Treatment of Subacute Traumatic Lower Limb Wounds by Assisted Healing and Delayed Selective Reconstruction

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1 Introduction and Background

Traumatic soft tissue defects that cannot be closed by direct suture are usually covered by split/full-thickness skin grafts, dermal substitutes, or different kinds of flaps (local, regional, or free flap), but timing of coverage has been a matter of discussion over the years [1–5].

Godina's [1] experience with coverage of acute wounds by free flaps within 72 h after injury which resulted in less infection, less free flap failure, and shorter time to bone healing and full weight-bearing, compared to coverage of subacute and chronic wounds, has become a milestone directing surgeons dealing with lower extremity trauma toward early closure of both simple and complex traumatic soft tissue defects [1, 2].

The "fix and flap" principle has become widely accepted all over the world.

Such treatment, however, requires a clean wound before coverage, which can be achieved only by a radical (pseudotumor) wound debridement (with little space for "second-look" procedures), copious irrigation of the wound, and full (often non-specific) antibiotic coverage.

The purpose of early coverage of acute traumatic wounds is to provide well-vascularized soft tissue cover, in particular for open fractures, exposed growth plates, and bone fixation materials, before wound colonization, inevitably leading to invasive infection and additional tissue loss [6]. On the contrary, Byrd [2] suggested the management of subacute wounds (lesions that have occurred more than 7 days from wounding that are characterized by signs of inflammation such as erythema, swelling, and cellulitis and/or by seropurulent drainage and are colonized or infected) by open wound technique "until the parameters of a chronic localized wound are established, at which time flap coverage is again indicated." Indeed, flap closure of subacute wounds, compared to acute and chronic ones, in Godina's [1] experience, leads to the worst results.

Many things have changed since the 1980s: devices such as negative pressure wound therapy (NPWT) increase vascularity of the wound,

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promote growing of granulation tissue, decrease edema and thus the circumference of the limb, and serve as an effective barrier against nosocomial infection [1–10].

Hydrosurgery performed by water scalpel (Versajet®) permits allows more accurate debridement and irrigation of the wound while protecting noble structures [1–4]. Piezoelectric bone cutters excise bones without thermal damage to cutting surfaces and with no possibility of transection of underlying noble structures [1].

Strong cooperation has been built between trauma/orthopedic and plastic surgeons who, instead of looking at the patient only from the standpoint of fractures or soft tissue problems, causing considerable delay in treatment, at present, see the patient together at the same time, in the emergency room, planning the treatment from the beginning to the end. Standards for the management of lower limb open fractures have been produced by BAPRAS/BOA detailing optimal treatment for patients with these challenging injuries [1].

From the results of such treatment, it became clear that complex lower extremity wounds should not be treated as medical emergencies, in the middle of the night, but instead in a programmed way. Two "time windows" exist: during the first day after injury, the wound debridement and temporary bone fixation are necessarily performed, whereas definitive wound cover (by a flap) can be carried out within 7 days from the day of injury. In the meantime, one or more "second-look" procedures and additional debridements can take place, after which the wound is always "sealed" by a NPWT device. At the time of the definitive reconstruction, within 1 week after injury, which takes place in the programmed trauma/orthopedic operating room during the normal working hours with the dedicated nurses and expert surgeons, the temporary (external) bone fixation is changed for the definitive one (internal) and immediately covered by well-vascularized tissue provided by transposition or free transfer of different types of flaps (muscle, musculo-/fascio-cutaneous, or perforator flaps) [11].

Due to several reasons, such as long cardiocirculatory instability in intensive care units following poly-trauma, other diseases precluding general anesthesia, problems with transport, etc., patients are still being referred for coverage of complex lower extremity wounds in the subacute phase of wound healing.

After 1 week from the injury, the wound enters the subacute phase of healing in which treatment of complex wounds becomes more prone to complication because the wound changes from contaminated to infected one (involving both bone and soft tissue infection) and blood vessels become fragile and, after microvascular anastomoses, more prone to vascular complications (spasm, thrombosis) leading to free flap failure [2, 6].

Additional time is necessary also to correct severe hyperglycemia in diabetic patients as well as to define targeted antibiotic therapy to fight wound infection. During this time the wound has to be covered by special dressings or, better, sealed by the negative pressure wound therapy. In addition, elderly traumatized poly-morbid patients with generalized atherosclerosis often present with stenosis/occlusion of one or more lower leg main arteries with critical distal perfusion requiring careful assessment and perhaps endovascular dilatation and stenting before definitive soft tissue reconstruction. All such situations require a different type of approach compared to acute traumatic injuries [4, 5].

By embracing the concept of ADH-DSR, the subacute wounds are treated conservatively at first. During this time the wound is debrided by several conservative debridements, sealed by NPWT or covered by modern dressings, while the patient's comorbidities are treated. Better vascularity of the wound is achieved by intraluminal vessel dilatation (PTA) and stenting, hyperglycemia is corrected, and cardiac and pulmonary problems are solved. During the wound bed preparation when granulation tissue growth is enhanced by NPWT, delayed selective reconstruction (by a combination of two or more reconstructive techniques such as skin grafts (SG), dermal substitutes (DS), and flaps) is planned to be performed when the wound is clean and the patient is prepared for operation (comorbidities under control, operation under general anesthesia possible, etc.).

How should patients with subacute traumatic wounds to lower limbs be treated? Is it possible to achieve results comparable to the results of contemporaneous acute wound closure? [4, 5].

2 Patients and Methods

We first manage subacute wounds conservatively by "assisted healing" and only after that by "delayed selective reconstruction." "Assisted healing" stands for trying to assist and speed up the natural healing process by fighting infection, by supporting and enhancing wound bed preparation (granulation tissue growth), and by treating comorbidities.

During this time the subacute wound is cleaned (when possible without any blood loss) by multiple conservative/operative debridements using hydrosurgery or piezoelectric scalpels, thus selectively removing only definitively necrotic tissues until it is macroscopically clean [12–16]. Excised tissues, including bone fragments, are sent for microbial tissue culture and definition of susceptible antibiotics (antibiogram) in order to program targeted antibiotic therapy. This phase is combined with optimal dressing care and/or, when indicated, negative pressure wound therapy, which decreases edema and promotes formation of granulation tissue (Figs. 1 and 2) [8–10, 17–23].

The aim of "assisted healing" is to reduce the size of the soft tissue defect requiring flap coverage by growing granulation tissue which leads to an increase of the wound surface that can be closed by dermal substitutes and skin grafts only (Fig. 2). Each patient is carefully assessed for comorbidities, which can impair the healing process.

Respiratory and cardiac problems are treated first, followed by correction of hypoproteinemia by appropriate nutrition. The healing potential is increased by revascularization of stenotic/occluded arteries by PTA, by providing glycemic control, by targeted antibiotic therapy, by offloading, and by compression therapy (Fig. 3).

During the wound bed preparation phase, the reconstruction is being planned. All reconstructive techniques (skin grafts, dermal substitutes,

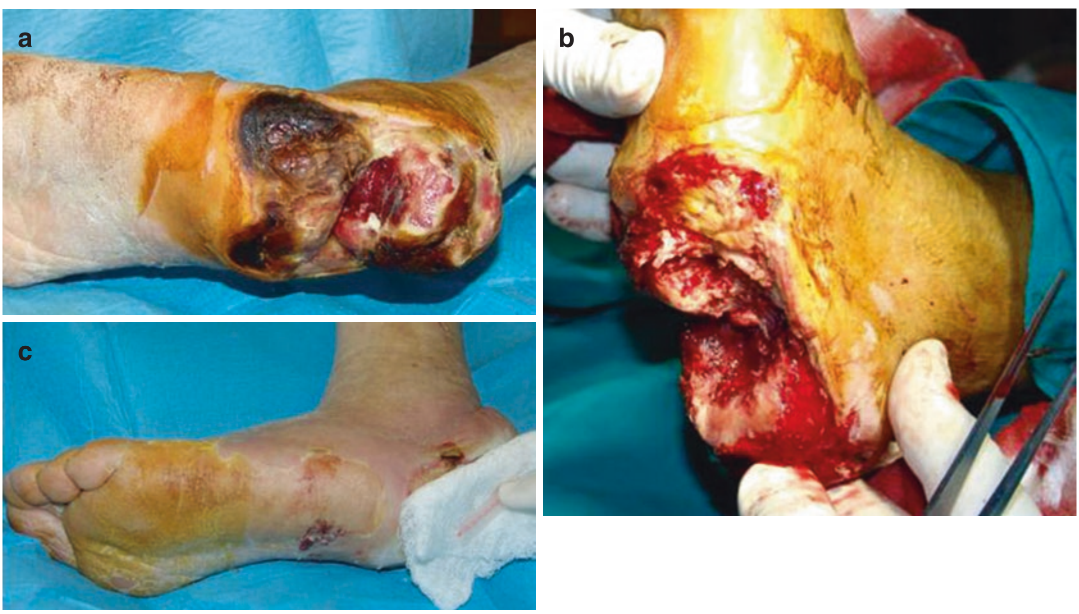

Fig. 1 (**a**) Open fracture of the calcaneus in a diabetic patient 3 weeks after injury. Note: extensive soft tissue defect on a weight-bearing zone, presence of necrosis and serous-purulent discharge. (**b**) First operation 3 days after admission: (conservative) debridement of soft tissues and bone. (**c**) First operation 3 days after admission: placement of NPWT (VAC®) after debridement

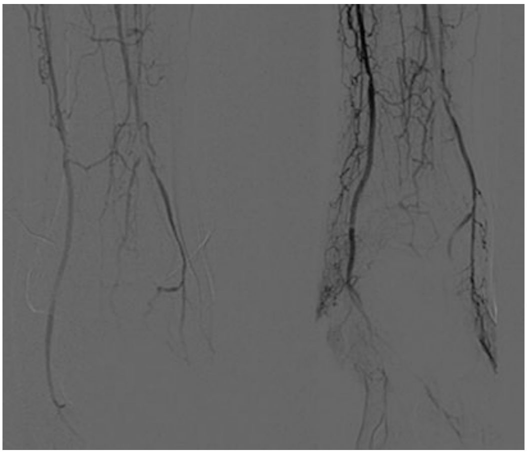

Fig. 2 (Left) Angiography of the lower leg after first debridement, performed on basis of partial tissue oxygen pressure level less than 20 mmHg measured the day before, showing poor perfusion of the foot. (Right) Angiogram after PTA performed during the same session showing improved perfusion of the foot

and all types of flap) are being considered alone or in combination to be used when necessary. Only when required, flaps are planned focusing on the requirements of the recipient site (size, thickness), tissue composition, but also the donor site (little/no functional deficit, hidden scar). For these reasons we are talking about delayed "selective reconstruction."

The goal of "selective reconstruction" is to use flaps only when truly necessary and cover areas that present granulation tissue, promoted during the assisted healing period, by dermal substitutes and skin grafts: in this way, the reconstruction requires flaps that are smaller in size, thus leading to better functional and esthetic results (Fig. 4)

The other available possibility would be a surgical conversion of the subacute wound into an acute one, by super radical debridement at the

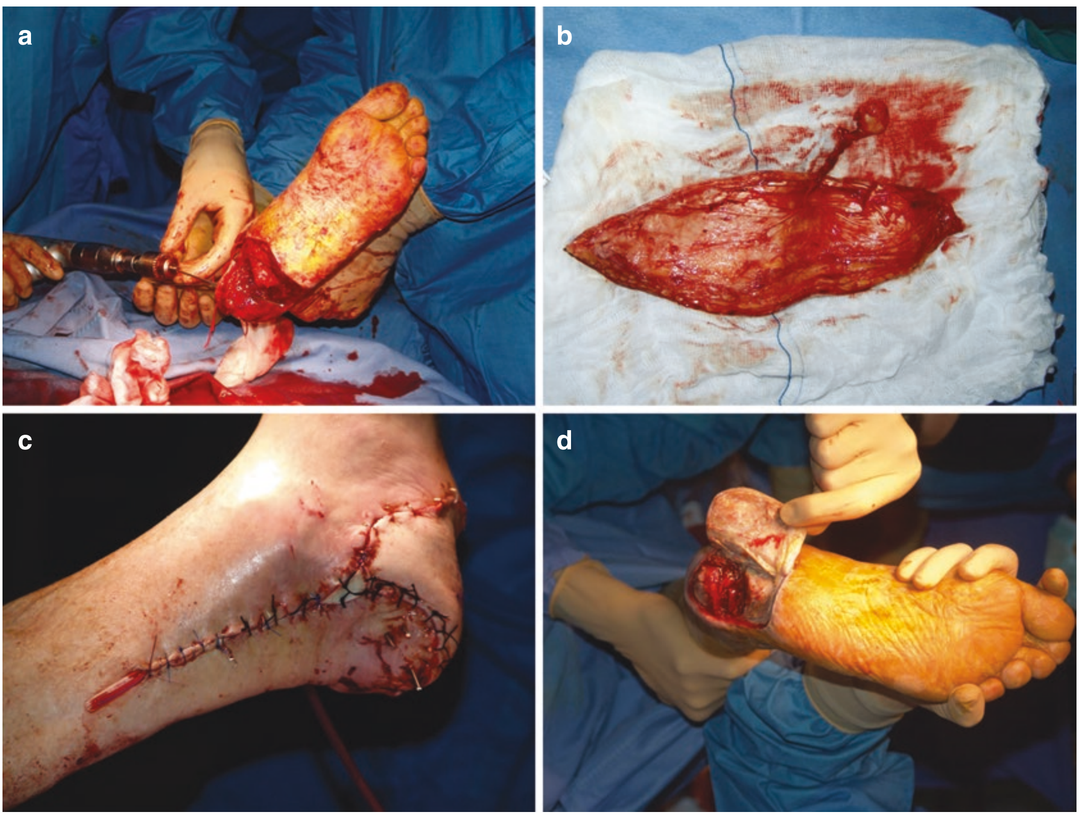

Fig. 3 (**a**) Second operation, 1 week after revascularization by PTA, consisted of radical wound debridement, bone fixation by two K wires, and wound closure by free ALT flap. (**b**) Free ALT fascio-cutaneous perforator flap. (**c**) Result after the second operation. Note: well-perfused flap, access to the posterior tibial vascular axis for end-to-side microvascular anastomosis, two percutaneous K wires for calcaneus fixation. (**d**) Third operation 5 weeks after radical debridement, bone fixation, and free flap transfer: cancellous bone grafting to the calcaneal bone defect

Fig. 4 Full weight-bearing and walking in normal shoes 6 months after last surgery showing good shape of calcaneus and healed fracture

cost of larger soft tissue defects and more chance of loss of function afterward. Further damage would be created at the flap donor site since larger flaps would be required for coverage; moreover, such operations, without managing comorbidities properly, can carry to increased risks of immediate systemic and local complications.

3 Results

During the period from 2007 to 2017, we treated subacute wounds on lower extremities by AH-DSR method in 34 patients (20 males [58.8%] and 14 women [41.2%]) with a mean age of 49.6 years (range, 16–88 years) (Table 1). Sixteen patients (47%) presented with a concomitant fracture: 1 (2.9%) had a Gustilo-Anderson (GA) type II fracture, 5 (14.7%) had GA IIIA fractures, and 18 (29.4%) had GA IIIB fractures [1, 2]. Eighteen patients (53%) had a lower limb injury with no fracture associated. All lower limbs sustained some degloving: 17 (50%) pattern 1, 13 (38.2%) pattern 2, and 4 (11.8%) pattern 4, according to Arnez et al. soft tissue degloving classification [24, 25].

The dimensions of soft tissue defect ranged from 28 to 880 cm^2 (mean 203.8 cm^2). The number of operations per patient ranged from one to five (mean 2.9) most of which were surgical debridements. Negative pressure wound therapy (NPWT)

Table 1 Patients' demographics, mechanism of injury, associated fractures, type of reconstruction, follow-up, and complications

Case	Sex	Age	Trauma	Poly-trauma	Fracture	Degloving	Operations	Hospitalization (days)	Follow-up (days)	Size (cm²)	Debridements	Antibiotic therapy	NPWT	Reconstruction	Complications
1	M	16	Road traffic injury	Yes	IIIB	1	4	47	96	750	2	Yes	No	ALT + DS + SG	Osteomyelitis
2	M	28	Road traffic injury	No	IIIB	1	3	61	36	150	2	Yes	No	ALT	No
3	F	21	Road traffic injury	Yes	–	1	3	39	18	100	2	Prophylaxis	Yes	DS + SG	No
4	F	80	Road traffic injury	No	IIIA	1	3	74	90	300	2	Yes	Yes	SG	No
5	M	56	Crush	No	IIIA	2	3	49	80	200	3	Yes	Yes	SG	No
6	M	48	Road traffic injury	Yes	IIIA	2	4	30	76	100 + 30	3	Yes	No	SG	Pseudoarthrosis
7	F	76	Road traffic injury	No	IIIA	1	2	33	12	150	1	Prophylaxis	No	SG	No
8	F	22	Road traffic injury	Yes	–	1	4	9	16	80 + 8	3	Yes	No	DS + SG	No
9	M	22	Road traffic injury	No	IIIB	2	4	20	30	36	2	Prophylaxis	No	SG	No
10	M	39	Road traffic injury	No	–	2	2	15	30	250	2	Yes	Yes, instill	SG	No
11	M	16	Road traffic injury	Yes	IIIB	2	3	61	57	100	3	Yes	Yes, instill	ALT + nerve graft	No
12	F	64	Fall	Yes	II	2	3	161	34	40	3	Yes	Yes	SG	No
13	F	29	Road traffic injury	No	–	2	5	53	44	75	3	Yes	Yes	SCIP + DS + SG	Venous thrombosis
14	M	55	Road traffic injury	Yes	IIIA	1	2	31	90	72 + 8 + 8	2	Yes	No	SG	No
15	F	76	Road traffic injury	No	–	2	3	59	30	200	3	Yes	Yes	SG	No
16	F	37	Road traffic injury	No	IIIB	2	4	47	18	40	4	Prophylaxis	Yes	Ulnar flap + palmaris longus + DS + SG	No
17	F	87	Road traffic injury	No	I- > IIIB	1	4	41	30	28	2	Yes	Yes	Local fascio-cutaneous flap	No

18	M	25	Road traffic injury	No	IIIB	4	3	61	90	50	2	Yes	Yes	ALT	No
19	M	49	Road traffic injury	No	IIIB	1	4	45	24	35	2	Yes	Yes	DS + SG	No
20	M	85	Fall	No	–	2	3	20	180	280	2	Prophylaxis	Yes, instill	SG	No
21	M	58	Fall	No	–	2	2	34	90	375	1	Prophylaxis	Yes	SG	No
22	M	30	Road traffic injury	Yes	–	4	3	30	600	880	1	Yes	Yes, instill	DS + SG	No
23	M	35	Road traffic injury	No	–	1	2	28	180	56	1	Prophylaxis	Yes	SG	No
24	M	29	Road traffic injury	Yes	–	1	3	37	180	50	2	Prophylaxis	Yes	DS + SG	No
25	M	51	Road traffic injury	No	–	1	2	31	60	20	1	Prophylaxis	Yes, instill	DS + SG	No
26	M	53	Road traffic injury	Yes	IIIB	2	4	80	360	280	1	Yes	Yes	ALT + DS + SG	No
27	F	59	Fall	No	IIIB	1	3	34	90	96	1	Yes	No	MSAP + DS + SG + local flap	No
28	F	70	Fall	No	–	1	1	11	30	48	1	Prophylaxis	No	SG	No
29	F	84	Fall	No	–	1	1	12	60	28	1	Prophylaxis	No	SG	No
30	M	20	Road traffic injury	No	–	1	2	25	30	105	1	Prophylaxis	Yes	DS + SG	No
31	M	62	Work injury	No	–	2	1	26	180	175	1	Yes	Yes	Local perforator flap + SG	No
32	F	88	Fall	No	–	1	2	28	30	220	3	Yes	Yes	SG	No
3	M	54	Road traffic injury	Yes	IIIB	4	4	120	110	600	2	Yes	Yes	DS + SG + ALT	No
34	M	61	Fall	No	–	4	1	21	10	600	1	Yes	No	SG	No

Fig. 5 (**a**) Open fracture of first metatarsal bone 2 weeks after injury. (**b**) After first debridement. Note: exposed extensor hallucis longus tendon requiring flap coverage and preserved dermis on the lateral dorsum of the foot which can be grafted by split-thickness skin grafts. (**c**) NPWT was started after the debridement

was used in 28 patients(82.3%), 23 times as VAC® and 5 times as VAC instill®. Antibiotics were given to all patients, in 12 (35.3%) as prophylaxis, as per our institution's guidelines, and in 22 (64.7%) as therapy, suggested by the infectious disease department consultants. The mean hospital stay was 34 days (range, 9–161 days).

The reconstruction was performed by split-thickness skin grafts (SG) in 16 patients (47%) (Fig. 5), by dermal substitutes (DS) in 8 patients (23.5%), by local fascio-cutaneous flaps in 2 patients (5.9%), and by free flaps in 8 patients (23.5%) (Fig. 6). All free flaps were planned in combination with DS and SG. In this case series, three (8.8%) complications were recorded: one osteomyelitis treated only with antibiotics, one intra-flap venous thrombosis in a free flap (complication that was solved through the revision of anastomosis), and one pseudoarthrosis that was treated by intramedullary nailing performed by

Fig. 6 (**a**) Ulnar artery perforator free flap (UAPF) after harvesting. (**b**) Result at the end of the second operation. Note: thin ulnar artery perforator free flap with anastomosis to the anterior tibial vessels covers the exposed tendon, whereas skin graft only is required for coverage of a partial thickness abrasion wound with preserved dermis

Fig. 7 (Left, middle, right) End result at 8 months after injury. Note: good functional and esthetic result. The patient is able to walk in normal shoes

our orthopedic surgeons. In addition, one free flap needed postoperative delayed debulking.

The mean follow-up was 90.9 days (range, 10–600 days)

Conclusions

Treatment of subacute traumatic wounds in the lower extremities by the AH-DSR approach in our case series is characterized by low infection rate (2.9%) and a low complication rate (8.8%), results comparable to other series [4, 5].

There was a single case of infection (an osteomyelitis treated without surgery, by antibiotics only). The complication rate was low in spite of the fact that we were dealing with complex wounds (47% were open fractures; 29% were GA IIIB open fractures [26, 27]). The three complications we recorded were the osteomyelitis described previously, a pseudoarthrosis of tibia resolved by intramedullary nailing in a wound covered by dermal substitute and SG, and an intra-flap venous thrombosis of a superficial circumflex iliac artery perforator flap which required operative revision resulting in a complete survival of the free flap. There was no free flap loss. Eight free flaps were used for coverage of open fractures and an exposed extensor hallucis longus tendon, and their average size was 192.6 cm^2 (range, 40–750 cm^2). Five anterolateral thigh (ALT) free flaps with a mean size of 266 cm^2 were used to provide coverage of larger defects, whereas smaller areas requiring thin flap coverage were treated by superficial circumflex iliac artery perforator free flap (SCIP) (75 cm^2), ulnar artery perforator free flap (UAPF) (40 cm^2) (Fig. 5), and medial sural artery perforator free flap (MSAP) (96 cm^2). Nine open fractures did not require free flap coverage and were managed by DS and SG only. Only one of them was complicated by the previously described pseudoarthrosis.

On the other hand, the wounds covered by dermal substitutes and SG averaged 202 cm^2.

The mean number of operations till final result was 2.9 (range, 1–5) per patient, while the average in-hospital stay was 34 days (range, 11–161).

These results are well comparable with the results of acute injuries treatment within 3 days of injury by the fix and flap principle [7].

By adhering to the AH-GSR approach and treatment of lower extremity subacute wounds, a surgeon can expect results which appear to be comparable to the ones obtained with the treatment of acute wounds during the first week after injury both in terms of function and esthetics (Figs. 4 and 7) [23].

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