when resection and reconstruction are performed in one procedure.14 In contrast, a published case series highlighted outstanding outcomes and unassisted ambulation in seven patients treated in this fashion.15 The procedure is also associated with shorter surgical time, reduced blood loss, and decreased hospital stays compared with reconstruction.

Depending on the amount of bone resected, the proximal femur or femoral head may be anchored or tied to the remaining ilium or sacrum in a procedure known as hip transposition. Typically, the proximal femur is anchored with transosseous sutures, bone anchors, or Gore-Tex tubing (W. L. Gore & Associates).16 Suspension and stabilization of the residual limb is crucial to maximize function and provide some stability.

The most common complications following resection arthroplasty are wound complications and nerve palsies. Typically, the nerve palsies are peroneal in nature. Very few of these complications require further surgical intervention. Thus, a major advantage of this method is that it markedly diminishes the risk of subsequent surgeries associated with prosthetic or allograft complications or infection.

Saddle Prosthesis
The saddle prosthesis was designed to maintain leg length in patients undergoing periacetabular resection (Figure 6). The prosthesis is anchored in the femur in a manner similar to that used in conventional total hip arthroplasty. An articulation notch is made in the remaining ilium, and the proximal prosthesis hinges over this notch.17 Reconstruction with a saddle prosthesis is associated with substantial morbidity, with high rates of infection, nerve palsy, dislocation, fracture, device migration, and heterotopic ossification.18 Benefits of this technique are ease of insertion, restoration of limb length, and modularity of the device. Although some patients achieve an acceptable functional outcome, the indication for this reconstructive option is narrowing because of the high complication rate.

Allograft/Prosthetic Composite
Massive alloprosthetic reconstruction using allograft bone combined with total hip arthroplasty in pelvic resections is an option for periacetabular resection. The reconstruction is technically demanding but has the ability to preserve limb length and maximize function.19 Deep infection, nonunion, nerve palsy, and hip instability are seen in almost 50% of the patients treated in this fashion.20 However, young patients who achieve union can gain good functional results and restored limb length.20

Custom Device
Although several implant companies have the capability to generate custom metallic devices, sufficient time is
required for FDA approval prior to the procedure. The lengthy approval process has limited the use of custom implants. Most of the literature on these devices consists of small series or reports in which this option is combined with various other reconstruction methods. Thus, it is difficult to draw conclusions about their efficacy. Loosening and infection are common complications, which limits the use of this option.

**Type III Resection**
Resection of the pubic rami requires no reconstruction. Most patients exhibit satisfactory functional outcomes and achieve unassisted ambulation.

**Combined Resections**
Depending on the location of the tumor, resection types may be combined (ie, type I/II, type I/IV). The more bone that is resected, the more limited the options for reconstruction. Compared with the resection techniques discussed above, resection arthroplasties perform better and are associated with less proximal migration when a portion of the ilium is left intact. Use of the saddle prosthesis requires an adequate amount of ilium to which to anchor the device. Similarly, allograft-prosthetic composites depend on an adequate foundation of bone on which to place plates and screws to fix the allograft to the host bone.

**Compound Resection**
Resection of abdominal viscera along with the bony pelvis is indicated in rare cases. These so-called compound resections require coordinated care with general surgery, urology, and plastic surgery staff as necessary. Traditionally, such reconstruction has been avoided in these cases because these resections constitute so-called clean-contaminated procedures (ie, class II surgical incisions according to the American College of Surgeons wound classification) and carry a significantly elevated risk of postoperative infection.

**Soft-tissue Considerations**
In any resection, soft-tissue reconstruction is an important component that is easily overlooked. Most pelvic resections and hemipelvectomies require elevation of the abdominal wall off the bone. After resection, if enough bone remains with acceptable tension, repair should be performed using non-absorbable suture through drill holes. The presence of a larger defect requires that the gap be spanned with a Gore-Tex sheet or other mesh in order to minimize the risk of herniation of abdominal content. A plastic or general surgeon may be required to assist.

**Future Directions: Computer-aided Tumor Resection**
Complex pelvic resections are ideal for computer-aided or -navigated assistance, given the proximity of vital structures and the complexity of the bony and soft-tissue anatomy of the region. The addition of intraoperative navigation has the potential to improve the accuracy of the resection margins.

Navigation could be useful in cases in which allograft is used in the reconstruction of a pelvic defect. This would allow for precision in size matching and placement of the allograft to the defect as well as in hardware placement, thereby theoretically decreasing the nonunion rate seen in this reconstruction.

Although the technological advances in these applications are promising, the indications are evolving and the technology is costly to incorporate and currently is reserved for experimental use at tertiary centers.

**Complications**
Although the mortality rate associated with hemipelvectomy is relatively low, the rate of associated morbidities is high. The literature regarding complications following hemipelvectomy is limited. The rate of postoperative complications ranges from 20% to 50%.

Wound infection and flap necrosis are the most common complications for both hemipelvectomies and pelvic resections. In their examination of the complications of 160 consecutive hemipelvectomies, Senchenkov et al found increased surgical time and complexity to be associated with increased rates of wound infection and flap necrosis. Flap necrosis was most commonly associated with common iliac vessel ligation. Complication rates for pelvic resections vary based on the complexity of the procedure. In a review of 27 saddle prosthetic reconstructions, Aljassir et al reported that infection occurred in 37% of patients. Given the great likelihood of complications associated with hemipelvectomies and pelvic resections, patients should be counseled on the potential predictable complications and negative outcome.

**Outcomes**
Few studies have addressed the functional outcomes of hemipelvectomies, and there is no standard against which to measure outcome scores. The Medical Outcomes Study 36-item Short Form, TESS, and MSTS are the most commonly used instruments. The TESS and MSTS were originally designed to assess functional outcome following limb salvage of tumors about the knee. There is no validated scoring system for assessing function following pelvic resection, and the TESS and MSTS have been applied empirically to assess function. Especially when performed to address malignancy, both hemipelvectomies and limb salvage pelvic resections lead to decreased functional and quality-of-life outcomes.
In a retrospective review, Beck et al30 found functional and quality-of-life outcomes to be similar between the 39 patients who underwent pelvic resection and the 58 treated with hemipelvectomy. The only statistically significant difference between the pelvic resection and hemipelvectomy groups was that patients with hemipelvectomies had better transfer ability at hospital discharge; however, they also had increased pain and bladder dysfunction at follow-up. Although few patients had independent functional status at discharge, patients in both groups had similar independent function at follow-up. Given the dramatic variability in pelvic tumor cases, however, it is important to note the potential loss of bowel and bladder function; this finding is more common with hemipelvectomy than with pelvic resection.

Summary

The main indication for pelvic resection (ie, internal hemipelvectomy) and hemipelvectomy is primary malignant tumors of the pelvis; in rare instances, these procedures may be indicated for metastatic lesions, infection, or trauma. The extent of the resection and remaining structures dictates reconstruction options. The current trend is to leave the hip flail; however, successful reconstruction can maintain limb length and maximize function, although it is associated with a higher complication rate. Hemipelvectomies are usually left unreconstructed, but reconstructing the pelvic ring may afford some benefits. Overall, the procedure is technically demanding and requires a thorough knowledge of pelvic anatomy and proximity of vital structures to minimize complications. Appropriate preoperative counseling with the patient and family is paramount to explain the magnitude of the procedure, common complications, and predicted functional loss.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, reference 20 is a level I study. References 8, 14, and 19 are level II studies. References 10-13, 18, 22, 25, 26, and 28-30 are level III studies. References 1-4, 15, 21, 24, and 27 are level IV studies. References 6, 9, and 16 are level V expert opinion.

References printed in bold type are those published within the past 5 years.


