A new type of reconstruction of the hemipelvis after Type 3 amputative sacrectomy using pedicled fibula

Technical note

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This is a technical note of pelvic reconstruction performed by an advanced multidisciplinary team. The authors report a new 3-stage reconstruction of the hemipelvis after Type 3 sacrectomy involving instrumented spinopelvic arthrodesis and pedicled fibula grafting in 2 patients.

The anterior stage of the procedure begins with a transabdominal approach to mobilize the viscera and to free up the tumor from the vessels. The posterior divisions of internal iliac vessels, the middle sacral vessels, and the lateral sacral vessels are then ligated. An anterior vertebodyectomy is done at the appropriate level, followed by an anterior osteotomy through the lateral planed surgical margin of the sacrum close to the salvaged sacroiliac joint. The second stage includes a major sacral resection with lower-extremity amputation from the pubic symphysis through the intact side of the sacrum, ipsilateral pedicled fibula harvesting, and closure with an ipsilateral pedicled quadriceps flap. The final stage involves reconstruction with lumboiliac instrumentation. The pedicled fibular graft left from the second stage is then placed distally within the previously created iliopectineal docking site and proximally within the L-5 docking site.

The authors believe that this is a feasible and reproducible technique with theoretical advantages that have to be proved in the long-term follow-up.

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Key Words • reconstruction • sacrectomy • fibula • sacral • vascularized tumor • pelvis

Sacral tumors are frequently large and are close to important anatomical structures, a combination that makes their resection problematic. In the past, resection of such tumors was associated with a local recurrence rate of up to 75%,10,49,50,52 This was attributed to the large tumor volume by the time of the diagnosis, the poor margination of the lesion, and the surgically challenging anatomical location.4,5,8,21,23

Fundamental goals of surgical treatment remain to remove the tumor safely with clear margins and to maximize postoperative function. Total sacrectomy is a surgical procedure used for tumor resections, resulting in significant neurological deficit regardless of the type of reconstruction.4,5,8,21,23,58 The type of sacral resection required to achieve local control will vary depending on the location, extent, and type of tumor. The level of sacrectomy is usually predictive of the resultant neurological deficit. Sacrifice of the S2–4 nerve roots bilaterally results in urinary and fecal incontinence, and impotence for males.5,20,51 Unilateral preservation of the S-2 root maintains bowel control, whereas bilateral S-2 nerve root preservation may only cause mild and reversible urinary sphincter dysfunction.21 Fortunately, lower-extremity function is only minimally, and certainly not functionally, affected with even total sacral root division.

Four different types of spinopelvic resection including the sacrum have been described46 (Fig. 1), with Types 3 and 4 being amputative. The subsequent development of instability or spinal deformity and the need for primary or secondary spinopelvic fusion after these operations is controversial.9,21,44,45 The extent of resection determines the functional deficit and influences the decision regarding the type of reconstruction, if any, that is recommended to optimize function. Many types of partial sacrectomies are well...
tolerated without the need for reconstruction. In the case of an external hemipelvectomy coupled with a hemisacrectomy, if the majority of the lumbosacral articulation is resected, patients likely benefit from instrumented spinoiliac fusion. However, total or nearly total sacrectomies with external hemipelvectomy necessitate a type of spinopelvic fusion. However, total or nearly total sacrectomies with external hemipelvectomy necessitate a type of spinopelvic fusion to allow load transition through the hemipelvis to the lower extremity. Several methods of reconstruction with various functional results, but also complications, have been described so far. Fibular grafting of the pelvic girdle after tumor resection has been previously described either as a free vascularized autograft or as nonvascularized allograft or autograft.

We report a new 3-stage Type 3 sacrectomy and reconstruction of the hemipelvis involving instrumented spinoiliac arthrodesis and pedicled fibula grafting in 2 patients. The first patient (Case 1), a 39-year-old woman who had a primary bone tumor of the sacrum (fibroblastic sarcoma) with a pelvis extension (Fig. 2), underwent a standard procedure. The second patient (Case 2), a 30-year-old man, underwent an extended version with additional visceral resections for a recurrent adenocarcinoma of the rectum with local extension into the sacrum and right sciatic nerve encasement (Fig. 3).

Methods

Indications

The primary indication for 3-stage Type 3 sacrectomy and reconstruction with pedicled fibula grafting is a primary sacral tumor with a hemipelvis extension requiring a Type 3 or 4 sacrectomy. Secondary indications include intraabdominal visceral tumors with local extension to the sacrum, requiring leg amputation either due to a major neurological deficit or hemipelvis infiltration.

Surgery and Technical Considerations

This is a multidisciplinary surgical intervention that includes colleagues from urology, vascular surgery, general surgery, colon and rectal surgery, orthopedic oncology, neurosurgery, plastic surgery, and spinal surgery.

Bowel preparation is done the evening before surgery. Diversion colostomy is not routinely necessary, and should only be considered if there is a possibility of violating the tumor’s margins when dissecting the rectum from the front of the sacrum or when the tumor involves a primary lesion of the rectum with local extension into the sacrum. Ureteral stents are inserted preoperatively for identification of the ureters during dissection. Central venous access with large bore catheters is obtained in the event that rapid transfusion of fluid is required during the procedure. Broad-spectrum antibiotics that cover skin and bowel flora are administered preoperatively at every stage. The procedure is done in 3 stages. The first stage involves an anterior approach to free up the ventral structures from the tumor in the presacral space and to perform a diversion colostomy and an ileal conduit urinary diversion, if necessary. The second stage is performed 4 days later, and it includes an external hemipelvectomy with an up to nearly total sacrectomy and a pedicled flap of leg flaps including the anterior thigh flap together with a pedicled fibula. Finally, a posterior approach is performed with the patient in the prone position to accomplish a spino-hemipelvis reconstruction. This is done 3–4 days after adequate resuscitation and recovery from the resection.

Stage 1: The Anterior Approach. Standard Procedure. The anterior stage of the procedure begins with a transabdominal approach. The descending colon and rectum are mobilized and displaced anteriorly and to the patient’s right. The iliac vessels and ureters are mobilized and protected. The posterior divisions of the internal iliac vessels, the middle sacral vessels, and the lateral sacral vessels are then ligated. The dissection is carried proximally to expose fully 1 level above the lowest involved vertebral body and to free up the vascular structures anteriorly at that level. The proximal margin of resection was the upper S-1 endplate in one patient and the lower L-5 endplate in the other patient. Adherent structures, if any, are left with the specimen and are removed en bloc through the lateral approach. An anterior disectomy is then done at the appropriate level, followed by an anterior osteotomy through the lateral planed surgical margin of the sacrum closed to the salvaged sacroiliac joint. An oval receptacle is then created in the healthy ilium to receive the fibular graft distally (Fig. 4). The receptacle should be placed at the intersection of the iliopectineal line and an imaginary straight line that connects the center of the lowest uninvolved vertebral body and the center of the hip joint. This facilitates placement of the pedicled...
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A fibular graft after tumor removal. An osteotomy through the pubic symphysis is then performed prior to anterior wound closure.

In cases of recurrent visceral tumor (rectal adenocarcinoma), appropriate additional resections should be performed at this stage (hemicolecction).

Stage 2: Tumor Resection—Extended Hemipelvectomy. Standard Procedure. Four days following Stage 1, the patient is positioned in the opposite lateral decubitus position for nearly total sacral resection with lower-extremity amputation from the pubic symphysis through the intact side of the sacrum, ipsilateral pedicled fibula harvesting, and closure with the ipsilateral pedicled quadriceps flap.

A posterolateral thigh incision extending up to the lumbar spine and distally just superior to the metaphysial flare of the femur is performed. The blood supply of the anterior thigh flap is primarily based on the descending branch of the lateral circumflex femoral artery. The center of the flap is located over the course of the common and superficial femoral vessels. The distal end of the flap is marked at the level of the adductor hiatus, utilizing the vast majority of the quadriceps femoris muscle and overlying skin so that the flap could reach the level of the umbilicus. Following incision of the fascia covering the superficial femoral vessels, these vessels are ligated and divided just before passing through the adductor hiatus. The quadriceps muscle is divided distally to the surface of the femur and is stripped off the entire length of bone. Dissection is then carried out on the deep surface of the

Fig. 2. Case 1. Transverse CT image (A), coronal CT image (B), and models (C and D) showing tumor extension in a 39-year-old woman with fibroblastic osteosarcoma of the left ilium with extension to left sacroiliac joint and left sacrum.

Fig. 3. Case 2. Transverse (A) and sagittal (B) MR images showing tumor extension to the right ilium, right sacroiliac joint, and sacrum obtained in a 30-year-old man with recurrent colorectal cancer.
superficial femoral vessels until the profunda femoris vessels are encountered. The profunda vessels are ligated as they pass between the pectineus and the adductor longus, and the medial circumflex vessels are ligated as they pass between the psoas major and adductor longus muscles. The proximal part of the profunda vessels and their lateral circumflex branches are preserved with the flap.

A direct lateral approach to the ipsilateral fibula is the next step to accomplishing harvesting with the peroneal artery, which is carefully dissected to meet the vessel’s origin from the posterior tibial artery and then to free the popliteal artery through the adductor hiatus to the femoral artery origin. All branches in between as well as distally, including the posterior and anterior tibial arteries and the inferior and superior genicular arteries, are ligated. The fibula is then osteotomized distally and proximally to the desired length. The dissection is then taken around the medial aspect of the thigh through the adductors’ compartment and up through the perineum. Part of the sartorius is preserved; the remainder of the adductor compartment is left behind. The osteotomized pedicled fibular graft is then passed carefully through the adductor hiatus to the medial aspect of the anterior thigh flap (Fig. 5). A small hole is drilled in the fibula and it is sewn into the flap to keep the pedicle from kinking. The anterior thigh flap is then swung superiorly and anteriorly and laid carefully on a support. The femoral nerve is protected throughout the course of dissection such that the flap will be sensate for the patient.

The dissection is then taken posteriorly along the opposite side of the sacrum to the lumbar spine. The sacrospinous and sacrotuberous ligaments are incised along with the origin of the gluteus maximus muscle. The contralateral sciatic nerve is identified and protected, and the perineal and rectal layers are elevated anteriorly from the sacrum. Finally, the dissection is taken from posterior to anterior along the ipsilateral iliac crest. The proximal margin level is verified using fluoroscopy, and L-4 and L-5 laminectomies are performed. The contralateral L-5 and S-1 nerve roots are preserved, while the ipsilateral L-5 and S-1 nerve roots and the remaining dural sac are divided and double tied. Then, the posterior spinal dissection is taken around to the front, and the proximal together with the lateral intact margins are osteotomized to separate the sacrum from the opposite hemipelvis. After this dissection, the tumor specimen, including the limb and innominate bone, the sacrum, and sometimes part of the vertebra and viscera, is removed en bloc. The proximal femur from the amputated limb is then removed—if it is not involved—and saved in a sterile manner for the third stage. Suction drains are placed in the pelvis, and the wound is closed with the anterior thigh flap. Postoperative imaging studies demonstrate the extent of bone resection and the “floating fibula” on vascular pedicle awaiting reconstruction (Fig. 6A and B).

Additional procedures for complicated cases involving viscera could include a cystoprostatectomy for en bloc resection of tumor including the leg, the sacrum, the bladder, and the rectal stump. Intraoperative radiotherapy

**Fig. 4.** Schematic illustrations. A: The oval receptacle for pedicle fibula graft is placed at the intersection of the iliopectineal line (divides the pelvis into the pelvis major above and the pelvis minor below) and an imaginary straight line that connects the center of the lowest uninvolved vertebral body and the center of the hip joint. B: Using a high-speed bur the oval receptacle is created at the iliopectineal docking site. C: The pedicled fibular graft left from the second stage is placed distally within the iliopectineal docking site in between the sciatic nerve and the iliac vessels (distally) and within the L-5 docking site proximally. Copyright Mayo Clinic. Published with permission.

**Fig. 5.** The pedicled fibular graft is passed carefully through the adductor hiatus to the medial aspect of the anterior thigh flap.
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Stage 3: Posterior Approach—Reconstruction. For the reconstruction, bilateral pedicle screws are placed in the last 2 caudal vertebrae. An oval receptacle is created using a high-speed bur in the center of the inferior aspect of the lowest remaining vertebral body. One or two iliac screws are inserted in the residual ilium cephalad to the fibular docking site, and one screw is inserted caudally into the body of the ischium to provide the distal fixation. The pedicled fibular graft left from the second stage is then placed distally within the previously created iliopectineal docking site in between the sciatic nerve and the iliac vessels (distally) and within the L-5 docking site proximally. The longitudinal rods are bent and positioned, and the construct is compressed before tightening the rod-screw fixation nuts. The saved bone autograft is placed at the distal and proximal graft-host sites and over the L-4 and L-5 transverse processes to facilitate solid bony arthrodesis. Two cross-links are then placed along the construct (Figs. 6C and D and 7).

Postoperative Course and Rehabilitation

The patient returns to the intensive care unit for postoperative optimization before being discharged to the ward. Physical therapy begins on the 2nd postoperative day and includes respiratory exercises, passive-assisted range of motion of the hip and knee joints, and active range of motion exercises of the upper extremities. Single leg gait is allowed 3 months postoperatively.

Unfortunately, the patient who experienced a recurrent rectal carcinoma (Case 2) died of disease 4.5 months postoperatively. The 39-year-old patient with the fibroblastic osteosarcoma (Case 1) remains disease free at the 2-year follow-up. The last follow-up plain radiographs obtained in both patients demonstrated satisfactory spinopelvic reconstruction and stability (Figs. 8 and 9).

Discussion

With the evolution of imaging and surgical techniques, implant technology, and neoadjuvant treatments, the ability to adequately resect tumors involving the pelvis has advanced greatly. The reconstruction of the large resultant defects remains problematic.
Bone malignancies of the sacroiliac joint spread to the nerves and hip before diagnosis.1,3,4 As a result, wide or even marginal resections require modified surgical approaches, and reconstruction is challenging. Amputative sacrectomies (Types 3 and 4) could possibly control tumor extension locally, but functional outcome can compromise patients’ overall satisfaction. In the past, the defects created by these procedures were closed primarily, resulting in wounds subjected to considerable tension and high rates of complications, such as wound dehiscence, hematoma, flap necrosis, and infection. Hence, pedicled or free musculocutaneous flaps have been used to tackle wound complications.34,36,37 The vertical rectus abdominis muscle flap (VRAM) is increasingly becoming more popular in the closure of large sacral defects given its abundant supply of well-vascularized tissue, reliability, and simplicity of dissection.17,53

After a partial sacrectomy, the mechanical sufficiency of the lumbo-sacro-iliac articulation left is of seminal value.29 Gunterberg and colleagues25,27 studied the biomechanical effects of transverse partial sacrectomy using a cadaveric model with an axial load applied to the lumbo-sacral junction. In those studies, transverse amputations of the proximal sacrum, especially those that involve the sacral ala, significantly weakened the ability of the spinopelvic segment to resist vertical loading. We believe that total or nearly total sacrectomies with external hemipelvectomyc necessitate some kind of spinopelvic reconstruction to allow load transition through the hemipelvis to the lower extremity for a functional single-leg gait. Previous methods of spinopelvic reconstruction were aiming for a relative instrumented stabilization of the lumbar spine to the ilia, bridging the gap between the ilia and the most caudal vertebral body with nonstructural bone graft.52 The bone graft did not provide immediate structural continuity between the spine and the pelvis, and it had multidirectional loading during its progression toward an anticipated fusion. Structural grafting has been previously reported to have biomechanical advantages when placed along the force transmission lines between the base of the most caudal remaining vertebra and the hip joint, creating a triangular construct that results in compression at the proximal and distal docking sites of the structural graft and the host bone. The stability of the construct is directly related with the forces applied as well as the time frame that those forces load the instrumentation. This means that implants are subject to failure by the time a solid fusion is achieved; hence, the likelihood of construct failure is inversely proportional to this time.

The hypothesis of our method is that a vascularized structural autograft possesses the best features biologically and biomechanically to accomplish a bony fusion within the shortest time. Vascularized bone flaps have been previously used to facilitate bone healing in cases of bone nonunions and large bony defects resulting either from trauma or from tumor excisions.12,13,56,70 These flaps have been demonstrated to be effective in patients with a compromised ability to heal, such as patients receiving chemotherapy.12,13

Vascularized fibula has been repeatedly and reproducibly used for bony reconstruction in multiple areas, including the pelvis, spine, humerus, and femur.7,9,11,14–16,20,24,30,39,48,61 Usually a free vascularized fibula flap is used.7,11,48,61 Autologous bone reconstruction of the pelvis using fibula has been described in the literature.2,11,18,40,48 Yajima and Tamai reported 2 cases of pelvic reconstruction using double-strut vascularized fibula flaps.59 Sakuraba et al.48 reported their experience with 5 cases of Type I and Type II hemipelvectomies that were reconstructed with double-barreled vascularized fibula flaps. In this series, flaps were successful in 4 patients, and 3 patients were able to ambulate independently. Nagoya et al.40 reported 4 total or near-total hemipelvectomies that were reconstructed with vascularized fibular flaps. Three of the 4 patients developed bone union within a maximum of 14 months after surgery. In this series patients were reported to have no pain and were able to ambulate independently.

Pedicled fibular flaps are relatively new, and their use has been reported in certain areas but they are limited by the distance from their origin.9,14,24,30,39 To the best of our knowledge this is the first report of a remote pedicled fibular graft to the pelvis. This grafting procedure necessitates the preservation of the peroneal artery, popliteal artery, femoral artery, and external iliac artery, and thus is suitable for use along with an anterior VRAM flap, which is a pedicled flap that requires the salvage of the external iliac artery. The method is limited by certain factors that are related to the salvageable vascular supply, the quality of the vessels, and some technical issues, such as the size of the fibula.9,30,39 With regard to the blood supply, it is anticipated that the vascular pathway from the aorta to the peroneal artery should be savable and should not be involved in an oncological resection. That also means, as mentioned above, that an anterior VRAM flap must be used and there should be no contraindication, such as tumor extension or extensive radiation of the skin. Diabetes mellitus is a relative limitation, but certainly performing preoperative MR angiography is strongly recommended to assess the briskness of the blood supply. Nevertheless, the plastic surgeon should evaluate all patients preopera-
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tively for the feasibility of this seminal step. Fibula size could also be a technical limitation. It usually ranges from 24 to 28 cm, and this length is sufficient for most cases. A sizing issue could possibly arise if resection extends to L-4 or incidental shortening of the fibula occurs during the harvesting.

Nevertheless, the described method is a technically feasible procedure with certain indications and limitations. Undoubtedly, it is time consuming and requires a multidisciplinary surgical intervention, but, on the other hand, it promises biomechanical and biological advantages that need to be proved in the long-term follow-up.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Rose, Yaszemski. Acquisition of data: Starantzis. Drafting the article: Starantzis, Sakellariou. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Starantzis. Administrative/technical/material support: Rose, Yaszemski.

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