Spare-Part Surgery

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Abstract

The authors discuss the use of scavenged tissue for reconstruction of an injured limb, also referred to as “spare-part surgery.” It forms an important part of overall reconstructive strategy. Though some principles can be laid down, there is no “textbook” method for the surgeon to follow. Successful application of this strategy requires understanding of the concept, accurate judgment, and the ability to plan “on-the-spot,” as well as knowledge and skill to improvise composite flaps from nonsalvageable parts. Requirements for limb reconstruction vary from simple solutions such as tissue coverage, which include skin grafts or flaps to more complex planning as in functional reconstruction of the hand, where the functional importance of individual digits as well as the overall prehensile function of the hand needs to be addressed right from the time of primary surgery.

Keywords

- spare parts
- microsurgery
- reconstruction
- replantation
- trauma

The incorporation of the concept of spare-part surgery allows the surgeon to carry out primary reconstruction of the limb without resorting to harvest tissue from other regions of the body.

Limb-mutilating injuries result in significant impairment with each patient presenting with a unique pattern of injury and tissue loss. It is a challenge for the surgeon to restore effective function and appearance of the hand.

A well-planned strategy with the form and functional goal of the hand in mind from the time of presentation is essential. Poor planning and judgment can result in an extended period of treatment, multiple surgeries, and patient morbidity with suboptimal functional results.

When tissue needs to be harvested from donor sites for reconstruction, this may be in the form of single tissue grafts such as skin, bone, nerve or veins, or vascularized composite flaps. These procedures invariably require violation of pristine sites in the body with additional donor site morbidity. The surgeon needs to achieve a compromise between the gain of function from reconstruction of the injured limb versus the morbidity of harvesting from an uninjured donor site. An alternative strategy is to scavenge tissue for reconstruction from parts that are nonsalvageable and will be discarded.

An interesting parallel to the philosophy of spare-part surgery can be drawn from Sun-tzu's *Art of War*, the ancient Chinese text on strategy, it states

A skillful warrior

Never conscripts troops a second time;

Never transports provisions a third

He brings equipment from home

But forages off the enemy.

It may be applied to reconstructive surgery when a skillful surgeon procures all the tissues necessary for reconstruction from the field (the site of injury) without exploiting the rest of the body for any fresh resources, i.e. tissues.

The Concept of Spare-Part Surgery (Tissue Scavenging)

Functional and aesthetic outcome guides surgical planning. In mutilating injuries, it is often impossible to achieve anatomical repair for all structures after removing the damaged tissues. Functional reconstruction is the logical treatment goal, which frequently involves soft tissue transfers. The

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surgical team needs to outline the entire treatment plan, which may involve staged surgery and be able to explain and communicate this with patients and their family.

Scavenging tissue components from nonsalvageable parts of the injured extremity to reconstruct more-critical parts of the hand loosely constitutes the concept of spare-part surgery. In essence, it can appropriately be called *tissue scavenging surgery*.

Spare-part surgery does not have an exclusive domain, but falls within the scheme of primary reconstruction of the limbs. The unique aspect of spare-part surgery in trauma is that the surgeon has to assess and create a strategy on the spot to maximize the use of tissues that otherwise would be discarded. This requires surgical expertise, experience, and planning at the time of primary surgery. Certain factors should be taken into consideration in the decision making, the first being prerequisites that must be satisfied when the surgeon contemplates spare-part surgery.

Prerequisites for Spare-Part Surgery

1. The spare parts need to have anatomical integrity and should preferably lie outside the zone of direct trauma.
2. Ischemia time should be within salvageable limits for revascularization for composite spare parts.
3. Reconstruction should offer better global function than primary amputation.
4. The spare part should serve a greater function when used for reconstruction of other parts than when being replanted in its anatomical location.
5. Use of spare parts should not exclude harvesting healthy tissue if it is necessary to obtain maximal hand reconstruction. If all the digits can be salvaged with the use of tissue from healthy donor sites, then that strategy should be adopted.

Soft Tissue Coverage versus Functional Reconstruction

Reconstruction is a very broad term. It incorporates procedures such as skin grafting for a simple skin defect to more complex microvascular free flaps and transposition of digits. Scavenging tissue for coverage as done in a limb stump reconstruction is simple compared with applying the same concept to the reconstruction of the hand where more-complex functional aspects have to be considered.

Principles of Primary Hand and Limb Reconstruction

Every injury presents a unique problem to the surgeon. An approach based on principles rather than a cookbook approach allows the surgeon flexibility to individualize the reconstruction and optimize functional outcome. In essence, the aim of any hand reconstruction is to achieve satisfactory prehension with sensory feedback. Midgely and Entin¹ in 1979 stipulated “strength, position, length, stability, mobility, and sensibility” as the six basic requirements in a functioning hand. All reconstructive procedures are aimed to address these requirements.

Our approach can be divided into the following stages:

1. Debridement
2. Assessment and planning
3. Technical execution (reconstruction)

Debridement

This is the first step in any limb trauma and it is the only way to reduce bacterial load for early commencement of a reconstructive procedure. The debridement aims to convert a dirty contaminated wound into a clean surgical wound by removing all tissue that is devitalized, that is of marginal viability, or contused and likely to be nonfunctional. The approach is similar in concept to tumor surgery. Currently, there is little role of staged debridement. A staged debridement may preserve some extra tissue, but it delays coverage of vital tissues and allows time for infection and desiccation of exposed structures.

According to Buchler and Hastings,² a conservative approach with preservation of contused and partially devascularized structures can result in fibrosis and scarring, which compromises the ultimate functional result.

Function-Centered Assessment of Hand Trauma

As proposed by Buchler and Hastings,³ assessment can be organized in terms of the eight different tissues present in the hand and loss of each tissue determined separately: dorsal skin, extensor tendons, bones, joints, flexor tendons, nerves, vessels, and palmar skin. This scheme allows a structural approach to the planning of primary reconstruction.

In addition to a tissue-oriented assessment in reconstruction of the hand, we prefer a function-centered approach. Different digits have different functional significance; the approach is based on the following considerations.

The Thumb

The thumb as the opposing digit forms 40% of hand function and is a priority in any reconstructive procedure and is essential for the majority of hand grips except hook grip and lateral pinch. A replanted thumb provides a better function than any other reconstructive procedure or prosthetic device.⁴ Reconstruction of a functional thumb has the highest priority. Ideal reconstruction involves an opposing thumb with adequate sensation, mobility, and strength; the most basic requirement is a static post.

The best available amputated segment of another finger as a spare part should be allocated for thumb reconstruction.

Radial and Ulnar-Sided Fingers (Position of Fingers Relative to the Thumb)

The index and the middle finger are preferentially used in precision grips whereas the ulnar digits (ring and little fingers) are used for span and power grip functions. Discussing and understanding the functional needs of the patient forms the cornerstone of decision making. A manual worker will have greater emphasis on span and grip, with the ulnar digits assuming more importance, whereas a white collar worker may put greater priority on his radial digits.

More-prehensile digits will obviously result in better function of the hand; hence, in a situation of multiple-digit injury, attempts should be made to salvage as many digits as possible. When not all of the digits can be salvaged, and the thumb remains intact, the aim is to restore the width of the palm by replanting or transposing digits to the ulnar side.⁵

Heterogenous Nature of Injury

Mutilating injuries of the hand generally involve digits in a heterogeneous pattern, which means some digits are less severely damaged than others and have a higher possibility of salvage with better functional outcome compared with others. These digits should be prioritized for salvage, whereas the more severely injured digits may be used as a source of spare-part tissue. In situations of replant, the best-preserved amputated segments are often replanted to the best-preserved stumps.

The main issue here is to define the severity of injury. Though there are no objective methods, the following factors provide an adequate guide to the surgeon.

1. Cross-sectional evaluation: The number of tissues damaged may be organized in terms of the layers of the hand. It includes the eight tissues mentioned earlier. The greater the number of tissues that are damaged, the greater is the severity of injury and may translate to poorer functional outcome.
2. Longitudinal evaluation: This refers to the extent of the zone of injury. Injuries caused by sharp objects have a narrow zone of injury, whereas crushing injury caused by large or blunt objects have a wide zone of injury to the tissues. The tissues within the zone of injury are usually unsuitable for repair and need to be replaced. In addition to the need for a more-complex reconstruction, a wider zone of injury also adversely affects the survival and functional recovery of the injured part.
3. Characteristics of tissue injury: The characteristics of tissue injury are determined by the directional characteristics of the injuring force. A tangential force may result in skin or vascular avulsion whereas a narrow edge striking the limb in a perpendicular direction may cause a clean amputation. In both these situations, the survival as well as functional recovery of the finger or the limb may be different.
4. Contamination of tissues: This refers to the extent and nature of environmental contamination. This again is a subjective assessment. The nature of contamination will determine postoperative infection. Contamination is usually dealt with by debridement through a healthy margin. In certain circumstances, especially those involving extensive biological contamination, it may be wiser to stage the reconstruction following an initial debridement.

Natural Learning and Adaptation

A patient with an opposable thumb and any available digits, ulnar or radial, with adequate length and mobility is able to adapt to both pinch and grip functions (► Fig. 1).

The patient shown is a young girl with loss of radial digits on the left hand and the ulnar digits on the right hand as a result of congenital ring constriction syndrome. The figure shows effective chuck pinch in both the hands. Younger patients have a

Fig. 1 A young girl with loss of radial digits on the left hand and the ulnar digits on the right hand as a result of congenital ring constriction syndrome. The figure shows effective chuck pinch in both the hands irrespective of position of digits relative to the thumb.

much greater capacity for adaptation and learning; hence, every attempt should be made to salvage the amputated parts. It will take many years of experience in treating hand trauma to be able to prognosticate about the learning and adaptation capabilities of each patient we come across.

Technical Aspects of Spare-Part Surgery

Planning and Pacing the Surgery

A concept of triaging the digits in terms of functional importance and salvageability immediately after the debridement and before commencing reconstruction is important. The greatest energy and priority should go toward salvaging digits that will give the patient the most function. This could be the least injured digits in the hand. It provides a clear roadmap that helps to divide a long surgery into clearly defined substages. The more severely injured digits may involve a lot of work and energy to salvage, but provide uncertain or little function even if it is successful. This can tire and frustrate a surgical team that does not do an initial critical triage and plan ahead.

We feel that a practical approach to maximize hand function would be to prioritize reconstruction based on severity of injury rather than location.

1. Thumb ray reconstruction is the first priority.
2. The least injured fingers are then salvaged irrespective of the position.
3. The best amputated segment is transferred to the best available stump.
4. Severely traumatized fingers may be used as a source of reconstructive components.

Spare-part surgery can be stratified into various levels of complexity. The surgery may be divided into graft harvest and vascularized tissue harvest.

Individual Tissues as Grafts

This is the commonest form of spare-part surgery.

Amputated or nonsalvageable components can be used as sources of tissue grafts. These include skin grafts, nerve grafts,

arterial or vein grafts, and bone grafts for reconstruction of the remaining hand or the limb.

These components fall within the “zone” of injury and a careful assessment is necessary, especially for vascular and nerve grafts where there is a high chance of surgical failure if injured segments are used.

Vascularized Flaps

Microsurgical techniques allow a more complex level of reconstruction. The nonsalvageable segments can be used as a source of vascularized tissue. Vascularized flaps can be stratified in terms of complexity as follows:

1. Pedicled filleted skin flap from an injured digit (case illustration 1)
2. Single digit as a source of digital transposition, nerve and vessel grafts, and filleted skin flap (case illustration 2)
3. Free flap harvested from an unsalvageable leg (case illustration 3)
4. Digit transposition (case illustration 2)

A detailed discussion on flaps has been presented by Kuntscher et al.⁶

This form of surgery requires expertise in microsurgery and an understanding of vascular anatomy of various tissues. Once successful, these surgeries may obviate the need for major secondary reconstructive procedures as well as donor sites. This useful concept has been frequently applied in hand injuries, major limb trauma, as well as major amputations in tumor surgery. Katsaros has described an extreme example of a free filleted “whole arm flap” in tumor surgery.⁷ Free vascularized flaps in nonsalvageable major amputations have been described by various authors.^{8–11}

Digit Transposition

Transposition of digits is an important concept in patients with multiple digit amputations, where some of the amputated digits are deemed nonsalvageable.

The healthy stumps are identified and used for restoration of digits based on the principles illustrated above.

Fig. 2 This 60-year-old patient suffered a severe crush injury to the index finger and the middle finger. It was a zone 2 amputation of the index at the proximal interphalangeal joint. The middle finger was devascularized with a volar soft tissue defect, with intact interphalangeal joints and no fractures.

The thumb is given the highest priority in the reconstructive scheme. The digits are replanted based on the philosophy of best finger to the best stump to reconstruct basic hand function.⁵

Application of Spare-Part Surgery in Late Reconstruction

Spare-part surgery in late reconstruction of the hand is a relatively uncommon concept. This concept stems from the idea of performing secondary reconstructive procedures to enhance the function of the hand without violating an uninjured site or creating any additional donor-site morbidity.

Fig. 3 (A) The index finger was sacrificed and a neurovascular island flap was fashioned based on the ulnar digital artery and nerve of the index finger simultaneously providing soft tissue cover, revascularization and reinnervation to the middle finger without violation of any other donor site. (B,C) Long-term functional outcome following the procedure.

A less-useful digit is sacrificed as a donor to enhance the function of the remaining digits. These procedures may be more acceptable to the patient compared with late reconstructive procedures involving newer donor sites.

Katsaros⁷ described the use of the great toe from a foot being amputated for chronic osteomyelitis to reconstruct the thumb. We have used this concept in enhancing the length of two finger stumps sacrificing the third finger proximal stump (case illustration 4).

Case Illustrations

We have selected four case illustrations to show the different applications of spare-part surgery in hand and lower limb reconstruction.

Case Illustration 1

A Pedicled Neurovascular Island Flap from an Injured Digit for Revascularization and Soft Tissue Cover of a Second Digit (►Figs. 2 and 3)

This 60-year-old patient suffered a severe crush injury to the index finger and the middle finger. It was a zone 2 amputation of the index at the proximal interphalangeal joint. The

middle finger was devascularized with a volar soft tissue defect, with intact interphalangeal joints and no fractures (►Fig. 2).

The index was terminalized at the proximal phalanx level as a zone 2 replant would result in stiffness. A neurovascular island flap was harvested from the stump of the index finger based on the ulnar neurovascular bundle (►Fig. 3A) and transferred to the middle finger.

The digital artery of the flap was used to revascularize the middle finger by anastomosis to the distal radial digital artery of the middle finger, providing a good size match with adequate vessel length. The ulnar digital nerve of the index was anastomosed to the radial digital nerve of the middle finger, thus simultaneously providing soft tissue cover, revascularization, and reinnervation to the middle finger without violation of any other donor site (►Fig. 3B and 3C).

Case Illustration 2

Use of Single Digit as a Source of Digital Transposition, Free Flap, and a Pedicled Flap (►Fig. 4)

This 40-year-old patient suffered a vehicle rollover crush injury to the left hand (►Fig. 4A and B). On assessment, the

Fig. 4 (A,B): Roller injury to the right hand. The distal phalanx of the thumb is amputated, the index finger is devascularized with soft tissue degloving. The middle finger had segmental injury with proximal phalanx fracture and devascularization; the ring finger had a proximal phalanx fracture. There was a dorsal skin defect over the hand. (C) The most severely injured finger (the index finger in this case) was harvested as the source of spare parts and divided into two halves. (D) Distal half of the index finger is microsurgically transferred to the thumb. Proximal index finger used as source of artery and nerve for grafting for revascularization and digital nerve reconstruction of the middle finger. Remnant skin from the index finger was used as a fillet flap to cover the dorsal skin defect. (E) A posterior interosseous artery flap performed at a second stage to cover the dorsal skin defect resulting from necrosis of the fillet flap harvested from the index finger. (F) Good long-term functional recovery following the procedure.

Fig. 5 (A,B) A traumatic below-knee amputation with severe soft tissue crush injury to the proximal leg and intact knee joint. (C) An innervated medial plantar flap is harvested from the sole as a free flap. (D) The medial plantar flap transferred to reconstruct a below-knee amputation stump preserving the joint. (E,F) Long-term outcome showing a well-healed below-knee stump.

distal phalanx of the thumb was amputated, and the index finger was devascularized with soft tissue degloving. The middle finger had segmental injury with proximal phalanx fracture and devascularization, the ring finger had a proximal phalanx fracture, and there was a dorsal skin defect over the hand.

The planning was based on prioritization of thumb reconstruction and the use of components from the most severely injured digit, which was the index finger.

The sequence of the reconstruction was as follows:

1. Fixation of ring-finger fracture (least injured finger) while bench work was performed
2. Distal index finger-heterodigital replant to reconstruct distal thumb
3. Proximal index finger used as source of artery and nerve for grafting in the middle finger
4. Revascularization of the middle finger using index finger vessel and nerve grafts
5. Remnant skin from index used as a fillet flap to cover the dorsal skin defect

6. The filleted skin flap failed and a posterior interosseous flap was performed as a secondary procedure to cover the residual defect on the dorsum of the hand.

The patient had a good functional recovery and returned to his previous occupation.

Case Illustration 3

Prevention of Above-Knee Amputation Using the Sole as a Free Flap to Construct a Below-Knee Stump in a Nonreplantable Below-Knee Amputation (→Fig. 5)

The patient presented with a crush amputation of the left leg following a road traffic accident. In view of the wide zone of crush injury, a replantation was not feasible and there was lack of healthy soft tissue for a below-knee stump. An above-knee amputation was considered as the option. To solve the problem of lack of tissue for a below-knee stump, an innervated medial plantar flap was harvested from the amputated leg to provide the critical sensate soft tissue cover for the tibia, and the above-knee amputation was prevented.

Case Illustration 4**Spare-Part Surgery in Late Reconstruction: Staged Lengthening of Index and Middle Fingers Using the Ring-Finger Stump as a Free Osteocutaneous Fillet Flap (►Fig. 6)**

A patient suffered amputations of the index, middle, and ring fingers through the proximal interphalangeal joints (►Fig. 6A).

The patient was initially treated with debridement and closure of the wound.

The patient was keen for secondary reconstruction to improve the function and appearance of the hand, but was not keen for toe transfers.

Reconstruction was planned after detailed discussions with the patient.

The concept was to use existing stumps in the hand for aesthetic and functional reconstruction. The ring finger stump was chosen as the donor to the index and middle finger stump because the aim was for a tripod pinch; he had a normal little finger for grasp.

Fig. 6 (A) Amputations of the index, middle, and ring fingers through the proximal interphalangeal joints. (B–D) The ring finger stump was harvested with both neurovascular pedicles to match the recipient site. It was split longitudinally to provide lengthening to the index and middle finger stump. The index and middle finger were initially syndactylized to preserve venous drainage and provide adequate skin cover. (E) X-ray of the hand following transfer of the ring finger stump to the index and the middle finger stumps with syndactylization of the fingers. (F) The fingers were separated at a second stage, with additional skin grafting resulting in a three-fingered hand. (G) X-ray of the hand after separation of the index and the middle fingers. (H) Schematic diagram of the fillet harvesting procedure. (I) Schematic diagram of transplantation of the filleted finger to the recipient index and middle finger stump and digit, respectively.

The ring finger stump was harvested with both the neurovascular pedicles to match the recipient site. It was split longitudinally to provide lengthening to the index and middle finger stump. The index and middle finger were initially syndactylized to preserve venous drainage and provide adequate skin cover.

The fingers were separated as a second stage, with additional skin grafting resulting in a three-fingered hand (► **Fig. 6B–G**). Schematic representations of the tissue harvest and transfer procedures are shown in ► **Fig. 6H and 6I**.

Summary

In a complex limb trauma, the aim is early restoration of form and function of the limb with the minimum number of procedures and with low donor-site morbidity.

Spare-part surgery is a useful concept that addresses primary reconstruction while obviating donor-site morbidity, and should be used whenever possible. It is limited by availability of healthy tissue in the nonsalvageable segments, and depends greatly on the surgeon's expertise and the ability to plan primary reconstruction.

As emphasized earlier, spare-part surgery falls within the overall scheme of the reconstruction process and can be used alone or in combination with other reconstructive procedures.

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