Flap Decisions and Options in Soft Tissue Coverage of the Upper Limb

Michelle Griffin[1], Sandip Hindocha[*,2], Marco Malahias[3], Mohamed Saleh[4] and Ali Juma[5]

[1]*Department of Plastic Surgery. St. Georges Hospital, London, UK*

[2]*Department of Plastic Surgery, Whiston Hospital, Merseyside, L35 5DR, UK*

[3]*Department of Plastic Surgery. Good Hope Hospital, West Midlands, UK*

[4]*Department of Plastic Surgery, Ain Shams University. Egypt*

[5]*Department of Plastic Surgery, Countess of Chester Hospital, UK*

Abstract: Soft tissue deficiency in the upper limb is a common presentation following trauma, burns infection and tumour removal. Soft tissue coverage of the upper limb is a challenging problem for reconstructive surgeons to manage. The ultimate choice of soft tissue coverage will depend on the size and site of the wound, complexity of the injury, status of surrounding tissue, exposure of the vital structures and health status of the patient. There are several local cutaneous flaps that provide adequate soft tissue coverage for small sized defects of the hand, forearm and arm. When these flaps are limited in their mobility regional flaps and free flaps can be utilised. Free tissue transfer provides vascularised soft tissue coverage in addition to the transfer of bone, nerve and tendons. Careful consideration of free flap choice, meticulous intraoperative dissection and elevation accompanied by post-operative physiotherapy are required for successful outcomes for the patient. Several free flaps are available for reconstruction in the upper limb including the groin flap, anterolateral flap, radial forearm flap, lateral arm flap and scapular flap. In this review we will provide local, regional and free flap choice options for upper limb reconstruction, highlighting the benefits and challenges of different approaches.

Keywords: Groin flap, hand reconstruction, radial forearm flap, soft tissue coverage, upper limb reconstruction.

INTRODUCTION

Soft tissue replacement in the upper limb is a common challenge presented to surgeons following burns, tumour resection, infection and trauma. The quality of the reconstruction has a significant effect on the patient's aesthetic and functional outcome [1]. There are several options for soft tissue reconstruction in the upper extremity including skin grafting, local flaps, regional flaps and free flaps [1]. The preferred approach is the simplest method which can provide the most stable coverage. The mechanism, time, location and extent of soft tissue injury, severity of contamination, nature of the structure exposed and expected outcomes of spontaneous healing of the defect will dictate the soft tissue reconstruction options used in the upper limb [1]. Successful soft tissue coverage requires removal of all necrotic tissue, control of contamination and confirmation of a good blood supply [2, 3]. Soft tissue restoration will take place as early as possible to prevent wound infection and allow earlier patient recovery and rehabilitation [4-6].

Adequate repair of the soft tissue of the hand is vital to ensure restoration of the aesthetic appearance and importantly the function of the hand. The soft tissue in the hand is often repaired using skin grafts, cross finger flaps or thenar flaps when the surrounding soft tissue is available. Free flap radial forearm flaps and groin flaps are alternative options for large defect presentations. Soft tissue reconstruction around the elbow requires thin but durable tissue to be able to withstand flexion and extension of the elbow. Local and distal donor tissue has been used to repair soft tissue defects at the elbow. Arm defects require thin, pliable and hairless skin for optimal soft tissue coverage. Several local, regional and free flaps have been described and successfully implemented.

In this review, we aim to provide a summary of currently used soft tissue reconstruction flap options for the upper limb. We will provide a summary of flap techniques used to restore the soft tissue defects of the arm, elbow and forearm and hand.

HAND SOFT TISSUE RECONSTRUCTION

Flaps will be considered for hand reconstruction when the soft tissue coverage is unsuitable for the application of skin grafts, there is need for subcutaneous tissue as well as skin tissue replacement and for the coverage of important structures including nerves and joints [7].

LOCAL FLAPS

Local tissue provides an excellent option for coverage of the hand as it is a similar thickness, colour and quality. Advancement flaps, cross finger flaps and island flaps have been traditionally used for small hand defects.

*Address correspondence to this author at the Department of Plastic Surgery, Whiston Hospital, Liverpool, UK L35 5DR, UK;
Tel: + 44(0)1244366265; Fax: +44(0)1244366265;
E-mail: hindocha2001@yahoo.com

1874-3250/14

Advancement Flaps

Bilateral V-Y advancements flaps described by Kutler in 1947 are useful for transverse or dorsal fingertip injuries. These flaps are cut from the sides of the injured fingers and then advanced to the tip by dividing the fibrous septa. Volar advancement flaps are used for transverse or dorsal oblique finger-tip amputations or resections [8]. The entire volar surface of an injured digit can be advanced distally to reconstruct an injured finger-tip using the volar neurovascular advancement flap (Moberg flap) [9]. This flap is often indicated in the treatment of volar oblique and transverse defects of the thumb [9].

Transposition Flaps

Cross finger flaps are the commonest used flap to repair more complex digital defects. A rectangular segment of the tissue from the dorsum of the adjacent digit is dissected, elevated and then inserted over the defect [10]. Two weeks later the pedicle will be divided. Reverse cross finger flaps are a modification of the standard cross finger flap and can also be used for coverage of dorsal digital injuries [11]. A traditional cross finger flap is designed and then de-epithelised [11]. The resulting flap is then rotated 10 degrees to cover a dorsal defect of the adjacent finger [11]. The donor defect will need to be covered by a skin graft [11].

Island Flaps

Some useful local flaps to restore the digit and hand defects are from the dorsal side of the hand. The kite flap or first dorsal metacarpal artery (FDMA) flap was described first bydescribed by Hilgenfeldt, refined by Hollevich and modified as a pure island flap by Foucher. It is used to restore the thumb and dorsal soft tissue injuries [12, 13]. The flap is drawn on the dorsum of the index proximal phalanx from the MCPJ to the PIPJ [12, 13]. The pedicle is dissected to include the interosseous fascia with the three branches of the FDMA with the inclusion of superficial veins, radial nerve and radial artery [12, 13]. After the pedicle is raised the flap is transferred into the defect. The arc of the FDMA flap can achieve 7 cm in the adult allowing it to reach the thumb tip [14].

REGIONAL FLAPS

When local flaps cannot provide the cover required for skin defects regional flaps will be required.

Radial Forearm Flap

The radial forearm flap has shown to be an excellent flap for injured hands and is the most reliable and versatile flap for upper limb soft tissue reconstruction [15, 16]. The radial forearm flap can be used as a free flap or pedicled flap [15]. The flap is based on the radial artery and the accompanying venaecomitans. Medial and lateral antebrachial cutaneous nerves can also be included to provide sensation in the flap. The radial forearm flap can be used to cover the dorsum of the hand [17]. The advantages of the flap includes the provision of up to 8 x 10 cm of thin, pliable and hairless skin and ease of harvest [17]. Unfortunately, the radial artery is sacrificed and there is potential bulkiness and often poor donor site morbidity with this flap [17]. An Allen's test should always be performed prior to undertaking this flap, with a deficient palmar arch circulation, indicating this flap option is unsuitable for patients. However, the sacrifice of the radial artery has shown not to have a detrimental effect on the circulation of the hand [18]. Ulnar artery forearm flaps have been used but are less preferred.

Posterior Interosseous Artery Flaps

The posterior interosessous artery flap, a classic septocutanous fasciocutaneous flap is a very useful for coverage of the dorsum of the hand [19]. This flap can provide thin and pliable coverage, which is ideal for the back of the hand without compromising the two main arteries in the hand [19]. The flap is usually designed on the emergence of the artery in the posterior compartment of the proximal forearm [20]. The limits of the flap are distally 3-4 cm above the wrist crease, medially not to extend subcutaneous border of the ulnar and radially not extend 3-4 cm beyond the epicondylar-ulnar line [20]. The flap pivot point is usually proximal to the level of the inferior radioulnar joint [20].

ELBOW AND ARM SOFT TISSUE RECONSTRUCTION

Local Flaps

Similar local flaps available for the elbow and arm when local skin is healthy and viable including advancement flaps and Z-plasties [21]. Rhomboid flaps are useful around the elbow when the defect is small and the defect can be excised in a triangular shape [22]. Small elbow and arm defects can be covered using a proximal based radial forearm [23].

Lateral Arm Flap

This local pedicled fasciocutaneous flap is a useful flap for the elbow soft tissue coverage based on the posterior radial collateral artery (PRCA) and the septocutaneous perforators [24]. The flap provides the skin from the distal posterior lateral aspect of the lateral arm, between the deltoid insertion and the lateral epicondyle of the humerus. This flap provides thin, pliable skin with the donor site being primarily closed completely or partially. However, some surgeons will advocate this flap for men primarily as women may dislike the appearance of the donor site [24, 25]. This flap can be used for elbow defect due to a range of causes including burns, trauma, tumours or olecranon bursitis. This flap can be used as composite flap with the inclusion of bone (from the ulnar) or tendon [24, 25]. The vascular anatomy of the region allows the lateral arm flap to be used a 'reverse lateral arm flap' [26]. Tung *et al.* illustrated a full range of movement and healing using reversed lateral flaps for elbow soft tissue coverage in seven patients [26].

Latissimus Dorsi Flap

This flap is extremely useful for the arm as a pedicled flap providing a large skin coverage particularly for the anterior or posterior arm and elbow [27-29]. The flap can also be harvested as a muscle flap with an extensive skin component. The low donor site morbidity of this flap makes this a very preferable flap [27-29]. The flap is supplied by the thoracodorsal artery and vein with a large arc of range allowing it to reach the elbow [27-29]. The thoracodorsal artery perforator flap can also be useful which contains skin without muscle and is based on the perforating musculo-cutaneous perforators or the direct cutaneous perforators of the thoracodorsal artery and vein [27-29].

FOREARM SOFT TISSUE RECONSTRUCTION

Local Flaps

Forearm defects can be approached similar to the hand defects with radial or ulnar forearm regional flaps providing good soft tissue coverage [30]. Retrograde ulnar forearm flaps are also useful to repair distal forearm wounds [30].

FREE FLAPS FOR THE UPPER EXTREMITY

There are situations in which the hand, forearm and elbow defects cannot be covered using local or regional flaps requiring the use of free tissue transfer. This may be because the injury is extensive precluding local soft tissue transfer and the need to cover important structures such as vessels, nerves. In addition, free flaps may be considered due to the ability to transfer composite structures following extensive injuries including bone, nerve and muscle. Free flaps are also useful because there are many free flaps that are available for coverage of upper limb defects. However, there is no free flap, which offers a solution to all problems, with different flap providing different advantages and disadvantages. The selection of the free flap will depend on several factors and should be tailored for each individual patient. In all cases it is important to minimise donor site morbidity. The flap chosen will depend on the mechanism of the injury, site and size, exposed structures, need for replacement of sensation and status of surrounding tissue [31]. The donor site should be considered in the terms of texture, colour and the components required in the desired flap. In the following section, we will briefly describe the free flaps most commonly used in upper limb soft tissue reconstruction, discussing the benefits and challenges of each flap.

Radial Forearm Flap

As highlighted earlier the radial forearm flap has been considered theworkhouse flap of soft tissue coverage in the upper limb. With a long pedicle of large calibre, being a thin flap and the option to be harvested as a composite flap, this flap technique is a very preferable method among microsurgeons [32]. The major disadvantage of this flap includes donor site morbidity which can be lessened with suprafascial flap harvest and full thickness grafting to the donor site [33, 34].

Technique: After a preoperative Allen's test is performed a skin incision is performed, which is either straight, curvilinear or zig-zag to begin dissection of the flap [32]. The flap is usually designed over the volar aspect of the forearm and may extend over the radial and ulnar aspect of the forearm if required [32]. The radial edge of the forearm is avoided to avoid damage to the radial cutaneous nerve branches [32]. The skin flaps are elevated and the fascia is then incised to fit the shape and size of the desired defect. The fascia is then elevated directly off until the osseocutaneous septum is reached to find the radial artery and its accompanying veins between the flexor carpi radialis and bradioradialis [32]. The radial artery is then ligated and divided distally for elbow coverage and proximally for hand coverage [32]. The flap is then elevated with fascia and subcutaneous tissue [32].

Groin Flap

The groin flap is based on the superficial circumflex iliac artery, which is supplied from the superficial femoral artery at the level of the inguinal ligament and drains into the saphenous system [34, 35]. The groin flap has several advantages including adequate skin thickness and minimal donor site morbidity, making it the most useable free flap for soft tissue coverage of the hand and forearm [34, 35]. The disadvantages of the flap include the short pedicle and that the artery size can be small [34, 35]. The groin flap was the first successful skin and soft tissue free flap, described by McGregor and Jackson in 1972 [34, 35].

Technique: The flap is raised in its entirety [36]. The first incision divides the superficial circumflex iliac arteriovenous system, raising the flap in a plane deep to these vessels until the lateral border of the sartorius is reached [36]. The fascia covering the muscle is then incised and included in the flap [36]. The flap is then elevated medially until muscle fibres are seen passing into the underlying muscles at the medial border of the sartorius muscle [36]. The secondary site of both groin flaps can be closed directly but may require split thickness grafts [36]. The pedicle of the flap is commonly tubed by suturing loosely to itself for attachment of the flap to the hand or forearm wound [36]. The arm is then placed in 'the hand in pocket' position to suture the flap to the wound site [36]. Gradually the flap will develop a growth of circulations from the new site and after no less than 3 weeks the surgeon will begin to divide the pedicle [36]. By 5 weeks the surgeon is able to divide the flap completely from the pedicle [36].

Superficial Inferior Epigastric Artery Flap

Originally described by Shaw, the hypogastric flap based on the superficial inferior epigastric artery can also be used for coverage of hand wounds, particular dorsal defects [37, 38]. It is based just proximal to the ipsilateral inguinal ligament and centred on the femoral artery and vein [37, 38]. This flap is useful has it provides minimal hair and thin flap [37-40]. The groin flap is now more commonly used than the hypogastric flap for hand reconstruction due to the concealed donor scar and better skin texture from the groin flap [39].

Technique: The flap is raised at the deep fascia proximally and superficially to the scarpa fascia proximally [37-40]. The base of the flap is tubed in the direction of the chosen resting hand position [37-40]. Movement of the shoulder, elbow, wrist and fingers will continue [37-40]. At three weeks the flap is usually divided [37-40].

Scapular Free Flap

This fasciocutaneous flap based on the circumflex scapular artery (CSA) [41]. This flap causes minimal donor site morbidity, which can often be closed primarily [42]. This flap is useful because it offers the opportunity for a flap with muscle latissimus or serratusmuscle) or bone (scapular) [43]. However, the flap does needs to be harvested with the patient in the prone position or lateral position, meaning the patient will need to be turned during the operation [44].

Technique: The harvest is started by identifying the muscular triangular space and localising the CSA within it by confirming using a doppler probe [41-45]. The scapular flap will be designed along the horizontal plane which is perpendicular to the lateral border of the scapula [41-45]. The superior limit is the scapular spine and the inferior limit is the tip of the scapula [41-45]. Flap elevation must proceed from medial to lateral in the plane just superficial to the facia of the infraspinatus, rhomboid and trapezius muscles with dissection in the subfascial plane [41-45]. The resulting skin flap is then inset according to the wound site with anastomosis carried out before or after the insetting of the flap [41-45]. Primary closure of the donor site is usually possible with split thickness skin grafts in the area being less desirable for use [41-44].

Anterolateral Thigh Flap

This flap is based on the lateral femoral circumflex artery and has become a preferred flap as it has a long pedicle, provides a large skin paddle and minimal donor site morbidity [45]. It is commonly used in hand reconstruction. It can be used to provide skin fat and fascia or thinned as necessary, providing to be a very versatile flap. With the lateral femoral cutaneous nerves of the thigh it can be used to provide innervation to the wound site [46-49]. The disadvantages of the flap are that the anatomy of the perforator vessels can be variable with perforator dissection difficult for inexperience surgeons [46-49]. Adani *et al.* illustrated that the anterolateral thigh flap provided soft tissue of the hand covering for nine patients suffering from severe scar contracture, burn and crushing injuries. All flaps survived and the donor site was closely directly in seven patients [46].

Technique: After the patient is placed in the supine position, a line is drawn from the ASIS to the lateral patella [46-49]. The hand-held doppler firstly maps out the descending branch of the lateral circumflex femoral artery starting from the midpoint to the drawn line. The perforators within 3-4 cm usually cluster anterolateral to the midpoint [46-49]. The flap is usually cantered around the perforators and can extend up to 15-16 cm in length. Dissection begins with incising down to the fascia overlying the rectus femoris muscle [46-49]. Medial dissection starts first continuing lateral until the skin perforators are identified [46-49]. Once the main pedicle is identified, the flap is dissected from its lateral border [46-49]. After transection of the vessels, the flap is brought to the defect with anastomosis to recipient vessel and insetting of the flap after successful re-perfusion [46-49]. Anastomosis can be completed for arterial using 9.0 nylon accompanied by anastomosis of two veins [46-49]. Closure of the donor site can be closed primarily or with a skin graft in large defects [46-49].

Lateral Arm Free Flap

A microvascular free transfer of the lateral arm fasciocutaneous flap is especially useful in hand reconstruction as the thinness, colour and texture of the flap provides an excellent functional result [50, 51]. Similar to the radial and ulnar forearm flaps, it has flow through characteristics, which means the structures distal to the flap can be vascularised with the distal part of the pedicle [50, 51]. The estimated length of skin transferred is approximately 10-14 cm and the width is restricted to around 6 cm, allowing primary closure of the donor defect [50].

Technique: The flap based on the posterior radial collateral artery, can be raised as a facial flap, with bone, the overlying skin and with/without innervation [50]. To design the flap the insertion of the deltoid and the lateral epicondyle is marked with the elbow extended [50]. A line is drawn between these two structures and the defect is placed in the centre [50]. The skin is usually excised posteriorly and distally until deep fascia is reached. Usually 2 cm of facia are included in the posterior extent of the flap before the deep fascia is incised [50]. The deep fascia forms the lateral intermusulcar septum at the anterior border of the triceps [50]. The pedicle is then visualised from the insertion of the deltoid to the lateral epicondyle with the septum in the distal two thirds. Small muscular perforators are encountered which can be coagulated [50]. The skin is incised at the anterior border of the triceps where the deep fascia is found and another 2 cm are included [50]. The deep fascia is this area requires further sharp dissection [50]. Once the vascular pedicle is found the lateral septum is elevated from the humerus starting distally [50]. Careful dissection is required at the level where the pedicle leaves the lateral intermuscular septum [50].

TIMING OF FREE FLAPS

As traumatic injury to the upper extremity often requires free tissue transfer to provide adequate soft tissue coverage, the time at which to perform this has become a subject of debate. The ultimate aim of free flap reconstruction is the early and optimal recovery of function. Early aggressive debridement of nonviable tissue is required before any soft tissue reconstruction can be performed. Using free flaps early has shown to be beneficial for severe injuries to allow for bone and soft tissue healing, decreased risk of infection, early rehabilitation, avoidance of multiple procedures and decreased patient hospital stay [50]. The upper limb can tolerate delayed reconstruction but the hand will not endure due the consequential joint stiffness and tendon adhesions. Godina advocated that within 72 hours wound coverage should be provided to prevent infection and oedema [53]. However, Derderian *et al.* found that in 133 patients flap failure and infection was lowered when performed between the days 6 and 21 [54]. A recent systematic review in 2012, evaluated the current literature on the timing of upper extremity reconstruction [55]. Fifteen articles were included in the systematic review finding that there was no significant association between the timing of reconstruction and rate of flap loss, infection or bony nonunion [55]. However, linear regression showed a significant association between shorter hospital stay and medical costs. The authors concluded that further information is required to define the optimal time periods for upper extremity reconstruction [55].

SUMMARY

There are multiple options for soft tissue reconstruction of the upper limb that can restore function in addition to stable coverage. Several local and regional flaps have been identified including advancement flap, rotation flaps in cases where local tissue is available and healthy. Microsurgical techniques have revolutionised reconstructive surgery and allowed several soft tissue techniques for the restoration of

hand, arm and forearm defects. Free flaps for soft tissue reconstruction for the upper extremity offer flap versatility, the ability to match colour and texture of the recipient site, coverage of vital structures with minimal donor site morbidity. A careful selection of flap choice for coverage of an upper extremity defectshould take into account the anatomy and functional requirements of the defect site, the patient's health condition and the surgeons experience to ensure good functional and aesthetic outcomes for the patients.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

Declared none.

REFERENCES

[1] Levin LS, Erdmann DE. Primary and secondary microvascular reconstruction of the upper extremity. Hand Clinics 2001; 17: 447-55.

[2] Lister G, Scheker L. Emergency free flaps to the upper extremity. J Hand Surg Am 1988; 13: 22-8.

[3] Godina M. Early microsurgical reconstruction of complex trauma of the extremities. Plast Reconstr Surg 1986; 78: 285-92.

[4] Chen S, Tsai YC, Wei FC, *et al*. Emergency free flaps to the type IIIC tibial fracture. Ann Plast Surg 1990; 25: 223-9.

[5] Chen SHT, Wei FC, Chen HC, *et al*. Emergency free flap transfer for reconstruction of acute complex extremity wounds. PlastReconstrSurg 1992;89: 882-8.

[6] Chen ZW, Yan W. The study and clinical application of the osteocutaneous flap of the fibula. Microsurgery 1983; 4: 11-6.

[7] Tymchak T. In: Grabb and Smith's Plastic Surgery. Charles H, Ed. Soft tissue reconstruction of the hand. 6th ed. USA: Lippincott Williams & Wilkins 2007.

[8] Atasoy E, Loakimidis E, Kasdan ML, *et al*. Reconstruction of the amputated fingertip with a triangular volar flap. A new surgical procedure. J Bone Joint Surg 1970; 52A: 921.

[9] Macht SD, Watson HK: The Moberg volar advancement flap for digital reconstruction. J Hand Surg 1980; 5: 372-6.

[10] Gurdin M, Pangman WI. The repair of surface defects of fingers by transdigital flaps. Plast Reconstr Surg 1950; 5: 368.

[11] Nuzumlali ME, Ozturk K, Bayri O, Cepel S, Gurbuz C. The versatile reverse-flow digital artery cross-finger flap. Tech Hand Up Extrem Surg 2007; 11: 259-61.

[12] Muyldermans T, HiernerR. First dorsal metacarpal artery flap for thumb reconstruction: a retrospective clinical study. Strategies Trauma Limb Reconstr 2009; 4: 27-33.

[13] Foucher G, Braun J-B. A new island flap transfer from the dorsum of the index to the thumb. Plast Reconstr Surg 1979; 63: 344-9.

[14] Small JO, Bernnen MD. The first dorsal metacarpal artery neurovascular island flap. J Hand Surg 1988; 13B: 136.

[15] MuÅNhlbauer W, Herndl E, Stock W. The forearm flap. Plast Reconstr Surg 1982; 70: 336-42.

[16] Fang QG, Shi S, Zhang X, Li ZN, Liu FY, Sun CF. Upper extremity morbidity after radial forearm flap harvest: a prospective study. J Int Med Res 2014; 42: 231-5.

[17] Megerle K, Sauerbier M, Germann G. The evolution of the pedicled radial fore arm flap. Hand (NY) 2010; 5: 37-42.

[18] Ho T, Couch M, Carson K, *et al*. Radial forearm free flap donor site outcomes comparison by closure methods. Otolaryngol Head Neck Surg 2006;134: 309e15

[19] Bayon P, Pho RWH. Anatomical basis of the dorsal forearm flap. J Hand Surg 1988; 13B: 435.

[20] Gswind CR and Tonkin MA. Posterior Interosseous Artery Flap. In: Grabbs Encyclopedia of flaps. Upper extremities 2009; 3rd Ed. Philadelphia: Lippincottt Williams & Wilkins pp. 255-9.

[21] Stevanovic M, Sharpe F. Soft-tissue coverage of the elbow. Plast Reconstr Surg 2013;132: 387e-402e.

[22] Giele H. Soft tissue coverage of the elbow. In: Operative Elbow Surgery. The Netherlands: Elsevier 2012; pp. 719-34.

[23] Tiengo C, Macchi V, Porzionato A, *et al*. The proximal radial artery perforator flap (PRAP-flap): an anatomical study for its use in elbow reconstruction. Surg Radiol Anat 2007; 29: 245-51.

[24] Katsaroj J, Tan E, Zoltie N. The use of the lateral arm flap in upper limb surgery. J Hand Surg 1991; 16A: 598.

[25] Patel KM, Higgins JP. Posterior elbow wounds: soft tissue coverage options and techniques. Orthop Clin North Am 2013; 44: 409-17.

[26] Tung TC, Wang KC, Fang CM, Lee CM. Reverse pedicled lateral arm flap for reconstruction of posterior soft-tissue defects of the elbow. Ann Plast Surg 1997; 38: 635-41.

[27] Hallock GC, Dingeldein GP. The thoracoepigastric flap as an alternative coverage of the burned elbow. J Burn Care Res 1982; 3: 393.

[28] Stevanovic M, Sharpe F, Thommen VD, Itamura JM, Schnall SB. Adani R. Latissimus dorsi pedicle flap for coverage of soft tissue defects about the elbow. J Shoulder Elbow Surg 1999; 8: 634-43.

[29] Pierce TD, TomainoMM. Use of the pedicled latissimus muscle flap for upper-extremity reconstruction. J Am Acad Orthop Surg 2000; 8: 324-31.

[30] Saint-Cyr M, LangsteinHN. Reconstruction of the hand and upper extremity after tumor resection. J Surg Oncol 2006; 94: 490-503.

[31] Saint-Cyr M, Gupta A. Indications and selection of free flaps for soft tissue coverage of the upper extremity. Hand Clin 2007; 23: 37-48.

[32] Grossman RH, Majidian AM, Brones M, Young M, Grossman AR. Radial forearm Fascial Flap. In: Grabbs Encyclopedia of flaps. Upper extremities. 3rd Ed. Philadelphia: Lippincottt Williams & Wilkins 2009; pp. 849-51.

[33] Chang SC, Miller G, Halbert CF, *et al*. Limiting donor site morbidity by suprafascial dissection of the radial forearm flap. Microsurgery 1996; 17: 136-40.

[34] Lutz BS, Wei FC, Chang SC, *et al*. Donor site morbidity after suprafascial elevation of the radial forearm flap: a prospective study in 95 consecutive cases. Plast Reconstr Surg 1999; 103: 132-7.

[35] McGregor IA, Jackson IT. The groin flap. Br J Plast Surg 1972; 25: 3.

[36] Choi JY, Chung KC. The combined use of a pedicled superficial inferior epigastric artery flap and a groin flap for reconstruction of a dorsal and volar hand blast injury. Hand (NY) 2008; 3: 375-80.

[37] McGreggor and Soutor. Groin Skin Flap. In: Grabbs Encyclopedia of flaps. Upper extremities. 3rd Ed. Philadelphia: Lippincottt Williams & Wilkins 2009; pp. 881-5.

[38] Barfred T. The Shaw abdominal flap. Scand J Plast Reconstr Surg 1976;10: 56.

[39] Millard DR, Cooley SGE. A solution to coverage in severe compound dorsal hand injuries. Plast Recosntr Surg 1972; 40: 215.

[40] Baudet J, Nassif T, JL Bovet and Panconi B. Scapular and Parascapular Flap. In: InGrabbs Encyclopedia of flaps. Upper extremities. 2009 3rd Ed. Philadelphia: Lippincottt Williams & Wilkins 2009; p. 902.

[41] Burda R, Kitka M. Combination of posterior interosseous and hypogastric flap for skin defect reconstruction in hand injuries. Acta Chir Plast 2007; 49: 13-7.

[42] Saijo M. The vascular territories of the dorsal trunk: a reappraisal for potential flap donor sites. Br J Plast Surg 1978;31: 200-4.

[43] Urken ML, Bridger AG, Zur KB, *et al*. The scapular osteofasciocutaneous flap: a 12-year experience. Arch Otolaryngol Head Neck Surg 2001; 127: 862-9.

[44] dos Santos LF. The vascular anatomy and dissection of the free scapular flap. Plast Reconstr Surg 1984; 73: 599-604.

[45] Gao W, Hong J, Li Z, Chen X. Hand reconstruction with lobulated combined flaps based on the circumflex scapular pedicle. Microsurgery 2008; 28: 355-60.

[46] Wang HT, Fletcher JW, Erdmann D, Levin LS. Use of the anterolateral thigh free flap for upper-extremity reconstruction. J Hand Surg Am 2005; 30: 859-64.

[47] Adani R, Tarallo L, Marcoccio I, Cipriani R, Gelati C, Innocenti M. Hand reconstruction using the thin anterolateral thigh flap. Plast Reconstr Surg 2005; 116: 467-73; discussion 474-7.

[48] Yildirim S, Avci G, Akoz T. Soft-tissue reconstruction using a free anterolateral thigh flap: experience with 28 patients. Ann Plast Surg 2003; 51: 37e44.

[49] Luo S, Raffoul W, Luo J, *et al*. Anterolateral thigh flap: A review of 168 cases. Microsurgery 1999; 19: 232e8.

[50] Kimura N, Satoh K, Hasumi T, *et al*. Clinical application of the free thin anterolateral thigh flap in 31 consecutive patients. Plast Reconstr Surg 2001; 108: 1197e208 [discussion 209e10].

[51] Scheker L, Lister G. Microvascular free transfer of the lateral arm fasciocutaneous flap. In: Grabbs Encyclopedia of flaps. 3rd Ed. Philadelphia: Lippincottt Williams & Wilkins 2009; pp. 895-7.

[52] Song R, Gao Y, song Y, *et al*. The forearm flap. Clin Plast Surge 1982; 9: 21.

[53] Schwabegger AH, Anderl H, Hussl H, *et al*. Complex hand injuries. Importance of primary repair with free flaps. Unfallchirurg 1999; 102: 292e7.

[54] Godina M. Early microsurgical reconstruction of complex trauma of the extremities. Plast Reconstr Surg 1986; 78: 285-92.

[55] Derderian CA, Olivier WA, Baux G, Levine J, Gurtner GC. Microvascular free-tissue transfer for traumatic defects of the upper extremity: A 25-year experience. J Reconstr Microsurg 2003; 19: 455-62.

[56] Harrison BL, Lakhiani C, Lee MR, Saint-Cyr M. Timing of traumatic upper extremity free flap reconstruction: a systematic review and progress report. Plast Reconstr Surg 2013; 132: 591-6.

Received: May 25, 2014 Revised: August 25, 2014 Accepted: September 12, 2014