Surgical Reconstruction of Radiation Injuries

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Significance: Patients with cancer receive benefits from radiation therapy; however, it may have adverse effects on normal tissue such as causing radiation-induced ulcer and osteoradionecrosis. The most reliable method to treat a radiation ulcer is wide excision of the affected tissue, followed by coverage with well-vascularized tissue. As usual, radiation-induced skin ulcers are due to therapeutic irradiation for residual cancer or lymph nodes; the locations of radiation ulcers are relatively limited, including the head, neck, chest wall, lumbar, groin, and sacral areas. Thus, suitable reconstructive methods vary according to functional and aesthetic conditions. I reviewed the practices and surgical results for radiation ulcers over the past 30 years, and present the recommended surgical methods for these hard-to-heal ulcers.

Recent Advances: At a minimum, flaps are required to treat radiation ulcers. Surgeons can recommend earlier debridement, followed by immediate coverage with axial-pattern musculocutaneous and fasciocutaneous flaps. Free flaps are also a useful soft tissue coverage option. The choice of flap varies with the location and size of the wounds.

Critical Issues: The most crucial procedure is the complete resection of the radiation-affected area, followed by coverage with well-vascularized tissue.

Future Directions: Recent developments in perforator flap techniques, which are defined as flaps with a blood supply from isolated perforating vessels of a stem artery, have allowed the surgeons to successfully resurface these difficult wounds with reduced morbidity.

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Abbreviations and Acronyms

FC = fasciocutaneous

LDMC = latissimus dorsi musculocutaneous

MC = musculocutaneous

PMMC = pectoralis major musculocutaneous

RAMC = rectus abdominal musculocutaneous

TFLMC = tensor fascia latae fasciocutaneous

SCOPE AND SIGNIFICANCE

RADIATION THERAPY IS EFFECTIVE for some patients with malignant neoplasms; however, it also damages the surrounding tissues. The skin problems most commonly encountered are dermatitis and ulcers, which are difficult to heal because of reduced blood supply, fibrosis, and a directly impaired cellular repair potential. Conservative therapies are ineffective in most patients. This review explores the general principles of treatment for radiation ulcers and investigates methods for resurfacing an ulcer.

TRANSLATIONAL RELEVANCE

Radiation-induced ulcers fail to heal because of decreased angiogenesis and persistently high concentrations of matrix metalloproteinases, which could be evidence for an early chronification, indicating a molecular environment in chronic wounds hostile for cell replication after injury.¹⁻⁴ Additionally, they accompany the fibrosis of surrounding tissue and disordered blood circulation. The lack of contraction caused by delayed myofibroblast function and repeated wound contamination are also factors for the non-improvement of wounds.⁵

Radiation-induced ulcers can be treated by stable wound resurfacing, following the radical removal of nonviable tissue including skin, fat, muscle, and sometimes bone.⁶

CLINICAL RELEVANCE

The most reliable method to treat a radiation ulcer is wide excision of the affected tissue, followed by coverage with well-vascularized tissue.^{7,8} As usual, radiation skin ulcers are due to therapeutic irradiation for residual cancer or lymph nodes, the locations of radiation ulcers are relatively limited, including the head, neck, chest wall, lumbar, groin, and sacral areas. Thus, suitable reconstructive methods vary according to functional and esthetic conditions.

BACKGROUND

Although patients with cancer receive benefits from radiation therapy, it can also damage surrounding tissues, which can progress to serious wound problems.¹ A knowledge of the altered pathophysiology of such tissues (mainly, diminished blood supply, fibrosis, and direct impaired cellular reparative potential) is necessary for the surgeon to make a proper judgment. Some successful conservative treatment has been reported such as irradiation of phototherapy with low intensity laser, and topical the use of pentoxifyllin and metronidazole. However, these conservative therapies are ineffective in most patients.²⁻⁴

Surgical treatment must include the excision of irradiated tissues, followed by coverage with well-vascularized tissue.⁹ As radiation skin ulcers are normally due to therapeutic irradiation for residual cancer or lymph nodes, the locations of radiation ulcers are relatively limited, including, head, neck, chest wall, lumbar, groin, and sacral areas. Thus, suitable reconstructive methods vary according to functional and esthetic conditions.

I searched PubMed for clinical trials, systematic reviews, and implementation articles from 1981 to 2013 using the following key words: radiation ulcer and surgical treatment. This synthesis of the English literature on surgical treatment for radiation-induced ulcer is based on 294 overviews/retrospective analyses. Among them, 80 articles specially emphasize the reconstruction of radiation-induced ulcer including a total of 121 patients. In this article, I reviewed the practices and surgical results for radiation-induced ulcer over the past 30 years and present the recommended surgical methods for these hard-to-heal ulcers.

DISCUSSION OF FINDINGS AND RELEVANT LITERATURE

General principles of treatment for radiation ulcers

Usual skin ulcers tend to improve and sometimes heal with adequate local wound management. However, radiation ulcers will progress and become worse, because of the underlying ischemia, infection, and lower viability of granulation tissue.¹⁰ The lack of contraction caused by delayed myofibroblast function and repeated wound contamination are also factors for the non-improvement of irradiated wounds.¹¹ The interval between irradiation and surgery was 3 months to 25 years, which suggested that influence of radiation would continue for more than 20 years, and "delayed radiation-induced ulcer" might develop long after the irradiation.^{12,13}

At first, when a patient presents with an open wound in an irradiated lesion, the patient must undergo biopsy to rule out a recurrent tumor. Physicians should be aware of radiation-induced squamous cell carcinoma and sarcoma, which may also develop in the lesion.⁷ Radiation ulcers can be treated by stable wound resurfacing, following the radical removal of nonviable tissue including skin, fat, muscle, and sometimes bone.⁸ At a minimum, flaps are required to treat radiation ulcers. The skin graft failure rate is near 100%, because a previously irradiated wound bed does not have a sufficient oxygen and nutrient supply.¹¹ The elevation of local (random-pattern, Fig. 1A) flaps is also not recommended because tissue surrounding the ulcer crater has often been compromised by radiotherapy, which results in the loss of at least part of the flap.⁹ Based on this, distal pedicled flaps which are harvested from non-irradiated areas provide effective results. However, they sometimes require multiple-stage surgery and prolonged hospitalization. The development of axial-pattern flaps (Fig. 1B) was a significant advancement in the reconstruction of post-radiation defects. With the development of axial-pattern musculocutaneous and muscle flaps, it is easier to deal with these ulcers.

Surgeons can now recommend earlier debridement of the entire irradiated area, followed by immediate coverage with a well-vascularized, axial-pattern musculocutaneous flap or revascularized free flap (Fig. 1C).¹⁰ When irradiated wounds increase in size, complete excision of the wound requires a well-vascularized, distant flap.^{8,10} These large musculocutaneous flaps enable surgeons to perform more radical debridement. Further, they

Figure 1. (A) Random-pattern flap. The blood supply for the flap is not derived from a recognized artery but, rather, comes from many little unnamed vessels. Many local cutaneous flaps fall into this category. (B) Axial-pattern flap. The blood supply for the flap comes from a recognized artery. Most muscle flaps have axial blood supplies. (C) Free flap. Free flap is defined as the vascular detachment of an isolated tissue, followed by transfer to another region of the body with reattachment of the divided artery and vein to separate artery and vein. (D) Perforator flap. The vessels that supply blood to the flap are isolated perforators derived from a deep vascular system through the underlying muscle or intermuscular septa. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

are supplied by large blood vessels that may promote the healing process in irradiated tissue.¹¹

With a greater experience in microsurgical reconstruction and the availability of a larger number of flaps, free tissue transfer has become common and reliable.^{6,8,11,14} The application of microvascular free tissue transfer allows the surgeon to select the tissue that is most suitable for the size and shape of the defect. When the radiation is directed toward the nutrient vessel of the flap or damages the muscle itself, using this flap involves a risk of developing flap necrosis.⁶ Further, free flaps can be a useful soft tissue coverage option in patients when the flap or its blood supply may be included within the surgical resection area, the flap may have been used previously, and the defect is too large to cover with the flap.¹⁴ However, to find an acceptable recipient vessel in the irradiated area is not always easy. Chronic endothelial angitis in the recipient vessels caused by radiation may be one of the factors leading to thrombosis.⁵ In this case, the free flap requires a long vein graft to reach and cover the wound.¹³

As mentioned above, musculo- and fasciocutaneous and microsurgical flaps are available for resurfacing of radiation-induced skin defects, be-

cause they have rich blood supplies through the major arteries. However, harvesting these flaps requires the scarification of major vessels, which vascularizes muscles, skin, and bones. Further, it leads to high-level morbidity at the donor site. Also, microvascular anastomoses have the potential disadvantage that they require considerable surgical skill and prolong the operative period.¹⁶⁻¹⁸ Recently, anatomical understanding of perforators and angiosomes has advanced, which has allowed regional flaps to cover skin defects, providing an alternative to free flaps.¹⁷ Perforator flaps (Fig. 1D), which are defined as flaps with a blood supply from isolated perforating vessels of a stem artery, are a good option for the coverage of complex wounds. They have allowed regional flaps to cover skin defects, providing an alternative to free flaps.¹⁷ The most significant advantage of the perforator flap is that there is no need to sacrifice any main arteries and muscles; thus, there is minimal morbidity at the donor site. An ideal flap is thought to be a good vascularized skin paddle with the same thickness and width as the wound, which creates a natural esthetic appearance, and requires a single-stage operation.¹⁸ Therefore, the perforator flap use has been attempted for radiation ulcer recon-

Table 1. Surgical reconstruction of head and neck radiation ulcers

Authors	Year	Location and Wound Size	Cause of Wound	Reconstruction	Flap Type	Number of Cases
Strawberry <i>et al.</i> ¹¹	1984	Head and neck	Radiation treatment	PMMC 27, LDMC 13	Pedicled MC	46
Di Meo and Jones ²¹	1984	Scalp	—	Trapezius MC 13	Free MC	3
Luce ²²	1985	Neck	Radiation treatment	Galeal flap 1, LDMC (free) 1 Occipital scalp flap (delay) 1 PMMC	Local flap Free MC Pedicled MC	1
Koh <i>et al.</i> ²³	2007	Neck, 8 cm × 6 cm	Radiation treatment	PMMC	Pedicled MC	1
Deganello <i>et al.</i> ²⁴	2008	Neck, 4 cm × 7 cm Neck, 5 cm × 5 cm	Radiation treatment	PMMC DP	Pedicled MC Axial skin flap	2

DP, deltopectoral flap; LDMC, latissimus dorsi musculocutaneous flap; MC, musculocutaneous flap; PMMC, pectoralis major musculocutaneous flap.

struction, when the ulcer is relatively small, and the perforator vessel and flap are outside the radiation field.^{7,17}

Some investigators reported a unique technique to repair the chest radiation ulcer by using the tissue expander in non-irradiated adjacent skin. The advantage of this approach is that extensive surgery can be avoided, and no functional defects of flap harvesting remain. Furthermore, the expanded skin is expected to provide a well-vascularized tissue for the irradiated wounds as a result of the delay phenomenon.^{19,20}

In conclusion, axial musculocutaneous flaps, microvascular free flap transfer, and perforator flap are recommended for the resurfacing of radiation ulcers, because they provide large and well-vascularized tissues, which promote successful wound healing. The choice of pedicled or free flap is decided by the location of an ulcer and general condition of the patient.

How to resurface radiation ulcers

Surgical treatment of head and face radiation ulcers. Reconstruction of defects in the head and neck region has remained a challenging problem for surgeons. When radiation ulcers develop on the head or in midfacial regions, free flap transfer is recommended for reconstruction, because no pedicled axial-pattern flaps can reach these distal areas safely. Table 1 briefly summarizes several reports of the surgical reconstruction of head and neck radiation ulcers.^{11,21–24}

Di Meo and Jones presented four patients with scalp ionizing radiation ulcers. The patients who underwent skin graft and conservative management required multiple surgeries and prolonged hospital stays. They concluded that the patient treated with free flap showed the most satisfactory course.²¹ Free flaps can be utilized for reconstruction, including the skull base, scalp, orbit, maxilla, and palate, all of which are hard to restore using

conventional pedicle flaps.^{11,21,25} I usually choose a rectus abdominis or a latissimus dorsi musculocutaneous flap when the defect requires massive tissue or develops infection (Fig. 2). However, musculocutaneous flaps for reconstruction of the skull are usually so bulky that the appearance of the head is not favorable esthetically. Thus, I usually use a free anterolateral thigh flap for skull reconstruction, which leads to a favorable result (Fig. 3). Further, the fascial components of these flaps are available for watertight closure of the dural defect.

Free flaps are also applicable for the release of extra-articular ankylosis caused by irradiation-induced fibrosis.²⁶

On the other hand, free flap transfer is sometimes not suitable for the reconstruction of very small tissue defects, for example, soft palatal radiation-induced fistulae, because it requires thickness and width for better flap circulation. In these cases, conventional, distant flaps are available (Fig. 4). However, the flap takes a longer period to adhere to the debrided wound, because the surrounding areas have usually been affected by irradiation.^{9,11} Thus, de-touching surgery should be prolonged compared to the usual distant flap method.

Surgical treatment of cervical radiation ulcers. Neck cancers, including lingual, laryngeal, pharyngeal, and esophageal cancers, are usually treated with irradiation, which often leads to neck ulcers and postsurgical wound dehiscence.^{9,11} They result in fistulae of the reconstructed esophagus and trachea, and cause long-term distress for the patient and decrease their quality of life.²⁷ Pinar *et al.* also reported that 12% of 33 free flap transfers after irradiation showed continued fistula formation.²⁸ Cervical skin flaps have been utilized in neck reconstruction from the time they were originally described, more than 100 years ago. However, the use of these flaps has declined because

Figure 2. (A) The patient underwent 80-Gy radiation treatment due to ethmoidal cancer after tumor ablation. Chronic ulcers on the forehead and in the left nasolabial fold area were observed. (B) A computed tomography scan revealed that the fistula had penetrated to the frontal sinus. (C) Intraoperative examination showed necrotic frontal bone. (D) Intraoperative examination showed that all necrotic tissues had been removed and the brain and skull were exposed. (E) Reconstruction using a free latissimus dorsi musculocutaneous flap was planned (harvested flap is shown). (F) The radiation ulcer and cavity were reconstructed using a free latissimus dorsi musculocutaneous flap. (G) View 1 year after the surgery. The radiation ulcer and cavity were filled and resurfaced without relapse. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

pedicled flaps do not provide a sufficient tissue volume for the reconstruction of large and deep radiation ulcers. Strawberry reported that only 6 of 52 patients with cervical irradiation ulcers could be successfully treated with either local skin flaps or a free skin graft; the remaining 46 patients required the use of musculocutaneous flaps, including pec-

toralis major musculocutaneous and latissimus dorsi musculocutaneous flaps.¹¹ Among them, pectoralis major musculocutaneous flap use remains an important reconstructive technique for neck skin defects, because it is associated with a low-risk procedure with acceptable morbidity (Table 1; Fig. 5).²²⁻²⁴

Figure 3. (A) The patient underwent 80-Gy radiation treatment due to ethmoidal cancer after tumor ablation. Atrophic soft tissue with necrotic frontal bone on the forehead was observed. (B) Reconstruction using a free anterolateral thigh flap was planned. The picture showed harvested flap. (C) Intraoperative examination showed that all necrotic tissues had been removed and the fascial components of the free anterolateral thigh flap are adapted for the watertight closure of the dural defect. (D) View 8 months after the surgery showed favorable esthetic result after revision of depressive deformity due to irradiation. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

Figure 4. (A) The patient underwent 60-Gy radiation treatment due to epipharyngeal squamous cell carcinoma after tumor ablation. Fistula occurred in the palate. (B) Design of the tongue flap. (C) The palatal fistulae was reconstructed, and the patient regained velopharyngeal competence. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

When the flap is completely elevated as a vascularized island flap, it can reach the cervical lesion easily. Sacrifice of this muscle leads to only minimal functional deficit because adjunct muscles of the shoulder belt can almost completely compensate for the loss.²⁹ The pectoralis major musculocutaneous pedicled flap is the most commonly indicated flap for the restoration of neck radiation ulcers.

Carotid blowout is a devastating complication in patients with head and neck malignancies, and is still associated with 60% neurological morbidity and 40% mortality.³⁰ Carotid artery rupture is

known to be closely associated with previous radiotherapy, because radiation weakens the arterial wall and results in the subsequent formation of pseudoaneurysms that may expand with arterial pressure, until blowout occurs.³⁰ Once carotid artery rupture occurs, endovascular treatments, including stent placement and coil embolization of the pseudoaneurysm, are suitable for the temporary or emergent treatment of carotid blowout (Fig. 6).³⁰

Surgical treatment of chest wall radiation ulcers. Breast cancer is the most common reason for

Figure 5. (A) The patient underwent 60-Gy radiation treatment due to laryngeal squamous cell carcinoma after tumor ablation. A chronic neck ulcer that formed a fistula penetrating to trachea was observed. (B) The photograph shows a pectoralis major muscle flap being elevated and rotated toward the neck. The flap remained attached to the donor site by a feeding artery. (C) The photograph shows the reconstructed wound 1 month after surgery. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

Figure 6. (A) A diagnostic angiogram of the right common carotid artery shows a pseudoaneurysm in the right internal carotid artery and profuse extravasation. Distal blood flow in the internal carotid artery was diminished, possibly due to spasm and massive hematomas. (B) The pseudoaneurysm was successfully coiled with no evidence of extravasation. Sufficient distal flow of the internal carotid artery resumed.

chest wall irradiation. However, all tissues of the chest wall and mediastinum are subject to post-radiation changes, including the skin, ribs, and pleurae. Radiation to the chest wall sometimes causes deep ulcers with osteonecrosis of the ribs

and sternum bone.¹⁹ The reconstruction of these irradiation chest ulcers must provide pleural and structural continuity to support the respiratory mechanism and a primary closure following radical ulcer resection.²⁰ A synthetic mesh or rib graft to reinforce the chest wall should not be used for contaminated radiation ulcers, but a thick musculocutaneous flap alone should be transferred.³³ Table 2 briefly summarizes various reports of the surgical reconstruction of chest wall radiation ulcers.^{1,6-8,10,12,14,19-20,31-37}

The choice of flap available for chest wall reconstruction is determined by the size and location of the tissue defect. Available axial-pattern flaps include the pectoralis major, latissimus dorsi, and upper rectus abdominal musculocutaneous flaps (Figs. 7 and 8). The pectoralis muscle can cover defects in the region of the sternum and upper chest, and the latissimus dorsi and rectus abdominal muscle can do so in all regions.⁷ A latissimus dorsi musculocutaneous flap is usually available for almost all chest wounds because it leads to minimal donor site problems, which is a potential advantage over the rectus abdominal musculocutaneous flap.

Surgical treatment of back wall radiation ulcers. Many radiation ulcers are caused by radiation therapy for malignant neoplasms, with those developing on the back likely to be a complication of prolonged fluoroscopic procedures.³⁸ Coronary angiography and intervention often lead to the occurrence of ulcers at dorsal and lateral thoracic location, which are difficult to resurface because the usual axial musculocutaneous flap (latissimus dorsi musculocutaneous flap) or its perforator vessels are damaged by the irradiation, or other musculocutaneous flaps are too distant to resurface the dorsal wounds. Various methods of local flap have been used to repair the large defects in the back and lumbar area, including musculocutaneous advancement flaps, rotation flaps, and bipedicle flaps. Large defects require free flap transfer to resurface because suitable pedicled flaps cannot be found in the back. Fudem and Marble advocated the free latissimus dorsi musculocutaneous flap with an extended pedicle by means of interposition vein graft.¹⁵ Table 3 briefly summarizes several studies of the surgical reconstruction of back wall radiation ulcers.^{15,38-41}

These days, a reversed latissimus dorsi musculocutaneous flap based on several perforators is a recommended option.³⁹⁻⁴¹ Narushima *et al.* and Motegi *et al.* presented successful cases of reversed latissimus dorsi musculocutaneous flaps based on the intercostal artery perforator-based reversed

Table 2. Surgical reconstruction of chest wall radiation ulcers

Authors	Year	Wound Size	Cause of Wound	Reconstruction	Flap Type	Number of Cases
Harashina <i>et al.</i> ⁸	1981	—	Radiation treatment	LDMC (free)	Free MC flap	7
Shack ¹⁰	1982	—	Radiation treatment	LDMC	Pedicled MC	Unknown
Stryker ³¹	1984	15 cm × 16 cm	Radiation treatment	LDMC 11	Pedicled MC	1
Reinisch and Puckett ⁶	1984	—	—	LDMC (free)	Free MC flap	Unknown
MacMillan <i>et al.</i> ¹⁹	1986	2 cm × 2 cm	Radiation treatment	Skin flap	Local flap + skin expander	1
Maruyama <i>et al.</i> ²⁰	1986	2 cm × 2 cm	Radiation treatment	RAMMC	Pedicled MC + skin expander	3
Bhathena ³²	1987	2 cm × 2 cm	Radiation treatment	PMMC	Pedicled MC	1
Seyfer ³³	1988	—	Radiation treatment	Skin flap (6), LDMC (11), PMMC (3) RAMMC (1)	Local flap Pedicled MC	21
Arnold and Pairolo ¹	1989	4 cm × 3 cm	Radiation treatment	LDMC (2), PM, RAM	Pedicled MC	4
Granick <i>et al.</i> ⁷	1993	18 cm × 19 cm	Radiation treatment	PMMC (1), LDMC (3), omental flap (1)	Perforator flap Pedicled MC	5
Hidalgo <i>et al.</i> ¹⁴	1993	12 cm × 8 cm, 5 cm × 5 cm	Radiation treatment	RAMMC	Free MC flap	2
Brenner <i>et al.</i> ³⁴	1995	4 cm × 3 cm	Accidental exposure to a radiation source	LDMC	Pedicled MC	1
van Geel <i>et al.</i> ¹²	1998	50–500 cm ²	Radiation treatment	Pedicled omental flap + FSG	Pedicled MC	18
Urayama <i>et al.</i> ³⁵	1998	5 cm × 10 cm	Radiation treatment	LDMC	Pedicled MC	1
Ferreira <i>et al.</i> ³⁶	2005	5 cm × 5 cm	Radiation treatment	LDMC	Pedicled MC	1
Droghetti <i>et al.</i> ³⁷	2007	14 cm × 13 cm	Radiation treatment	RAMMC	Pedicled MC	1

RAMMC, rectus abdominal myocutaneous flap.

thoracodorsal artery, which was used to resurface the large radiation ulcer on the lower back.^{40,41} This concept of perforator-based reversed musculocutaneous flaps may be applicable, especially, in resurfacing difficult ulcers in the lower back.

Surgical treatment of groin radiation ulcers. The groin region is the most frequent site of radiation ulcers because inguinal lymph node metastasis is sometimes treated with irradiation. Table 4 briefly summarizes several reports of the surgical reconstruction of groin, sacral, and vulvar radiation ulcers.^{6,10,13,41–45}

A sartorius muscle flap is usually used to cover ulcers of the groin region. The sartorius muscle receives several segmental vascular pedicles. The division of more than three proximal vascular pedicles results in muscle necrosis, because the blood supply of the sartorius muscle becomes tenuous.⁴⁶ Thus, the indication for using this flap for groin ulcers is limited by the ulcer size and location. The rectus femoris muscle is one of the choices for the resurfacing of a groin ulcer. However, the use of this muscle risks morbidity, such as a weakened knee extension and decreased range of motion of the knee.⁴⁷

Figure 7. (A) The patient underwent radiation treatment with an unknown therapy schedule due to breast cancer after tumor ablation. Chronic chest ulcers that formed fistulae penetrating to the ribs were observed. (B) Intraoperative examination showed necrotic ribs that were ablated with the parietal pleura. (C) Intraoperative view of the latissimus dorsi musculocutaneous flap elevation. (D) The radiation ulcer was reconstructed without disturbance of shoulder movement. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

Figure 8. (A) The patient presented in Fig. 7 developed another “delayed radiation ulcer” with rib necrosis 3 years later. (B) Intraoperative view of the complete debridement and the upper rectus abdominis musculocutaneous flap elevation. (C) View 2 years after the second surgery. The radiation ulcer was reconstructed with two musculocutaneous flaps. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

The tensor fascia latae fasciocutaneous flap is also available for reconstruction of the groin region. Although, this flap does not contain muscle, it has been used to salvage infected abdominal mesh or treat the exposure of an artificial vascular graft successfully.⁴⁸ Tensor fascia latae fasciocutaneous flap transfer ensures a stable blood supply and has minimal associated morbidity. We recommend using this flap for the reconstruction of a groin radiation ulcer (Fig. 9).

The groin area has a unique anatomical structure and important vessels that feed the muscles of the thigh and leg run through this area. Thus, when obstruction of the main branches of the femoral artery occurs due to radiation, the most useful musculo- and fasciocutaneous flap cannot be taken from the thigh. In this case, the omental transposition can be used in the reconstruction of complex

groin ulcers.⁴² However, it necessitates laparotomy and brings a potential risk of developing inguinal hernia through a hole where the flap pedicle goes.

Surgical treatment of sacral radiation ulcers. The options to resurface the sacral radiation ulcers are severely limited (Table 4), as non-radiated tissues hardly remain around the ulcer. The usage of large gluteal musculocutaneous and fasciocutaneous flaps remains an important reconstructive technique for covering sacral radiation ulcers, because both involve low-risk procedures (Fig. 10). They can be still used in a reconstructive procedure after radical debridement.

Many other methods involve difficulties in maneuvers. The reversed latissimus dorsi pedicled flap is an option, but it usually will not reach

Table 3. Surgical reconstruction of back wall radiation ulcers

Authors	Year	Wound Size	Cause of Wound	Reconstruction	Flap Type	Number of Cases
Søvik <i>et al.</i> ³⁸	1996	7 cm × 7 cm	Cardiac catheter ablation	Skin flap	Local flap	1
Fudem and Marble ¹⁵	1996	18 cm × 16 cm	Radiation treatment	LDMC	Free MC flap	1
Monaco <i>et al.</i> ³⁹	2003	30 cm × 30 cm	Cardiac catheter ablation	LDMC	Pedicled MC	1
Motegi <i>et al.</i> ⁴⁰	2007	5.5 cm × 5 cm	Radiation treatment	LDMC	Reversed perforator flap	1
Narushima <i>et al.</i> ⁴¹	2011	12 cm × 9 cm	Coronary angiography	LDMC	Reversed perforator flap	1

Table 4. Surgical reconstruction of groin, sacral, and vulvar radiation ulcers

Authors	Year	Location and Wound Size	Cause of Wound	Reconstruction	Flap Type	Number of Cases
Shack ¹⁰	1982	Groin, —	Radiation treatment	TFLMC	Pedicled MC	1
Mayer <i>et al.</i> ⁴²	2010	Groin, 15 cm × 5 cm	Radiation treatment	Omental flap	Pedicled flap	1
Reinisch and Puckett ⁶	1984	Sacral, —	Radiation treatment	LDMC (free)	Free MC flap	1
Evans <i>et al.</i> ⁴³	1993	Sacral, —	Radiation treatment	MC V-Y advancement flap	Pedicled MC	1
Krasniak ⁴⁴	1995	Sacral, 10 cm × 6 cm	Radiation treatment	RAMMC	Pedicled MC	1
Cheon <i>et al.</i> ⁴⁵	2008	Sacral, 15 cm × 7.7 cm × 6 cm	Radiation treatment	Gluteal artery FC flap	Perforator flap	10
Roberts <i>et al.</i> ¹³	1991	Vulva, 12 cm × 8.5 cm × 5 cm	Radiation treatment	Gracilis MC (6), femoral FC (1), local flap (1), primary closure (3)	Pedicled MC Free MC flap Skin flap	11

FC, fasciocutaneous; TFLMC, tensor fascia latae fasciocutaneous flap.

beyond the sacrococcygeal region.¹⁵ The musculocutaneous free flap is also a good treatment candidate; however, it is not easy to find an acceptable recipient vessel in the irradiated sacral area. Krasnik presented a unique case involving the closure of a chronic sacral radiation ulcer with the retroperitoneal transfer of a transverse rectus abdominis musculocutaneous flap. The idea of passing the flap pedicle through the retroperitoneal tunnel is novel, but this method requires laparotomy and a retroperitoneal operation, and it is not easy for either the surgeon or the patient.⁴⁴

Compared to these flaps, gluteal artery perforator flaps are able to preserve intact muscle with minimal donor-site morbidity and are widely used for the reconstruction of sacral pressure ulcers.⁴⁵ These well-vascularized fasciocutaneous flaps are also sufficient to control infection in the sacral area. Cheon *et al.* presented favorable clinical re-

sults whereby 10 patients with chronic non-healing sacral radiation ulcers were successfully treated with gluteal artery perforator flaps.⁴⁵ When an appropriate perforator is recognized pre-operatively, this perforator flap may be a valuable alternative for treating sacral radiation ulcers.

The effect of irradiation of the sacral area sometimes involves the dura of the spinal cord, which can lead to a spinal-cutaneous fistula with cerebrospinal fluid leakage in association with the ulcer. In this case, aggressive bony debridement with dural patching and wound resurfacing is indispensable for the prevention of recurrence of the fistula.⁴³

Surgical treatment of vulvar radiation ulcers. Vulvar skin is less tolerant to radiation therapy than that of other areas, because of its moisture, friction, and non-flat surface.¹³ When a radiation-

Figure 9. (A) The patient underwent 60 Gy of radiation treatment to the bilateral groin region due to lymph node metastasis of Paget's disease after tumor ablation. Subacute radiation ulcers that formed deep ulcers were observed. (B) Intraoperative view of the tensor fascia latae fasciocutaneous flap elevation. (C) The wound was resurfaced with bilateral tensor fascia latae fasciocutaneous flaps. (D) View 1 year after the surgery. The radiation ulcer was resurfaced without relapse. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

Figure 10. (A) The patient underwent radiation treatment with an unknown therapy schedule due to ovarian adenocarcinoma. A chronic sacral ulcer that formed fistulae penetrating to the sacral bone was observed. (B) The radiation ulcer was reconstructed using a gluteal fasciocutaneous flap. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

induced ulcer develops on the vulva, the patient is in severe pain and there is a foul odor. Patients with vulvar cancer usually undergo interstitial radiation therapy, which carries a 60% risk of necrosis.¹³ However, the effect of the interstitial radiation is thought to be more local in comparison with that of external radiation. Roberts *et al.* showed 11 cases with vulvar radiation ulcers, which were resurfaced successfully. Three of them underwent direct closure, and one received a local flap (Table 4).¹³ Usually, these simple procedures are not options for the reconstruction of radiation ulcers because the wound within an irradiated field are hardly adhered.^{10,11} These favorable results suggest that the vulvar skin is less tolerant to irradiation and develops ulcers easily, but the viability of tissue around the ulcer remains. Other reconstructive options, including a gracilis musculocutaneous flap, femoral free flap, and V-Y fasciocutaneous gluteal flap are thought to be a favorable. However, they lead to high-level morbidity at the donor site, including a long scar, wide resection area, and sensory disturbance. To resolve these problems, application of the perforator flap concept has many advantages.

If the cutaneous perforator vessels from the internal pudendal artery are recognized preoperatively using a Doppler flowmeter, a gluteal-fold perforator flap should be recommended as the first

Figure 11. (A) An intraoperative photograph shows elevation of the skin flap. A perforator vessel can be recognized (arrow). (B) View of the reconstructed vulva using gluteal-fold perforator flap 2 months after surgery, showing a favorable result without contraction and numbness. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

choice for vulvar resurfacing (Fig. 11). This flap fully satisfies the requirements for an ideal flap: a good vascularized skin paddle with the same thickness and width as the wound, which minimizes negative impacts on walking, creates a natural esthetic appearance and requires a single-stage operation.⁴⁹

SUMMARY

When a patient develops a wound in an irradiated lesion, biopsy and histological examination must be performed immediately to rule out a recurrent tumor. Patients with radiation-induced ulcers are initially treated with narcotic analgesic agents, antibiotics, debridement, and local care. However, these conservative therapies are ineffective in most patients.

The most crucial procedure is the complete resection of the radiation-affected area, including necrotic skin, fat, muscle, and sometimes bone, followed by coverage with well-vascularized tissue. To resurface the wound following complete ablation, several vascularized musculocutaneous flaps and fasciocutaneous flaps are usually available, including free flaps. The choice of flap varies with the location and size of the wounds. Recent developments in perforator flap techniques have allowed the surgeons to successfully resurface these difficult wounds with reduced morbidity.

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TAKE-HOME MESSAGES

- **Biopsy and histological examination:** A recurrent tumor must be ruled out when evaluating a wound in an irradiated lesion.
- **Complete resection of the radiation-affected area:** Conservative therapies are ineffective in most patients with radiation-induced ulcers.
- **Coverage with well-vascularized tissue:** To resurface the wound, several vascularized musculocutaneous flaps and fasciocutaneous flaps are usually available, including free and perforator flaps.

listed in this article, and is not currently participating in any product development. This article has not been previously presented at any meeting. No ghostwriters were used to write this article.

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