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Soft tissue coverage in devastating hand injuries

Goetz A. Giessler, MD*, Detlev Erdmann, MD, Guenter Germann, MD, PhD

Department for Hand, Plastic and Reconstructive Surgery, Burn Center, BG Trauma Center Ludwigshafen, Plastic & Hand Surgery, University of Heidelberg, Ludwig-Guttmann-Strasse 13, 67071 Ludwigshafen, Germany

Mutilating hand injuries can be defined as severe multistructural injuries regularly including destruction of bones, tendons, soft tissues, and the integument to a various degree. The etiology includes burns, crush and degloving injuries, amputations, penetrating injuries, and high-pressure injections. Plastic surgical therapy is focused on early rehabilitation by restoration of functional anatomy and cosmesis. It represents a multifaceted task to the hand surgeon, where considerations about indication, timing, and structure of the soft tissue coverage play a major role in the reconstructive concept [1–3]. A sophisticated structural reconstruction of the osseotendinous framework is useless if not protected with adequate soft tissue cover. It is the soft tissue envelope of the hands that transfers touch, sensibility, temperature feeling, pinch, and grip. A stabile but flexible integument is also required for the extremely important individualized intensive physiotherapy after mutilating hand injuries. Furthermore, the hands are important instruments of interpersonal communication being some of the few constantly visible contact zones.

The complexity of soft tissue reconstruction after a devastating trauma [2] with the wide variety of possible tissue transfers from local, regional, or distant areas, sensate or not sensate, isolated or combined in shape and structure needs a systematic approach to adjust it to the individual case profile as follows:

Patient-specific factors (age, general health, mobility, comorbidity, profession, and socioeconomic status)
Defect genesis (crush, penetration, degloving, thermal, amputating, and so forth)
Localization
Size and depth
Exposed structures
Structures to be reconstructed
Contamination
Surrounding tissue (color, hair, and texture)

Algorithms based on the reconstructive ladder help in decision making about soft tissue coverage (Fig. 1) [2]. Based on the case profile, the quickest, easiest, safest, and best suited methods have to be used for the best possible outcome. This implies that even a sophisticated free flap procedure is no longer considered as an "ultima ratio option," but is chosen rather early, if it provides the best possible result. This is supported by a more aggressive approach with respect to procedure timing, which evolved in recent years. Encouraging data were provided by Godina [4], who showed that with early microsurgical reconstruction (up to 72 hours) following radical debridement, the postoperative morbidity, infection rate, and the number of subsequent procedures was significantly lower than with delayed or late operations. These results were supported by the data of Lister and Scheker [5] and Ninkovic et al [6] using emergency flap coverage within 24 hours after injury. All authors equally demonstrate successful long-term results both clinically and socioeconomically.

Reconstructive algorithms

Even if the concept of early integrative reconstruction promotes early vascularized flap coverage, a thorough wound preparation is still mandatory to prevent placement of a healthy flap

* Corresponding author.
E-mail address: giessler@hotmail.com (G.A. Giessler).

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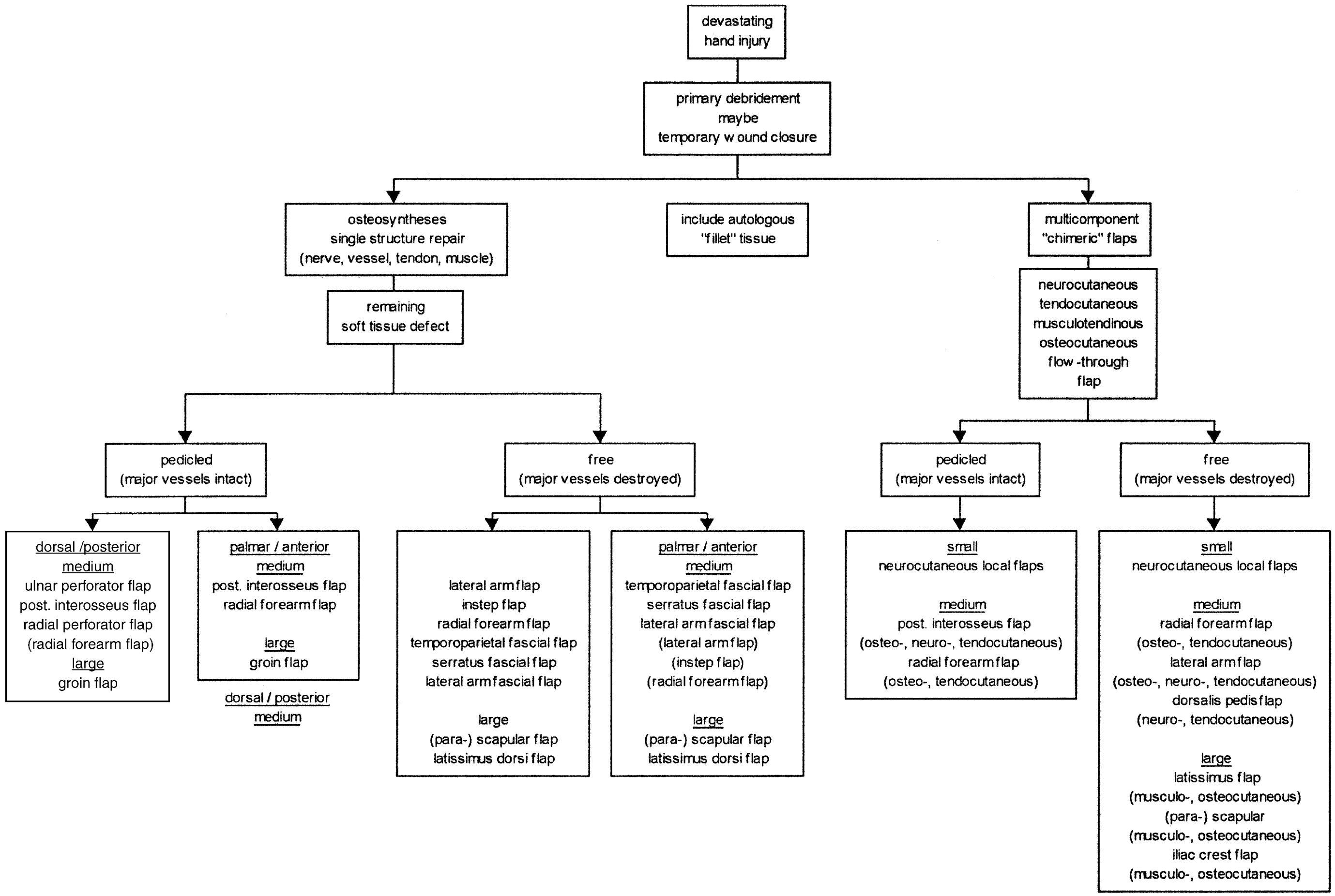

Fig. 1. Reconstructive algorithm for soft tissue coverage of devastating hand injuries.

in a contaminated wound bed with remaining devitalized tissue [1]. All reconstructive procedures must be preceded by a thorough surgical debridement. This is initiated by tissue cleaning using soft detergents, such as chlorhexidine. Pulsed irrigation (jet lavage) is rarely indicated in the delicate structures in the hand, but may help in wounds with large amounts of particulate foreign material. Necrotic and questionably viable material is carefully excised [7]; vital functional structures should be preserved whenever possible. The resulting defect after debridement is often much larger than previously estimated. In wounds with areas of indeterminate tissue viability, heavy contamination, or in a vitally threatened patient it is wise to close the wound temporarily. Vacuum sealing and drainage or skin substitutes provide adequate coverage until a scheduled second look is performed 24 to 48 hours later [8].

In devastating hand injuries, the surgeon rarely is confronted with superficial skin losses, which can be closed with various techniques of split- and full-thickness skin grafting [9]. The high contracture potential, limited scar flexibility, and disappointing sensibility limit their successful use in hands, except in donor site coverage of some locoregional flaps. Although both grafting techniques still play a central role in burn surgery, meshed skin grafts should be definitively avoided in the hand.

Local flaps

Complex, full-thickness losses of the integument are more frequently encountered in complex trauma to the hand. In the hand, it can be difficult to replace "like with like" by local flaps, because the availability of surrounding tissue can be scarce, especially in the digits. Local flaps often play only a minor role in mutilating injuries, but can still be of importance in special reconstructions (ie, by providing sensibility to the fingertips).

Nevertheless, the reconstructive surgeon has always to take into account the additional operative trauma to the extremity, which results in scar formation, and may acutely or chronically impair lymphatic and venous drainage. There is an abundance of local flaps in the hand, but the hand surgeon dealing with mutilating hand injuries should be familiar with some reliable examples. Fingertip amputations can often be treated with various transposition flaps [10,11] to provide a stable fingertip with acceptable two-point discrimination. Smaller defects on the lateral aspect and the dorsum of the fingers are preferably closed with pedicled flaps, especially when the extensor tendon mechanism is exposed. Cross-finger flaps [12], flaps based on the dorsal metacarpal arteries [13], and various sensate kite flaps [14,15] bring their own blood supply and provide stable coverage, rapid healing, and good pliability. Their donor sites are homodigital or heterodigital or from the dorsum of the hand, and are closed primarily or with small skin grafts.

In severe hand injuries with involvement of several regions of the hand, availability of local flaps is frequently limited because of the potential damage of the donor area. Especially in crush injuries and high-pressure injection trauma, tissue viability often cannot be estimated properly in the first hours after the trauma, significantly increasing the risk of using local solutions. In these cases, regional or distant flaps provide more safety.

Regional flaps

The development of axial-pattern regional flaps was a major breakthrough several decades ago [16], but their importance has somewhat decreased since the introduction of microsurgery. They can still be extremely helpful, however, where the latter is not available, and the use of a free flap is contraindicated or for other reasons is not possible.

The best known axial pattern flap in the upper extremity is the radial forearm flap, based on the radial artery. It can only be used if the patency of both major vessels is preserved, and an Allen's test has been performed before the operation. Although studies have shown that the perfusion of the hand is not decreased when the radial artery is missing, its use has decreased because the donor site leaves a significant aesthetic impairment. In young patients, preservation of limb vessels in case of possible future injuries seems wise. In general, pedicled flaps from the forearm should not be based on major vascular axis whenever this is permitted by the local conditions. The reverse pedicled posterior interosseous artery flap [17], the reverse ulnar perforator flap [18], or the reverse radial artery perforator flap can provide excellent results for mid-size soft tissue defects without sacrificing a major artery.

Distant flaps

One of the most important distant flaps is the groin flap [16]. It is used mostly as an ipsilateral pedicled flap, which is divided after 3 weeks, but can also be used as a free flap. The latter is used less frequently because of frequent vascular anomalies of the arterial pedicle [19]. The definite advantage of this flap is its donor site, where primary closure is often possible up to a width of 10 to 12 cm, and the scar easily can be hidden. The groin flap provides good coverage of defects for the hand and distal forearm. Because a relatively large skin area can be dissected with the pedicle, the flap has certain importance in wound closure of amputations (thumb), where the additional tissue can provide sufficient bulk for a later toe transfer [1]. It must not be forgotten that despite its easy dissection, the groin flap usually requires four to five procedures to obtain a definite result, which is in part caused by the variable volume of the flap depending on the patient's habitus. Finally, the patient treated with a groin flap needs to be very compliant throughout the whole pedicled phase, especially when physiotherapy is performed in this stage.

Free flaps

Microvascular free flaps demonstrate the highest versatility of all soft tissue coverage procedures and are among the first choices in treating mutilated hands. The main advantages are that they can be harvested in almost any size required; are raised from a distant donor site; bring their own blood supply and angiogenic and lymphogenic potential; and not only cover defects, but actively improve venous and lymphatic drainage of the traumatized area [20]. Although they are frequently inferior to local flaps regarding texture and color match, this is considered less important in mutilating injuries. In severely injured hands, often considerable areas of skin and subcutaneous structures are missing, and tendons, joints, vessels, or nerves are exposed. Free flaps have adequate dimensions, and allow harvesting of additional vascularized tissue components, which make complete single-stage reconstructive procedures possible (ie, chimeric flaps [see Fig. 1]) [21–23]. Free transfer of equivalent tissue from the contralateral hand should be performed exclusively in bilateral mutilating injuries carefully balancing the soft tissue situation in both extremities. The following free flaps are part of the standard armamentarium in soft tissue reconstruction of mutilated hands, and provide a wide variety of procedures for certain indications.

Parascapular, scapular, and latissimus dorsi flaps

These flaps belong to the subscapular artery system, and are established work horses in plastic surgery [24,25]. They can cover large defect areas, have reliable and long vascular pedicles, and can be combined with each other and other flaps of this vascular system (eg, M. serratus flap) [25,26]. The cutaneous parascapular flap yields good results especially in slim patients, and usually provides hairless skin. Equally important for upper extremity and hand defects is the possibility of gaining gliding tissue by simultaneous elevation of fascia. The latissimus dorsi muscle is one of the largest flaps of the body and extremely pliable, but may be bulky in the upper extremity. A skin island can obviate the need for a split-thickness skin graft (Case 1, Fig. 2). Both flaps can be harvested with a vascularized bone segment from the lateral border of the scapula (R. angularis), which can be used for structural reconstructions of skeletal injuries [27]. The donor site can always be closed primarily, and becomes inconspicuous under normal clothes.

Lateral arm flap

Clinically introduced by Katsaros et al [28] the cutaneous lateral arm flap is a versatile flap for medium-sized defects. It is mostly harvested ipsilateral, and structural elements, such as a humeral bone segment of several centimeters length or a tendon slip from the triceps muscle, can be harvested with it [22]. The posterior cutaneous nerve innervates the flap, which can make it useful for reconstruction of the first web space or the palm. Donor sites of up to 6 to 8 cm width usually can be closed primarily, but may still result in a conspicuous scar. The flap may have a distinct subcutaneous fat layer, which later requires debulking.

Radial forearm flap

Since its clinical introduction during the early eighties [29], the pedicled or free radial forearm flap represents one of the most popular flaps in reconstructive surgery [23,30]. The skin is thin, very pliable, and of good texture and color match in hand defects. The pedicle is long, large, and of constant anatomy, but includes one of the main arteries of the hand, which sometimes can impair perfusion to the hand. A preoperative Allen's test is mandatory. The main drawback of the radial forearm flap is the donor site, which usually has to be closed with a skin graft, frequently leaving unacceptable scars especially in young women. Dissection of the flap either includes the contralateral extremity into the surgical intervention where one side is already involved, or imposes additional donor site morbidity, such as tendon adherence

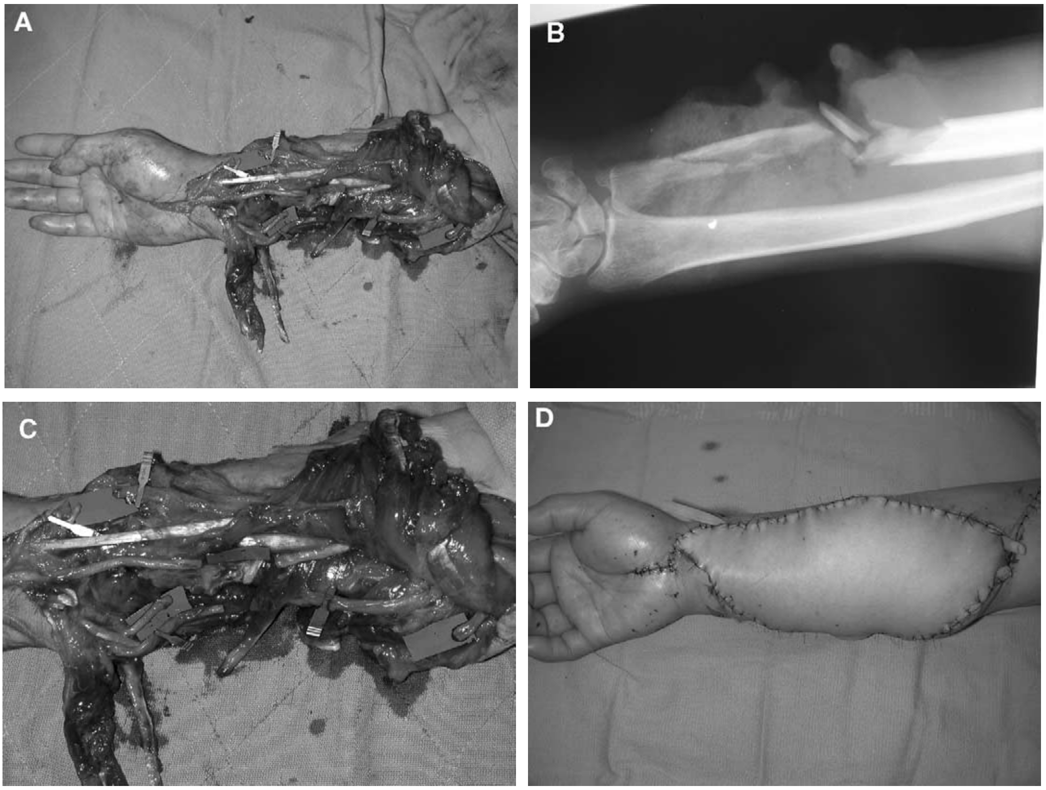

Fig. 2. (*A–D*) The patient was injured by a power saw cutting chain, which destroyed the complete anterior compartment of his right arm. Initial thorough debridement and plate osteosynthesis were followed by a segmental reconstruction of the radial and ulnar artery using an interposition saphenous vein graft. Both median and ulnar nerves demonstrated 8- and 10-cm long defects and were reconstructed with sural nerve grafts in the same operation. Torn muscles were adapted, tendons repaired, and the wound closed temporarily with a skin substitute. The remaining skin defect was closed 48 hours later with a myocutaneous latissimus dorsi free flap.

and lymphedema on the traumatized side. In the authors' experience, the forearm flap is no longer one of the prime choices in defect coverage in mutilating hand injuries.

Temporoparietal and serratus fascia flap

As a superior extension of the facial superficial musculoaponeurotic system (SMAS), this flap combines very thin and pliable tissue with a hidden donor site in patients with hair. Based on the superficial temporal vessels, it is one of the best flaps for the dorsum of the distal forearm, the hand, and the fingers (Case 2, Fig. 3) [31]. The authors have successfully used fascial flaps also in the palm (Case 3, Fig. 4). The skin grafts usually take easily on this well-vascularized gliding tissue, and provide sufficient mechanical stability. The temporoparietal fascia flap is of limited size, with an average of 12×8 cm in adults, whereas the serratus fascia flap measures approximately up to 15 $\times$ 20 cm. Care has to be taken about the auriculotemporal nerve when elevating the temporoparietal fascia with the usual Y- or T-shaped incision (Fig. 3B) [32]. The long thoracic nerve has to be spared when the serratus fascia flap is raised.

Discussion

Soft tissue coverage of mutilated hands is not seen distinct from the other reconstructive steps, such as osteosynthesis and tendon reconstruction, but rather is integrated into the strategic surgical concept. This is especially demonstrated by the growing field of multicomponent chimeric flaps [21–23]. The concept of early primary reconstruction (including emergency procedures) and fast rehabilitation should be pursued. It can result in excellent outcomes in the hands of an experienced

Fig. 3. (*A–F*) A 40-year-old taxi driver sustained a severe tangential tissue loss on three long fingers as his arm was forced out of his car during a motor vehicle accident. After initial thorough debridement the fractured distal phalanx of the fifth finger was stabilized with a K-wire, missing extensor tendon structures were reconstructed by palmaris longus tendon, and the three injured fingers were syndactylized by running nylon sutures. A free microvascular temporoparietal fascia flap covered with a split-thickness skin graft was used for closure and connected to the radial artery and a neighboring vein. The hand was splinted during healing. Seventeen days later the fingers were divided again and individual physiotherapy for each finger achieved excellent results.

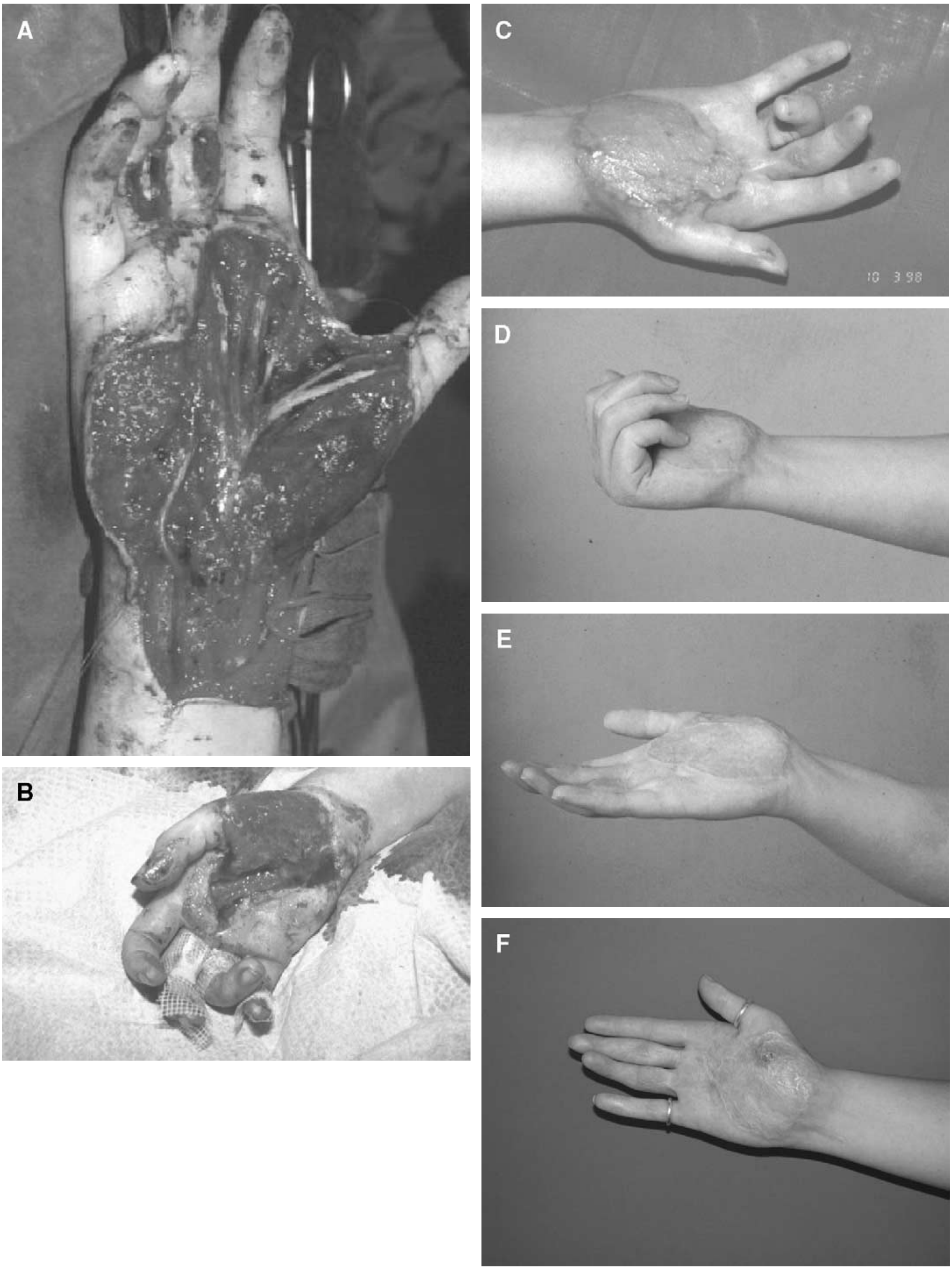

Fig. 4. (*A–F*) A bicycle accident from this 28-year-old female soccer team keeper resulted in a degloving-avulsion injury to her right palm. No tendons or nerves were injured, but the skin defect after debridement was quite large. A serratus fascia free flap was dissected and transplanted to the injured area, covered with a split-thickness skin graft. The extremity was splinted for healing. Subsequent physiotherapy was limited by flexor tendon adherence, so surgical tenolysis was performed directly through the well-healed flap, which resulted in a good functional outcome.

hand-plastic-micro surgeon including either single-stage (Case 3) or multistage procedures (Cases 1 and 2). Mastering of a wide spectrum of surgical techniques is mandatory for success.

Caution is recommended in evaluation of the burn, crush, and injection injuries, because the assessment of tissue viability can be extremely difficult in these cases [33]. A proper temporary wound closure followed by a second look may improve the chances for a successful definitive closure. Forced one-stage reconstructions carry an inherent risk of failure if the complexity of the case is not matched by the correct assessment of the problem, the infrastructure available, the individual surgical experience, and the available surgical solutions. A realistic assessment of the case profile and of one's own surgical abilities is of direct benefit for a patient with a mutilating hand injury, and markedly increases the chances for good long-term results.

Case 1

A 35-year-old patient was injured by a jammed power saw, and the cutting chain destroyed the complete anterior compartment of his right arm. After initial thorough debridement and osteosynthesis, a segmental reconstruction of the radial and ulnar artery was performed using an interposition saphenous vein graft to salvage the avascular hand. The median nerve demonstrated an 8-cm defect and the ulnar nerve showed a 10-cm gap. Both were reconstructed with sural nerve grafts in the same operation. Torn muscles were coapted, tendons repaired, and the wound closed temporarily with a skin substitute. Intravenous antibiotics started preoperatively were continued. The remaining skin defect was closed 48 hours later with a myocutaneous latissimus dorsi free flap (see Fig. 2).

Case 2

A 40-year-old taxi driver sustained a severe tangential tissue loss on his left middle, ring, and small finger as his arm was forced out of his car during a motor vehicle accident. After initial thorough debridement the fractured distal phalanx of the fifth finger was stabilized with a K-wire, missing extensor tendon structures were reconstructed by palmaris longus tendon, and the three injured fingers were syndactylized by running nylon sutures. A free temporoparietal fascia flap was harvested from the right side and anastomosed to the radial artery and a neighboring vein on the injured hand. It was covered with a split-thickness skin graft and the hand was splinted during healing. Seventeen days later the fingers were divided and individual physiotherapy for each finger achieved excellent results. No further surgery was needed (see Fig. 3).

Case 3

A 28-year-old keeper of a German female soccer league team suffered a bicycle accident with a degloving-avulsion injury to her right palm. Fortunately, no tendons or nerves were injured, but the skin defect after debridement was quite large. A serratus fascia flap was dissected and transplanted to the injured area, covered with a split-thickness skin graft, and the extremity splinted for healing. Subsequent physiotherapy was limited by flexor tendon adherence, so surgical tenolysis was performed directly through the well-healed flap resulting in a good functional outcome (see Fig. 4).

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