# Radiation Wounds and Their Management: Reconstructive Options

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## 1 Introduction

The most common cause of radiation injury is an adverse effect of therapeutic irradiation which is used to treat cancer and a few noncancerous diseases by utilizing high-energy particles or waves. Treatment is delivered via external beam radiation or by brachytherapy within the patient's body, although more rare, radiation-related wounds could also stem from occupational and environmental exposures as a result of physical contact with radioactive material.

The common pathway of injury, regardless of the source of radiation, is a structural damage to the DNA, which could lead to both acute and chronic tissue effects. DNA damage can induce apoptosis or aberrant replication and causes endarteritis, microthrombi, inflammation, and fibroblast dysfunction [1–4]. Microvascular injury leads to ineffective delivery of oxygen and nutrients. As a result of cellular changes and hypoxia, irradiated tissues heal slow and have a decreased capacity to resist infection.

Early effects after radiation exposure are similar to a thermal burn and include erythema, hyperpigmentation, edema, and desquamation. These are due to a transient increase in vascularity that peaks in the second week, gradually decreasing afterward [5]. Initial phase is usually self-limiting and resolves with minimal treatment, unless there is acute high-dose radiation, which could result in tissue necrosis. Superimposed infections may also complicate the clinical course necessitating additional treatment.

Chronic or late effects could manifest from weeks to decades after radiation exposure. These include tissue fibrosis, delayed wound healing, ulcers, lymphatic and blood vessel damage (microthrombi), malignant transformation, and bone necrosis. Irreversible fibroblast dysfunction results in permanent and progressive skin damage, decreasing wound tensile strength. The late term effects are disabling and even life threatening in some cases.

## 2 Initial Work-Up

Biopsy of long-standing ulcers should be done to rule out malignancy that might develop in setting of chronic wounds (Marjolin ulcer). If malignancy is present, a full cancer work-up is indicated with appropriate resection. Malignancies

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arising in irradiated beds are usually more aggressive and frequent follow-up is indicated.

Radiation injury generally extends beyond the visible field, necessitating a work-up of the condition of the underlying bone. Plain radiographs, computed tomography, magnetic resonance imaging, and biopsies are utilized as needed. Assessment of the bone is particularly important in chronic wounds with draining sinus tracts, which may indicate osteoradionecrosis.

Wound healing of oncologic patients may be impaired due to immunosuppression, malnutrition, and anemia, in addition to radiation-induced damage [6].General medical assessment is critical with optimization of nutritional parameters such as albumin and prealbumin prior to reconstructive surgery.

## 3 Conservative Management

Skin effects of acute radiation injury are amenable to supportive treatment, including protection from trauma and infection. Topical antibiotic ointments (i.e., silver sulfadiazine) could be used to prevent infections or to help recovery of partial thickness injury. Full-thickness necrosis is unlikely to heal with secondary intention and usually requires surgical reconstruction.

Use of hyperbaric oxygen treatment in radiation wounds is controversial. Even though it appears to be an attractive modality with potential increase in oxygen supply to tissues, stimulation of angiogenesis, and collagen formation, it is utilized as a supportive measure only due to lack of evidence of its benefits [7–10]. Another indication of hyperbaric oxygen treatment is for prophylaxis, such as when dental work is needed in a radiated field.

## 4 Surgical Management

### 4.1 General Principles

Even though surgeons are usually reluctant to operate in the irradiated field, surgery may be indicated for debridement and closure of radiation wounds or extirpation of recurrent tumors. Healing of radiation wounds is usually very slow if left to secondary intention due to minimal development of granulation tissue. As such, surgical intervention is generally required. Outcome of skin graft application to a radiated wound bed is at best unpredictable, and skin grafting generally is not advised. However, there is emerging evidence that with the advances in negative wound pressure therapy, successful results can be obtained [11]. A negative pressure dressing could be applied prior to reconstruction to optimize the wound or after skin grafting to enhance healing. Majority of the reconstructions will require a vascularized flap transfer from a regional or distant site that can provide new blood supply to the wound. The choice of flap depends on depth of the injury, tissues involved, presence of exposed vital structures, and anatomic location. Tissues that are free from radiation injury are preferred for reconstruction [4, 12].

Adequate debridement is the most critical step for a successful reconstruction. Debridement should include all nonviable structures until fresh bleeding is confirmed and existing foreign materials are usually removed [4]. Failure to do this may result in recurrent problems and infections. Zone of injury typically extends beyond the visible field which should be taken into consideration during debridements [13]. Another critical point is the amount of skin contracture present. Excision of radiated skin will result in a larger than anticipated defect due to fibrotic skin envelope.

Irradiated tissues are prone to bacterial contamination and wound breakdown. These problems can be reduced by planning prophylactic regional or distant flap use, should a need to operate on irradiated tissues without any evidence of wound arise (Fig. 1).

Meticulous tissue handling is essential in the irradiated field. Special care should be taken during free tissue transfer and microsurgery since blood vessels are fragile. Excessive bleeding is possible, and surgeons should be prepared for possible transfusions in debridement of large wounds. Microvascular anastomoses are preferably performed outside the zone of radiation where healthy recipient vessels exist. Close postoperative follow-up is also of importance in order

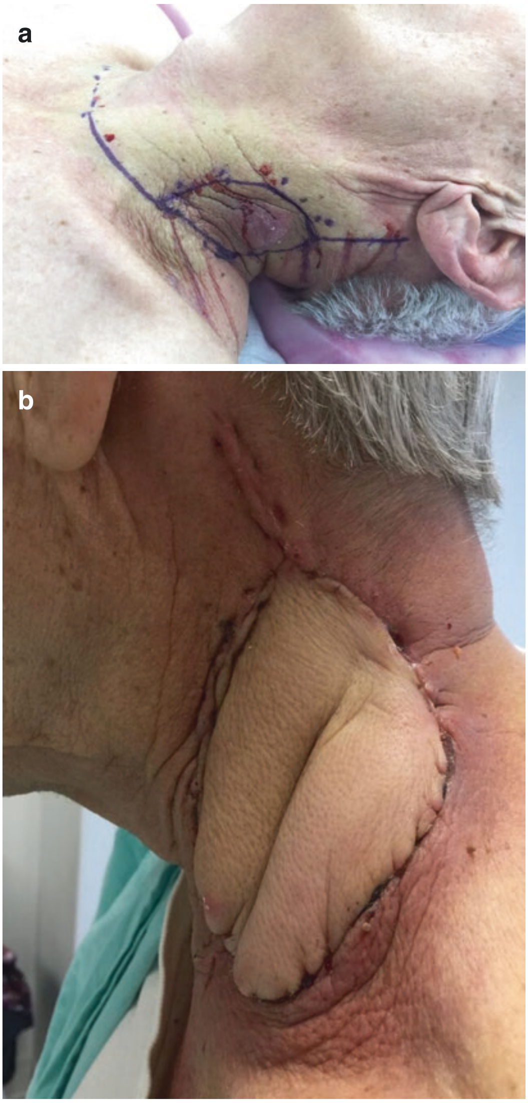


**Fig. 1** (**a**) 66-year-old male patient with a history of chemoradiation for squamous cell carcinoma of the right tonsil presented with a growing left neck mass which was diagnosed as recurrent squamous cell carcinoma after fine needle aspiration. Ablation surgery and salvage radical neck dissection were performed. (**b**) A free flap was planned in advance and a left-sided radial forearm free flap was transferred to the left neck for soft tissue reconstruction

to initiate timely treatment if there are complications. Aggressive antibiotherapy and early incisional revisions could make the difference between salvage and failure.

There is emerging evidence on the role of autologous fat grafting and stem cell therapy to irradiated tissues. Adipose-derived stem cells that are transferred during fat grafting have the potential to improve healing and enhance skin quality [14]. Fat grafts are harvested via liposuction and injected into the field through small incisions, providing a minimally invasive technique.

## 4.2 Reconstruction According to Anatomic Site

### 4.2.1 Head and Neck

Cancer surgery in the head and neck region often results in defects with exposed vital structures and multiple missing layers that require complex reconstruction. Patients usually undergo induction or postoperative radiation therapy due to aggressive nature of these tumors. Bony reconstructions of maxillofacial area or calvarium offer additional reconstructive challenges as they commonly require hardware (i.e., titanium plates), which subsequently should be covered with flaps. Non-vascularized bone grafts are not advisable in the setting of radiation, as they would need a well-vascularized bed for healing.

Several local and regional soft tissue flap options exist in the head and neck region. Pectoralis flap is the workhorse due to its reliability and ease of harvest; however it is limited by bulkiness, arc of rotation, and limited extension to the oral cavity. Supraclavicular perforator flap is another good option which provides pliable, thin tissue with extensive reach [15, 16]. However, care should be taken in previously irradiated necks and with history of neck dissection as the pedicle could be damaged [17]. Temporalis muscle/fascia flap is a smaller flap which is readily usable for defects of the upper face and palate. Scalp can be reconstructed with large rotation flaps for which many designs and variations exist [18].

With the advances in microsurgical techniques, most of the larger head and neck defects, specifically irradiated areas, are now reconstructed with free tissue transfer which provides reliable long-term coverage and preservation of form and function. Fasciocutaneous flaps such as radial forearm, anterolateral thigh perforator, and scapular or parascapular are the most commonly used options. Most of these flaps could be harvested with adjacent muscle or bone as needed. Free fibula flap is the workhorse for bony reconstruction and provides sufficient amount of bone for extensive defects, even for total mandibulectomies (Fig. 2). Other flaps (i.e., rectus abdominis, latissimus dorsi) could be indicated depending on the defect (Fig. 3). Even though there is an abundant supply of recipient vessels for microsurgery in the head and neck region, their dissection could pose difficulties due to postradiation fibrosis and adhesions. In some cases, the free flap may need to be anastomosed to the contralateral neck vessels, necessitating vein grafts for reach. Vein grafting generally increases complication rates and should be avoided if possible [19, 20].

A rare complication of radiation in the head and neck region is an infection or salivary fistula that can cause vessel rupture, which in turn could be lethal. In the setting of radiation, soft tissue healing takes longer, and neck vessels are at risk for a prolonged period of time. Sternocleidomastoid muscle transposition or pectoralis muscle flaps could be used for protection of vessels even if the skin can be primarily closed.

Osteoradionecrosis of the facial bones, specifically the mandible, could occur after radiation therapy to the oropharynx. It is defined as the presence of a nonhealing, exposed bone for 3 months in a previously radiated area [21]. Although the pathophysiology of osteoradionecrosis is evolving, there is a consensus that poor blood supply contributes to the damage [22]. Osteoclast suppression inhibiting bone turnover is also thought to play a role [9]. The necrotic bone is usually surrounded by already damaged tissues of weaker resistance, mucosa, skin, and muscle. The unhealthy bone does not allow soft tissues to heal, and the clinical picture is further complicated with fistulas, mucositis, trismus, and pain [23].

Conservative modalities such as pentoxifylline, tocopherol, clodronate, and hyperbaric oxygen may have value in treatment of early, reversible phase of osteoradionecrosis [23–25]. These medications could also be used prior to surgical intervention, to help with healing. Aggressive debridement of necrotic bone and coverage with well-vascularized tissue (free flaps) is often indicated when clinical signs of bone and tissue necrosis develop. Attempts to utilize local flaps may devascularize the surrounding tissue, further amplifying radiation-induced damage. This approach could also limit extent of resection, and if unhealthy bone is left behind, likelihood of recurrence is high [13, 23, 26]. For these reasons, distant flap reconstruction is preferred in treatment of osteoradionecrosis.

### 4.2.2 Trunk

Patients with previous history of radiation to the trunk, specifically chest wall, are often complicated with cardiothoracic comorbidities requiring multidisciplinary management. Chronic wounds, infections, fistula tracts tracing to sternal hardware, resection of recurrent tumors, and metastases are the most common indications for surgery. Long-standing radiation ulcers or chronic infections may need serial debridement procedures to accurately judge viable tissues.

The primary goal in the thoracic region is stabilization of skeletal structures, maintaining respiratory mechanics and protecting the vital intrathoracic organs in addition to coverage of the soft tissue defect. The chest wall is reconstructed in conjunction with thoracic surgery team. Posterior chest wall defects are usually more tolerant to skeletal resection when compared to anterior defects, yet skeletal reconstruction should be tailored according to the patient's functional status [27–29]. Skeletal reconstruction options are either synthetic mesh and hardware (i.e., polytetrafluoroethylene, methyl methacrylate, absorbable plates, titanium plates) or biologics (i.e., autologous fascia and rib grafts, acellular

**Fig. 2** (**a**) A 57-year-old male patient with osteonecrosis of the central mandible secondary to radiation. Intraoperative indicates the submandibular approach for resection of the mandible. (**b**) Resection of the necrotic segment of the mandible sparing the inferior alveolar nerves bilaterally. (**c**) In situ shaping of the fibula and fixation to the reconstruction plate that is prepared according to the shape of the mandible prior to resection. (**d**) Free fibula flap was revascularized using right-sided facial vessels. (**E**, **F**) Postoperative at 3 months


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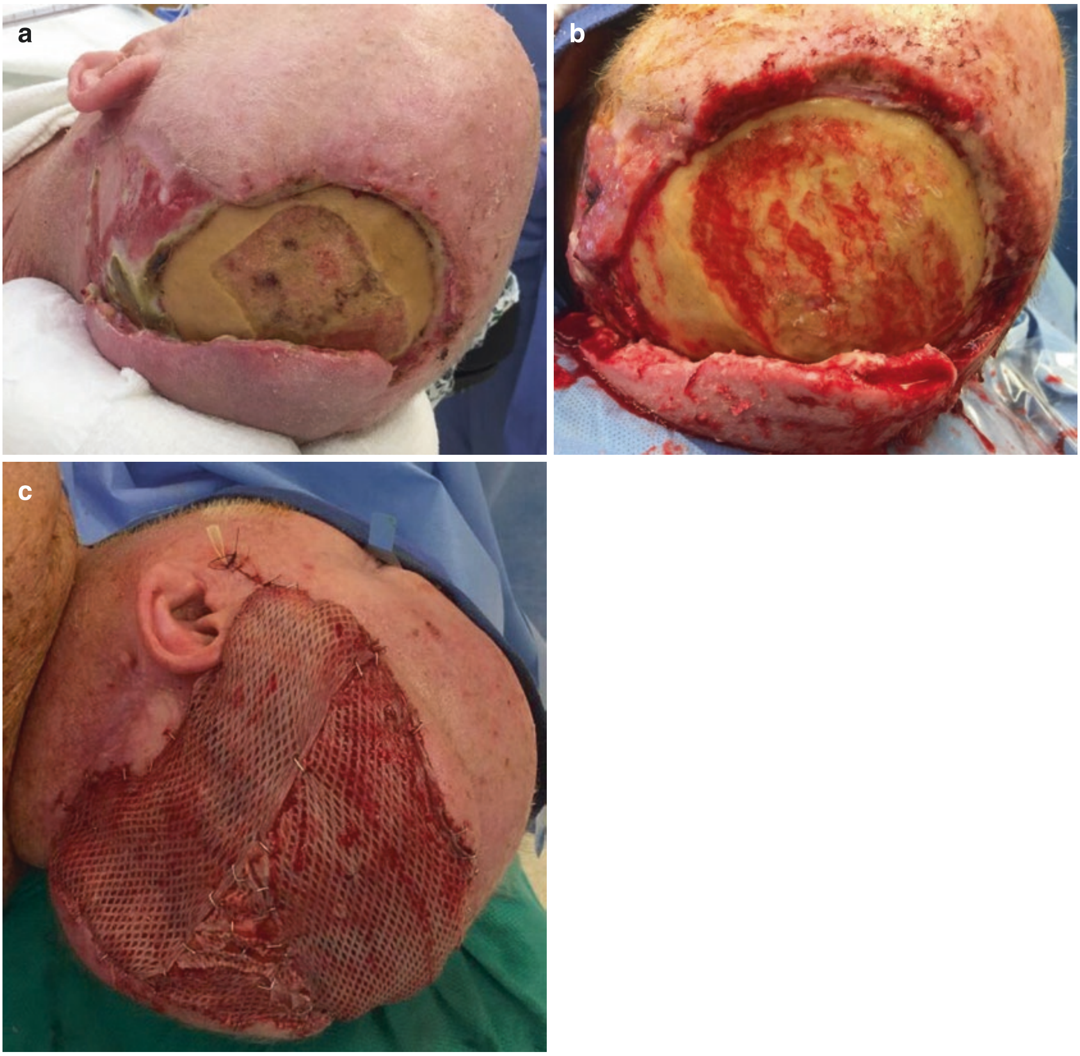


**Fig. 3** (**a**) A 55-year-old male patient with a history of surgery for squamous cell carcinoma of scalp and radiation, presented with large scalp wound with exposed bone and evidence of osteoradionecrosis. He had received multiple failed attempts for wound closure using local scalp flaps and skin grafting. (**b**) Recurrent malignancy was ruled out and proper debridement of the bone and soft tissues were performed. (**c**) A free latissimus dorsi muscle flap was employed along with split skin grafts (microvascular anastomoses were done using the left-sided superficial temporal vessels)

dermal matrix). Biologic mesh is preferred when attempting to seal the thoracic cavity as utilization of synthetics in a previously radiated bed could result in recurrent infection or exposure. Once the thoracic cavity is sealed and separated, flap reconstruction is carried out. Regional flaps include pectoralis, latissimus or rectus muscle flaps, and omentum. The latter has the benefits of great vascularity, large surface area, and pliability, but has disadvantages of breach of a second body cavity and lack of support [30].

In patients with previous radiation therapy, the blood supply to a regional pedicled flap may prove to be unreliable, and augmenting the blood supply (supercharging via additional microanastomosis) should be considered [31]. Patients who require complex chest wall reconstruction are not tolerant to even minor wound complications, and all measures should be taken to optimize healing. Even though there is an abundance of regional flaps for chest wall reconstruction, in cases with multiple complications where these options have been already utilized, free flaps may be necessary. In such cases contralateral free flaps (i.e., latissimus and rectus) and anterolateral thigh perforator flaps provide sufficient surface area and support.

The spine is the most common site of metastatic disease, requiring radiation and instrumentation to preserve neurologic function and to improve the overall quality of life. Paraspinous muscle, scapular fasciocutaneous, latissimus, and trapezius flaps have been used for coverage of defects or for prophylactic measures [32]. Reconstruction of radiation wounds in the lumbosacral region is quite challenging due to scarcity of regional options and recipient vessels [13]. The skin in this region is not elastic and has tight adhesions to the deeper layers. Gluteal artery perforator flaps are a good choice as they can be performed with minimal donor site morbidity. Field of radiation should be taken into consideration when planning these flaps, as the pedicle could have been exposed to radiation. Free flap coverage is usually needed for lumbosacral wounds that are large and irradiated.

### 4.2.3 Breast

Radiation-related issues in the breast usually pertain to outcomes of breast reconstruction and not to radiation wounds. Postmastectomy and post-lumpectomy radiation increases the complication rates of implant-based breast reconstruction and results in poor cosmetic outcomes [33]. Delayed surgical healing, skin necrosis, and periprosthetic infection, if severe, may require removal of implant and the surrounding capsule. The skin usually heals well with primary closure once the implant and capsule are removed. Incomplete capsulectomy or presence of unusual microorganisms (i.e., anaerobic or fungal infections) could result in continuation of healing problems. Osteoradionecrosis of ribs should also be considered if there is a chronic draining wound. In such cases, flap reconstruction is indicated, after adequate debridement.

The workhorse regional flap for breast reconstruction is the latissimus dorsi flap, which could be utilized with or without an implant, depending on contralateral breast size [34] (Fig. 4). However, since latissimus flap does not create an as large breast mound, most reconstructive surgeons utilize flaps from the abdominal region. Abdominally based flaps (deep inferior epigastric artery perforator, muscle sparing transverse rectus abdominis, transverse rectus abdominis) are almost always raised as free flaps to maximize tissue perfusion via dominant blood supply, specifically in cases of radiated breast reconstruction [35]. Pedicled transverse rectus abdominis flap (based on non-dominant blood supply) is notorious for having diminished blood supply and is more prone to healing complications and fat necrosis, which could further complicate a radiated breast reconstruction. Internal mammary artery and vein are typically selected as recipient vessels for microsurgery, which are accessed by removing a small rib cartilage. Dissection of the subcostal space could prove to be quite difficult when irradiated, and meticulous technique is necessary to avoid bleeding from these fragile but robust vessels.

Radiation-related breast wounds could also develop from elective surgery that is performed on a patient with prior lumpectomy radiation. Patients with large breasts who undergo unilateral lumpectomy commonly develop asymmetry and present requesting breast reduction after radiation. Breast reduction with extensive undermining and repositioning of tissues is not advisable after radiation [36]. Such a procedure to address asymmetry could result in nonhealing wounds that, in turn, could necessitate a salvage mastectomy. Elective surgery on a previously radiated breast should indeed be avoided or be carried out via minimally invasive techniques such as liposuction or fat grafting.

### 4.2.4 Extremities

Historically, amputation was the mainstay of treatment for malignancies of the extremities, specifically sarcomas, due to high recurrence rates. More attempts at limb salvage are being undertaken today due to advances in microsurgery and chemoradiation treatment [27]. Surgeons are confronted with the dilemma of salvage versus amputation, commonly in setting of radiation. Preserving limb function is the goal instead of just obliterating the defect, which sometimes means amputation could provide superior outcomes.

Extremity resections often include bone, requiring orthopedic reconstruction with prosthetics or autologous tissues. Stable coverage of prosthetic materials, bone, neurovascular

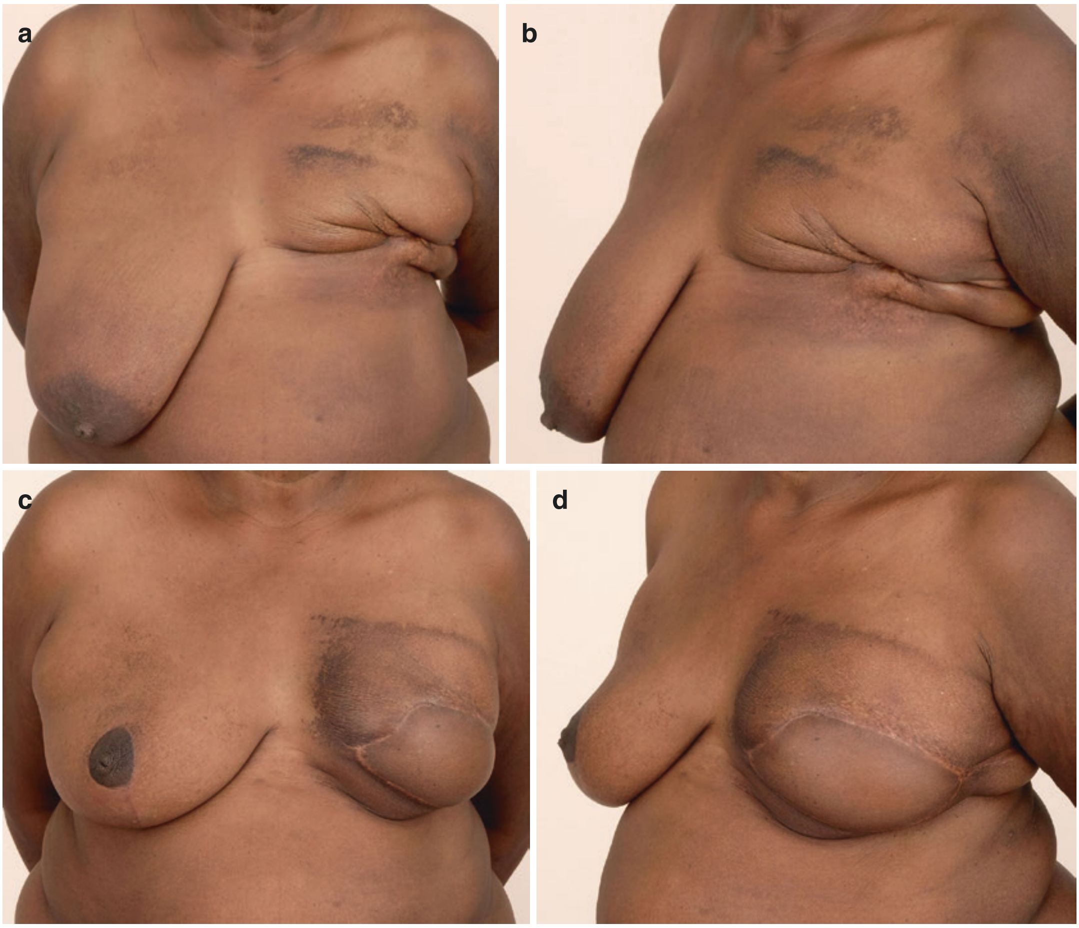


**Fig. 4** (**a**, **b**) Preoperative 69-year-old female patient with a history of mastectomy and radiation presented with a long-standing left-sided breast pain and unstable scar/wound in the left breast. (**b**) Preoperative. (**c**, **d**) Postoperative at 1 year after breast reconstruction using latissimus dorsi flap and implant and right-sided breast reduction. Latissimus dorsi muscle flap provided robust blood supply to the area

bundles, and tendons is required. There is a paucity of regional flap options in the extremities, and limb salvage commonly necessitates a free flap coverage. Bringing a distant, non-radiated flap preserves available local tissues and blood supply. As mentioned earlier, it is prudent to select a flap over primary skin closure to prevent future complications in the irradiated field.

Upper extremity has unique appearance and function that are difficult to replicate with reconstruction. Functional or sensate reconstructions with tendon, nerve, or innervated muscle transfer (i.e., gracilis muscle, rectus femoris muscle) may be indicated depending on individual needs. Latissimus and rectus abdominis muscle flaps could be used to cover larger defects. Workhorse fasciocutaneous flap options are free radial forearm, anterolateral thigh, and lateral arm flaps.

Flap selection for the lower extremity depends on many different factors. In general, muscle flaps with a skin graft yield good outcomes as they atrophy in time and adhere to underlying structures better, being less mobile. However, in areas where tendon gliding is important (knee, ankle, and dorsal foot), fasciocutaneous flaps provide mobile tissue coverage [27]. The knee is particularly challenging as the reconstruction should allow a wide range of motion. Gastrocnemius flap is a commonly used pedicled flap for lower extremity reconstruction, but its pedicle could lay in the field of radiation and its size is limited. For the foot, a muscle flap with a skin graft provides good adherence and stability. It is important to consider the eventual functional outcome of reconstruction as bulky flaps may prevent weight bearing, shoe or orthotic device wear. Outcomes of below-knee amputations are sometimes superior to flap reconstruction as they allow for a faster recovery and excellent prosthetic rehabilitation. The thigh is relatively easier to reconstruct due to the presence of more tissue bulk to work with. Flaps from regional sites, such as the abdomen, are also available (Fig. 5).

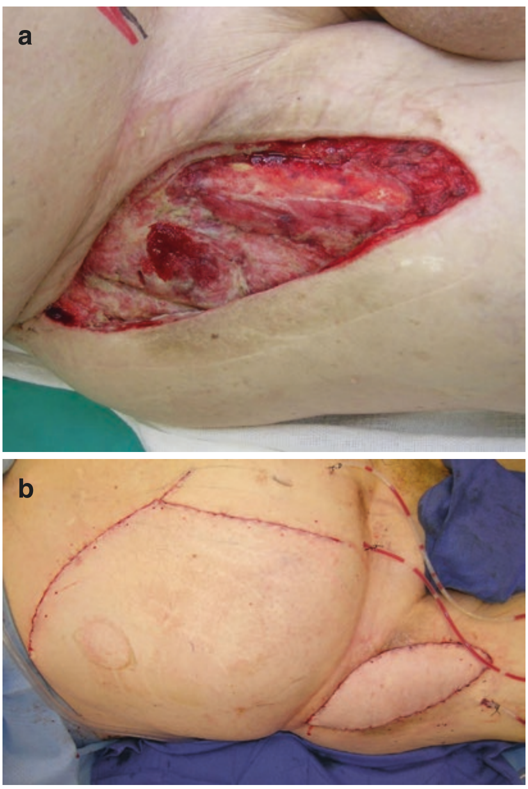

**Fig. 5** (**a**) A 55-year-old male patient with a history of sarcoma resection and radiation involving the right anterior thigh presented with wound breakdown and infection. (**b**) After ensuring no recurrence and adequate debridement, pedicled rectus abdominis myocutaneous flap was utilized for soft tissue reconstruction

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