2 The History of Pelvic Tumor Surgery

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2.1 Introduction

The field of pelvic tumor surgery has advanced over the last 125+ years; this progress has been based on advances in several related areas of medicine:

- Improved anesthesia and perioperative care capabilities.
- Greater understanding of sarcomatous disease processes and margins.
- Improved imaging capabilities, particularly the use of computed tomography and magnetic resonance imaging.
- The development of adjuvant chemo- and radio-therapy.
- Expansion of orthopedic resections to locally advanced visceral disease processes.
- Critical examination of patient results and outcomes.

At present, most patients with localized pelvic sarcomas are candidates for curative resection, although high immediate and long-term morbidity remains inherent to these procedures. As well, the majority of patients are candidates for limb salvage operations. Several controversies remain in the selection and management of patients for these aggressive surgeries.

2.2 Early History

The first known attempted hemipelvectomy was by Bilroth in 1891 with a fatal outcome from hemorrhagic shock [1]. A subsequent successful operation (for advanced tuberculosis of the hip) was performed in 1900 by Hogarth-Pringle and is the first reported in the English literature [2]. Kocher described the first limb sparing pelvic excision in the late nineteenth century [3], but Putti provides the first well-documented case of internal hemipelvectomy in 1914 with successful outcome [4].

Speed popularized the term "hemipelvectomy" to describe radical amputation through the pelvis and replace the cumbersome "inter-ilio-abdominal amputation," while Gordon-Taylor referenced the procedure as a "hindquarter amputation" [5, 6]. The modern term "internal hemipelvectomy" to describe limb sparing approaches was first reported by Eilber in 1979 [7], and by analogy amputative resections are often referred to as "external hemipelvectomies" in contemporary practice.

The early twentieth century publications were primarily case reports or small case series which emphasized the surgical anatomy of approaches with relatively little data on patient outcome

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beyond mortality [6, 8]. Initially, operative mortality remained prohibitively high during the first half of the twentieth century. Gordon-Taylor reported operative mortality in 31 of 55 patients (56%) treated with hemipelvectomy for sarcoma or tuberculosis in 1934 and described the procedure as "one of the most colossal mutilations practiced on the human frame" [5, 9]. This operative mortality decreased to 22% in a later report as their team gained experience [10]. The decrease is likely due to a combination of team experience and improved perioperative care.

2.3 Advances in Disease Understanding

The mid-twentieth century brought significant advances in the scientific understanding of sarcomatous disease processes and the treatment of tuberculosis (an early indication for major pelvic resection). This included the establishment of sarcoma diagnostic categories and a tabulation of the natural history of conditions. For example, Dahlin and Henderson enumerated the basic treatment principles of chondrosarcoma in 1956 which remain true for the treatment of pelvic chondrosarcomas to this day [11]:

1. An adequate biopsy specimen for diagnosis should be obtained.
2. The definitive operation that is carried out is performed in such a manner that the biopsy wound will be excluded from the incision and will be removed with the specimen or limb, or both, without being opened again.
3. The tumor itself should be completely excised with a zone of surrounding tissue so that the surgeon does not break into or see the tumor at any time.

Dahlin and Henderson documented the difficult and morbid course of tumor recurrence as justification for aggressive initial treatment. They noted that only 3.4% of patients with inadequate surgical treatment survived or remained disease-free at 10 years, while 41% of patients treated according to these principles remained disease-free, a decade or more after surgery. This work remains one of the first and clearest tabulation of the principles of bone sarcoma resection and the greater than tenfold increase in survival seen with proper treatment.

Similar results accrued in other bone sarcomas and in soft tissue sarcomas to define the strong importance of proper biopsy and en bloc resection techniques in the treatment of sarcomas [12, 13]. Enneking, a pioneering pelvic sarcoma surgeon who helped usher in the modern era of treatment, tabulated and popularized these principles to guide sarcoma surgery in general [14]. The accumulating experience which helped to define disease processes and these principles and the dissemination of them to surgeons helped propel the role of surgery as a part of curative treatment protocols for pelvic neoplasms.

2.4 Imaging Advances

The imaging of pelvic sarcomas remains complex today, even with the variety of advanced imaging modalities available. The first pelvic tumor surgeries were based on plain film radiographs, physical examination, and surgical exploration. Later surgeons used plain film tomograms to better image the bone in combination with catheter angiograms and barium enemas to infer soft tissue extension [15]. Bone scans were incorporated as well but lacked spatial resolution.

The lack of imaging frequently lead to poorly placed biopsies, inadequate margins, and poor outcomes. Enneking's large series published in 1978 (patients operated between 1957 and 1977) revealed that one-third of patients treated with pelvic resections had oncologically inadequate surgeries for these reasons [16]. Tumor recurrence was seen in 100% of patients with inadequate surgeries. The certain morbidity of these procedures and far from certain surgical outcomes naturally tempered the enthusiasm of physicians and patients alike in selecting aggressive management of pelvic sarcomas.

The advent of computed tomography in the 1970s significantly improved the ability to image patients with pelvic tumors [17, 18]. CT imaging

provided surgeons with two primary benefits. First, it allowed much improved anatomic definition of the extent of pelvic sarcomas to define their osseous and soft tissue extension as well as visceral relationships. Second, CT scans of the chest provided improved sensitivity to detect pulmonary metastases compared to chest radiographs or lung tomograms. This second benefit allowed teams to more reliably exclude from surgery patients with established metastatic disease. CT became widely available at regional tumor centers in the early 1980s. In a similar fashion, magnetic resonance imaging provided additional anatomic discrimination of tumor extent and became widely available by 1990 [19]. In the recent two decades, positron emission tomography has similarly increased the ability of physicians to properly stage sarcoma patients [20].

These imaging advances improved the ability of surgeons to assess patients for resectability, decrease inadvertent positive margins, and to avoid morbid surgery on patients with metastatic disease. The current imaging of pelvic sarcomas is center-specific but typically combines CT and MR imaging of the local disease with CT of the chest and bone scan (or potentially PET) for staging.

2.5 Adjuvant Treatments

The three most common bone sarcomas encountered in the pelvic region include chondrosarcoma, osteosarcoma, and Ewing's sarcoma. Chondrosarcoma remains stubbornly resistant to any known adjuvant treatment, with prognosis heavily influenced by grade and surgical margin for patients with localized pelvic tumors [21]. However, dramatic advancements in chemotherapy have improved the prognosis for patients with osteosarcoma and Ewing's sarcoma.

Prior to adjuvant chemotherapy, the survival of clinically localized osteosarcoma was <15% [12]. While specific survival rates for pelvic osteosarcoma in the prechemotherapy era are not reliably recorded, these tumors are known to carry an even worse prognosis than extremity tumors, and it is reasonable to infer that long-term disease-free survival was rarely achieved in these patients.

The advent of doxorubicin-based chemotherapy immediately and dramatically improved the survival of patients with osteosarcoma [22]. These advances provided a meaningful potential for survival for patients with high-grade axial sarcomas and opened the door to consideration of aggressive surgical treatment for what had generally been considered a fatal disease. Parallel advances were made in the treatment of Ewing's sarcoma during this era as well [23].

Simultaneous advances were made in the understanding of the use of radiotherapy for pelvic Ewing's sarcoma [24]. Because of the uncertainties of imaging, margin, and prognosis, the majority of patients with Ewing's sarcoma of the pelvis were treated with radiation therapy for local control. Greater enthusiasm grew for surgical management of pelvic Ewing's tumors (with or without radiation) in the 1980s and 1990s with improved imaging, although this remains a controversial aspect of pelvic sarcoma treatment [25, 26].

2.6 Application to Visceral Diseases

While initially associated with high morbidity, the same conditions which led to advances in pelvic sarcoma surgery provided parallel advances in surgery for pelvic visceral diseases [27]. This allowed for the identification of a subset of patients with locally advanced visceral malignancies and musculoskeletal involvement and no distant metastases; typical examples would be locally advanced primary or recurrent colorectal cancer invading the sacrum or gynecologic malignancy invading the pelvic sidewall or ilium with no distant tumor spread.

Musculoskeletal involvement of visceral malignancies had traditionally been considered a marker of unresectability. However, by combining the advancing understanding of tumor biology and pelvic resection techniques, extended en bloc resections of visceral disease and involved musculoskeletal structures began in the

mid-1980s to provide curative treatment for select patients [28, 29]. While initially limited to patients with modest osseous involvement, expanding experience showed that reasonable oncologic results and survival could be obtained even with extensive resections [30]. At present, extended pelvic exenterations (en bloc resection of the visceral malignancy and associated musculoskeletal structures) are now offered at select cancer centers with reasonable patient morbidity and oncologic outcome. As is seen in virtually all pelvic tumors, margin status is a key determinant of outcome, highlighting the role of aggressive resections in curative intent procedures.

2.7 Collaboration and Examination of Results

A key aspect of surgical and scientific advancement is the collaborative sharing and critical examination of results. In parallel with the development of the field of pelvic sarcoma surgery, several professional organizations formed to improve progress and better evaluate the outcomes of patients with musculoskeletal malignancies. Notable organizations in this field include:

- The Musculoskeletal Tumor Society (MSTS, est. 1977)
- The International Society of Limb Salvage (ISOLS, est. 1981)
- The European Musculoskeletal Oncology Society (EMSOS, est. 1987)
- The Connective Tissue Oncology Society (CTOS, est. 1995)

These multidisciplinary professional organizations have (and continue) to actively advance the practice and understanding of pelvic tumor surgery. A prime example of this is the evaluation system for the systematic evaluation of patient outcomes initiated at the inception of ISOLS in the 1981 meeting. This culminated in the standard MSTS outcome instrument for evaluating the results of musculoskeletal tumor surgery [31] which remains in use to this day.

2.8 Current Practice in Pelvic Tumor Surgery

Modern imaging now allows reliable determination of tumor extent and the overt metastatic status of patients presenting with pelvic malignancies. As well, current practice provides for limb sparing resections in the majority of patients. The common nomenclature for amputative resections is either "external hemipelvectomy" or "hindquarter amputation." Limb sparing resections are termed "internal hemipelvectomies" and classified as outlined by Enneking and Dunham as to involvement of the iliac bone, acetabulum, or pubic region [16]. Clinical outcome assessment is still most commonly performed using the Musculoskeletal Tumor Society rating scale [31], although more generalizable patient reported outcomes are becoming more common.

Time and institutional practice patterns have seen different approaches and shifts in the management of pelvic sarcoma patients. The initial management of these patients focused on tumor removal alone; reconstruction was rarely used and difficult with the techniques available [7]. Recent reports have demonstrated the enduring value of this technique, and it remains a viable surgical option in contemporary practice [32].

However, other centers have demonstrated improved functional results with restoration of femorosacral continuity (anatomic reconstruction or substitution) following limb sparing resection in the pelvis [33]; this is most difficult in resections which remove the acetabulum.

A number of different approaches have (and continue) to be used in these patients. While cemented and reinforced conventional arthroplasty constructs have been reported (commonly referred to as the Harrington technique), they are most commonly used after surgery for periacetabular metastases which typically remove less bone than a primary tumor excision with oncologic margins [34]. Iliofemoral arthrodesis was initially performed for these patients but remained technically challenging with pseudarthroses and modest functional outcomes [35].

Early anatomic reconstruction experience utilized massive pelvic allografts or processed

autograft for reconstruction [36]. These reconstructions were technically demanding and suffered high complication rates. The saddle prosthesis, an adaptation of an implant for massive bone loss after failed or infected hip arthroplasty, was utilized in tumor resections in an attempt to provide a reconstructive option utilizing a modular endoprosthesis [37]. However, greater experience and follow-up have highlighted the limitations of this method, and its use in current practice is rare [38].

Modern techniques of periacetabular reconstruction include modular endoprostheses, custom prostheses, and porous tantalum implants [39, 40]. Each of these techniques has relative advantages and disadvantages based on resection and remaining bone stock as well as center experience and preferences. The use of intraoperative navigation or preprinted custom cutting guides allows precise resections to be made to match prefabricated implants.

Not all pelvic resections are commonly considered for reconstruction. While reconstructions have been reported following pubic resections [41], most centers provide soft tissue reconstructions only for these resections. Controversy exists as to whether resections of the supra-acetabular ilium require reconstruction or not. Some centers advocate for no reconstruction to minimize complications and allow medialization of the hip center to decrease Trendelenberg gait (at the expense of leg length discrepancy) [42]. Other centers have shown good results with reconstruction of these defects [43].

Despite advances on many fronts, there remains a role for external hemipelvectomy/hindquarter amputation in current clinical practice [44]. Patients are currently considered for hemipelvectomy in three primary scenarios:

1. En bloc resection of a tumor would leave a limb with such little function as to make amputation preferable. This primarily occurs when tumor extent would require removal of two or three of the critical elements of limb function (the sciatic nerve, the femoral neurovascular bundle, and the acetabulum).
2. Patients in whom resection will result in a soft tissue defect so large that the wound cannot be closed without the benefit of an amputation flap. With increasing experience with free flap coverage and the use of omentum for closure, this scenario is becoming less common.
3. For salvage of patients who experience tumor recurrence following internal hemipelvectomy.

While many teams have been pessimistic about patient function following external hemipelvectomy, modern prosthetic management can allow single hand-free ambulation for many individuals [45].

2.9 Contemporary Issues in Pelvic Tumor Surgery

Despite the large number of advances made since the first reported attempt at hemipelvectomy in 1890, a number of areas of pelvic tumor surgery remain unresolved. The need for (and if performed method of) bony reconstruction after major pelvic bone resection remains unclear. Reconstruction appears to offer better function at the price of higher complications, but selection and center treatment bias clearly influence these results. True long-term follow-up studies of patients are rare and show an expected decline in function in long-term survivors of their malignancies [46].

The uncertainties of the role and method of reconstruction are magnified in pediatric patients in whom little published literature exists to guide surgeons [47]. Most children undergoing major pelvic surgery have consideration of reconstruction for iliac defects. If the acetabulum is resected, consideration for reconstruction is given in older adolescents; young patients are generally treated with resection arthroplasty. While not strictly tabulated, the authors' clinical experience of this in young patients is generally favorable.

The role of amputation or limb salvage remains controversial. The criteria outlined above represent the classic criteria for hindquarter amputation, but some centers strive to avoid the morbidity of this by offering limb salvage to "borderline" cases. It is not clear which path provides better functional and oncologic outcomes.

Because of the morbidity of surgical resection, many centers try to employ radiotherapy when possible. This is most common in patients with Ewing's sarcoma in whom local control may be achieved with surgery, radiotherapy, or both. The combination of surgery and radiotherapy appears to decrease the risk of local failure [48]. Some studies have suggested improved survival with surgical treatment [25, 26, 49]. However, others have not shown a clear benefit [50]. No studies randomize patients between treatment arms. In addition to Ewing's sarcoma, some groups have attempted to employ high-dose proton-based radiotherapy to achieve local control of otherwise adversely presenting pelvic sarcomas with some success [51]. To date, the authors' personal experience with this for non-Ewing's tumors has been uniformly poor.

The timing of chemotherapy around major pelvic resections is an area of concern. It is established in extremity osteosarcoma, for example, that delays in resumption of chemotherapy after surgery negatively impact survival [52]. Additionally, a prospective randomized trial showed no difference in oncologic outcomes in osteosarcoma treated with immediate surgery followed by chemotherapy compared to a standard regimen of preoperative chemotherapy, surgery, and postoperative chemotherapy [53]. The magnitude (and complication profile) of large pelvic tumor surgeries is such that patients are at high risk to experience significant postoperative delays in chemotherapy resumption. This has led some centers (including the authors') to complete most or all chemotherapy prior to surgical resection in select pelvic sarcoma patients judged to be at high risk for perioperative complications. It must be stated that data regarding this practice are still being gathered, and patients undergoing "front-loading" of chemotherapy are carefully monitored with serial imaging studies for disease response.

Finally, readers should know that the oncologic staging of pelvic sarcomas has recently changed. An analysis by the American Joint Commission on Cancer (AJCC) highlighted the adverse prognosis of axial location on sarcomas. In light of this, the recently released eighth Edition AJCC Staging Manual has incorporated anatomic location in the staging of bone sarcomas (with specific criteria for pelvic tumors) in an attempt to better predict the clinical outcome of these difficult cases [54]. Accumulating data will hopefully demonstrate whether this change has value in clinical care.

2.10 Conclusions

The field of pelvic tumor has undergone a series of advances since the first major pelvic resections were undertaken over a century ago. Modern imaging, improved disease understanding, and adjuvant therapies are the pillars of these advancements. However, the morbidity of these treatments remains formidable and the prognosis guarded. Unfortunately, the words of Gordon-Taylor, a pioneering pelvic tumor surgeon, remain true in this field over a half century after they were written [9]:

> *I still cherish the hope of a golden era of cancer therapy when gross mechanical destruction of disease and cruel mutilation of tissue shall be no more. Unfortunately, these times are not yet.*

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